Basic Manufacturing Processes



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BASIC MANUFACTURING PROCESSES



3G E-LEARNING

BASIC MANUFACTURING PROCESSES

Authored and Edited by 3G E-learning LLC, USA

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3G E-LEARNING

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PREFACE

Manufacturing processes are the steps through which raw materials are transformed into a final product. The manufacturing process begins with the creation of the materials from which the design is made. These materials are then modified through manufacturing processes to become the required part. Manufacturing processes can include treating, machining, or reshaping the material. The manufacturing process also includes tests and checks for quality assurance during or after the manufacturing, and planning the production process prior to manufacturing. Manufacturing takes turns under all types of economic systems. In a free market economy, manufacturing is usually directed toward the mass production of products for sale to consumers at a profit. In a collectivist economy, manufacturing is more frequently directed by the state to supply a centrally planned economy. In mixed market economies, manufacturing occurs under some degree of government regulation. Modern manufacturing includes all intermediate processes required the production and integration of a product's components.

Content Coverage

Chapter One starts with the concept and classification of manufacturing engineering. *Chapters Two* and *Three* present about metal casting and metal joining processes, separately. *Chapter Four* details about metal forming that is a very important manufacturing operation. It enjoys industrial importance among various production operations due to its advantages such as cost effectiveness, enhanced mechanical properties, flexible operations, higher productivity, considerable material saving. *Chapter Five* explores the basic concepts of plastic part manufacturing processes. Plastics typically have high molecular weight, meaning each molecule can have thousands of atoms bound together *Chapter Six* covers about machining used to describe a variety of material removal processes in which a cutting tool removes unwanted material from a work piece to produce the desired shape.

The following are the salient features of the book:

- This Textbook provides all the concise information needed to identify the ideal process for a specific manufacturing requirement.

- Topics are logically arranged according to the course outline of the subject.
- The use of simple language to facilitate a better understanding of each chapter.
- Illustrative examples of varying difficulties, wherever needed, are presented to enhance the interest of students.
- The provision of knowledge check test for each chapter is given at the end of chapter to strengthen the learning process of students.
- Case Study, Role Model, Keywords, and Examples are also provided to enrich the knowledge of students.

CHAPTER

1

INTRODUCTION TO MANUFACTURING PROCESSES

LEARNING OBJECTIVES

After studying this chapter, you will be able to:

1. Discuss the concept of manufacturing engineering
2. Explain the classification of manufacturing processes
3. Describe product simplification and standardization

INTRODUCTION

Manufacturing is the backbone of any industrialized nation. Manufacturing and technical staff in industry must know the various manufacturing processes, materials being processed, tools and equipments for manufacturing different components or products with optimal process plan using proper precautions and specified safety rules to avoid accidents. All kinds of the future engineers must know the basic requirements of workshop activities in term of man, machine, material, methods, money and other infrastructure facilities needed to be positioned properly for optimal shop layouts or plant layout and other support services effectively adjusted or located in the industry or plant within a well-planned manufacturing organization. The complete understanding of basic manufacturing processes and workshop technology is highly

difficult for anyone to claim expertise over it. The study deals with several aspects of workshops practices also for imparting the basic working knowledge of the different engineering materials, tools, equipments, manufacturing processes, basic concepts of electromechanical controls of machine tools, production criteria's, characteristics and uses of various testing instruments and measuring or inspecting devices for checking components or products manufactured in various manufacturing shops in an industrial environment. It also describes and demonstrates the use of different hand tools (measuring, marking, holding and supporting tools, cutting etc.), equipments, machinery and various methods of manufacturing that facilitate shaping or forming the different existing raw materials into suitable usable forms. It deals with the study of industrial environment which involves the practical knowledge in the area of ferrous and non-ferrous materials, their properties and uses. It should provide the knowledge of basic workshop processes namely bench work and fitting, sheet metal, carpentry, pattern making, mold making, foundry, smithy, forging, metal working and heat treatment, welding, fastening, machine shop, surface finishing and coatings, assembling inspection and quality control. It emphasizes on basic knowledge regarding composition, properties and uses of different raw materials, various production processes, replacement of or improvement over a large number of old processes, new and compact designs, better accuracy in dimensions, quicker methods of production, better surface finishes, more alternatives to the existing materials and tooling systems, automatic and numerical control systems, higher mechanization and greater output.

1.1 CONCEPT OF MANUFACTURING ENGINEERING

Manufacturing is derived from the Latin word *manufactus*, means made by hand. In modern context it involves making products from raw material by using various processes, by making use of hand tools, machinery or even computers. It is therefore a study of the processes required to make parts and to assemble them in machines. Process Engineering, in its application to engineering industries, shows how the different problems related to development of various machines may be solved by a study of physical, chemical and other laws governing the manufacturing process. The study of **manufacturing** reveals those parameters which can be most efficiently being influenced to increase production and raise its accuracy.

Advance manufacturing engineering involves the following concepts:

- Process planning
- Process sheets
- Route sheets
- Tooling
- Cutting tools, machine tools (traditional, numerical control (NC), and computerized numerical control (CNC)

- Jigs and fixtures
- Dies and molds
- Manufacturing information generation
- CNC part programs.
- Robot programmers.
- Flexible manufacturing systems (FMS), group technology (GT) and computer integrated manufacturing (CIM).

1.1.1 Scope of Manufacturing Engineering

Manufacturing Engineering is one of the streams of engineering which deals with various manufacturing processes. It also focuses on research and development process, machines, tools and equipments. It trains individuals on how to handle various machines which turn raw material into a finished product. This specialized stream develops and creates physical artifacts, production processes, and technology. It's a vast field as it includes the design and development of products. The Manufacturing Engineering is a collaboration of mechanical engineering, industrial engineering, electrical engineering, electronic engineering, computer science, materials management, and operations management.



Manufacturing is the production of merchandise for use or sale using labor and machines, tools, chemical and biological processing, or formulation.

1.1.2 Production Process

It is the process followed in a plant for converting semi-finished products or raw materials into finished products or raw materials into finished products. The art of converting raw material into finished goods with application of different types of tools, equipments, machine tools, manufacturing set ups and manufacturing processes, is known as production. Generally there are three basic types of production system that are given as under.

- Job production
- Batch production
- Mass production_

Job production comprises of an operator or group of operators to work upon a single job and complete it before

proceeding to the next similar or different job. The production requirement in the job production system is extremely low. It requires fixed type of layout for developing same products.

Manufacturing of products (less in number say 200 to 800) with variety of similar parts with very little variation in size and shape is called batch production. Whenever the production of batch is over, the same manufacturing facility is used for production of other batch product or items. The batch may be for once or of periodical type or of repeated kinds after some irregular interval. Such manufacturing concepts are leading to GT and FMS technology. Manufacturing of products in this case requires process or functional layout.

Whereas mass production involves production of large number of identical products (say more than 50000) that needs line layout type of plant layout which is highly rigid type and involves automation and huge amount of investment in special purpose machines to increase the production.



REMEMBER

Manufacturing process is that part of the production process which is directly concerned with the change of form or dimensions of the part being produced. It does not include the transportation, handling or storage of parts, as they are not directly concerned with the changes into the form or dimensions of the part produced.

1.1.3 Process Planning

Process planning consists of selection of means of production (machine-tools, cutting tools, presses, jigs, fixtures, measuring tools etc.), establishing the efficient sequence of operation, determination of changes in form, dimension or finish of the machine tools in addition to the specification of the actions of the operator. It includes the calculation of the machining time, as well as the required skill of the operator. It also establishes an efficient sequence of manufacturing steps for minimizing material handling which ensures that the work will be done at the minimum cost and at maximum productivity. The basic concepts of process planning are generally concerned with the machining only. Although these concepts may also be extended to other processes such as casting, forging, sheet metal forming, assembling and heat treatment as well.

1.2 CLASSIFICATION OF MANUFACTURING PROCESSES

Manufacturing processes are the steps through which raw materials are transformed into a product. The manufacturing processes can be broadly classified into three categories viz.

shaping, joining and finishing processes as shown schematically in Figure 1.1. The selection of a particular process from a wide range of choices for a given application requires a hierarchical classification of the processes.

For example, Figure 1.2 depicts how the shaping family can be expanded in different classes such as casting, deformation, molding, composite and powder processing, and prototyping. Next, molding as a class can be enlarged into a number of member processes such as compression, rotational, transfer, injection molding, etc. Lastly, each member process can be identified with a number of attributes, which would facilitate the selection of a member process for a given material, dimension, level of requisite tolerances and so on. Similarly, Figure 1.3 depicts how the joining and machining family can be expanded in different classes and actual processes. A brief description of the three broad categories of the manufacturing processes and the corresponding classifications are outlined in the following.

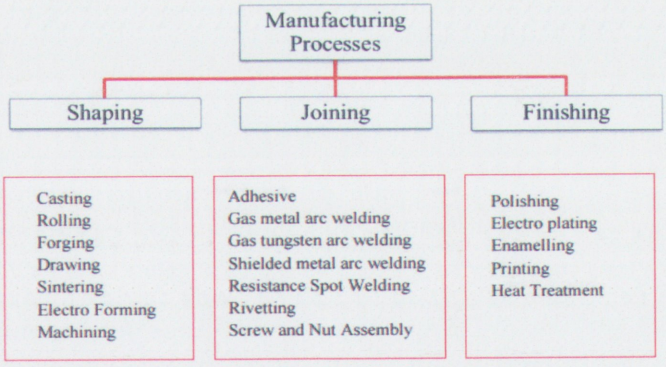


Figure 1.1: Different classes of manufacturing processes.

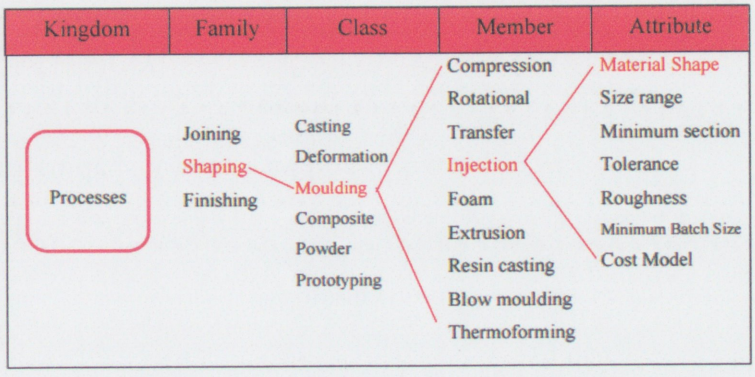


Figure 1.2: Taxonomy of process with part of the shaping family.

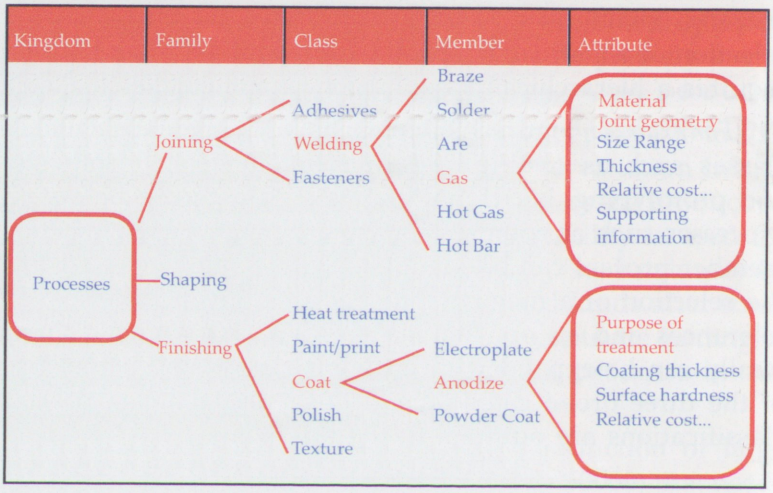


Figure 1.3: Taxonomy of processes with part of the joining and finishing family.

REMEMBER

Manufacturing becomes successful by understanding how the system works, how goods are controlled, the decision making at the correct level. Engineers must possess a broad fundamental knowledge of design, metallurgy, processing, economics, accounting and human relations.

1.2.1 Primary Shaping Processes

Primary shaping processes are manufacturing of a product from an amorphous material. Some processes produces finish products or articles into its usual form whereas others do not, and require further working to finish component to the desired shape and size. Castings need re-melting of scrap and defective ingots in cupola or in some other melting furnace and then pouring of the molten metal into sand or metallic molds to obtain the castings. Thus the intricate shapes can be manufactured. Typical examples of the products that are produced by casting process are machine beds, automobile engines, carburetors, flywheels etc. The parts produced through these processes may or may not require to undergo further operations.

Some of the important primary shaping processes is:

- Casting,
- Powder metallurgy,
- Plastic technology,
- Gas cutting,
- Bending and
- **Forging**

1.2.2 Secondary or Machining Processes

As large number of components require further processing after the primary processes. These components are subjected to one or more number of machining operations in machine shops, to obtain the desired shape and dimensional accuracy on flat and cylindrical jobs. Thus, the jobs undergoing these operations are the roughly finished products received through primary shaping processes. The process of removing the undesired or unwanted material from the workpiece or job or component to produce a required shape using a cutting tool is known as machining. This can be done by a manual process or by using a machine called machine tool (traditional machines namely lathe, milling machine, drilling, shaper, planner, slotter). In many cases, these operations are performed on rods, bars and flat surfaces in machine shops. These secondary processes are mainly required for achieving dimensional accuracy and a very high degree of surface finish. The secondary processes require the use of one or more machine tools, various single or multi-point cutting tools (cutters), job holding devices, marking and measuring instruments, testing devices and gauges etc. for getting desired dimensional control and required degree of surface finish on the workpieces. The example of parts produced by machining processes includes hand tools machine tools instruments, automobile parts, nuts, bolts and gears etc. Lot of material is wasted as scrap in the secondary or machining process.



Forging is a manufacturing process involving the shaping of metal using localized compressive forces.

Some of the common secondary or machining processes are:

- Turning,
- Threading,
- Knurling,
- Milling,
- Drilling,
- Boring,
- Planning,
- Shaping,
- Slotting,
- Sawing,

- Broaching,
- Hobbing,
- Grinding,
- Gear cutting,
- Thread cutting and

Unconventional machining processes namely machining with numerical control (NC) machines tools or computer numerical control (CNC) machines tools using ECM, LBM, AJM, USM setups etc.



Rolling is a type of motion that combines rotation and translation of that object with respect to a surface, such that, if ideal conditions exist, the two are in contact with each other without sliding.

1.2.3 Metal Forming Processes

Forming processes encompasses a wide variety of techniques, which make use of suitable force, pressure or stresses, like compression, tension and shear or their combination to cause a permanent deformation of the raw material to impart required shape. These processes are also known as mechanical working processes and are mainly classified into two major categories i.e., hot working processes and cold working processes. In these processes, no material is removed; however it is deformed and displaced using suitable stresses like compression, tension, and shear or combined stresses to cause plastic deformation of the materials to produce required shapes. Such processes lead to production of directly usable articles which include kitchen utensils, rods, wires, rails, cold drink bottle caps, collapsible tubes etc.

Some of the important metal forming processes is:

Hot working Processes

- Forging,
- **Rolling**,
- Hot spinning,
- Extrusion,
- Hot drawing and
- Hot spinning.

Cold Working Processes

- Cold forging,
- Cold rolling,
- Cold heading,
- Cold drawing,
- Wire drawing,
- Stretch forming,
- Sheet metal working processes such as piercing, punching, lancing, notching, coining, squeezing, deep drawing, bending etc.

1.2.4 Joining Processes

Many products observed in day-to-day life, are commonly made by putting many parts together may be in subassembly. *For example,* the ball pen consists of a body, refill, barrel, cap, and refill operating mechanism. All these parts are put together to form the product as a pen. More than 800 parts are put together to make various subassemblies and final assembly of car or aero-plane. A complete machine tool may also require to assemble more than 100 parts in various sub assemble or final assembly. The process of putting the parts together to form the product, which performs the desired function, is called assembly. An assemblage of parts may require some parts to be joined together using various joining processes. But assembly should not be confused with the joining process. Most of the products cannot be manufactured as single unit they are manufactured as different components using one or more of the above manufacturing processes, and these components are assembled to get the desired product. Joining processes are widely used in fabrication and assembly work. In these process two or more pieces of metal parts are joined together to produce desired shape and size of the product. The joining processes are carried out by fusing, pressing, rubbing, riveting, screwing or any other means of assembling. These processes are used for assembling metal parts and in general fabrication work. Such requirements usually occur when several pieces are to be joined together to fabricate a desired structure of products. These processes are used developing steam or water-tight joints. Temporary, semi-permanent or permanent type of fastening to make a good joint is generally created by these processes. Temporary joining of components can be achieved by use of nuts, screws and bolts. Adhesives are also used to make temporary joints.

Some of the important and common joining processes are:

- Welding (plastic or fusion),
- Brazing,
- Soldering,

- Riveting,
- Screwing,
- Press fitting,
- Sintering,
- Adhesive bonding,
- Shrink fitting,
- Explosive welding,
- Diffusion welding,
- Keys and cotters joints,
- Coupling and
- Nut and bolt joints.

Mechanical Joining Processes

The permanent joining processes, which are mechanical in nature, are, in principle, derivatives of the basic metal working processes. These are often referred to fasteners. The most common mechanical joining methods are rivet, nut and bolts, staple, seam joint etc. Figure 1.4 schematically depicts a number of mechanical joints.

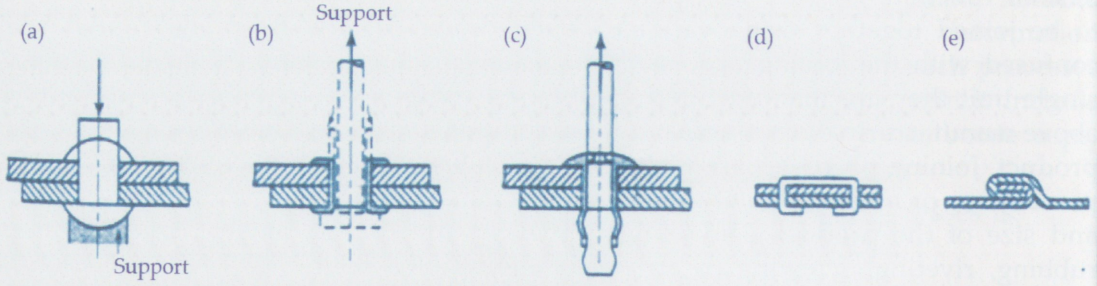


Figure 1.4: Schematic presentation of five mechanical joints: (a) rivet, (b) tubular rivet (c) blind rivet, (d) staple, (e) seam.

Solid State Joining Process

In solid state joining processes, the bonding between the assembled members occurs through adhesion and / or diffusion across the original joint interface. However, adhesions between the two surfaces are difficult due to the presence of surface contaminants such as oxide layers, adsorbed gas films, residual lubricants, etc.

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Various techniques are adopted to promote the adhesion between two surfaces such as:

- Relative movement of faying surfaces under an axial force that helps to break up surface films facilitating the exposure and mating of clean surfaces,
- Plastic deformation of the contacting bodies leading to growth and extension of the contacting surfaces that would result in rupture of interfacial contaminants and exposure of fresh, clean surfaces, subsequently, creating a solid-state weld,
- Softening of contacting interfaces by localized heating, applied externally or generated in-process, to promote easy plastic deformation and / or inter-atomic diffusion creating a solid-state bond.

Various solid-state joining processes are developed following some of the principles mentioned above. Figure 1.5 schematically depicts three common solid state joining processes.

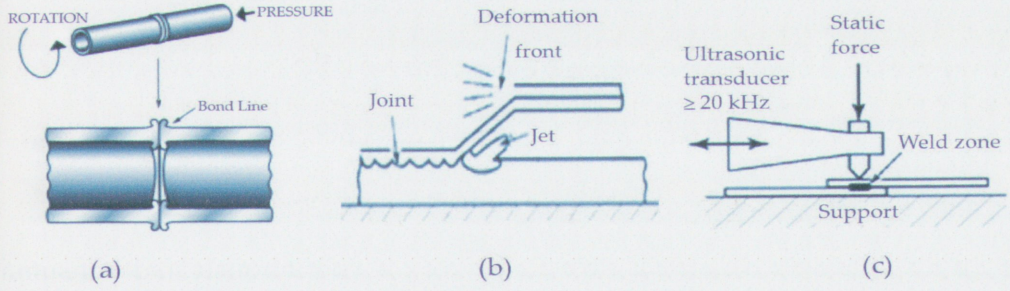


Figure 1.5: Three different types of solid state joining process; (a) Friction welding, (b) Explosion welding, and (c) Ultrasonic welding.

Liquid State Joining Process

The liquid state joining processes involve localized melting and solidification of workpiece materials with or without the addition of external filler material. The liquid state joining processes are commonly referred to as fusion welding. Based on the characteristics of the external filler (electrode) material, the welding processes can also be classified as consumable electrode and non-consumable electrode welding processes. Some of the common fusion welding processes are given.

Shielded Metal Arc Welding Process (SMAW)

Shielded metal arc welding (SMAW) Process is a manual welding process where

an electric arc is used for localized melting of workpiece materials. The electric arc is created between a consumable electrode and the workpiece material as shown schematically in Figure 1.6. The electrode is covered with a coating (referred to as flux), which is extruded on the surface of the electrode. During welding, the electrode coating decomposes and melts providing a protective atmosphere on the weld area to avoid the reaction between hot liquid metal and atomospheric gases. The SMAW process is the most popular amongst all other fusion arc welding processes since the equipment is inexpensive and easy to use. The SMAW process can be used on carbon steels, low alloy steels, stainless steels, cast irons, copper, nickel, and aluminium.

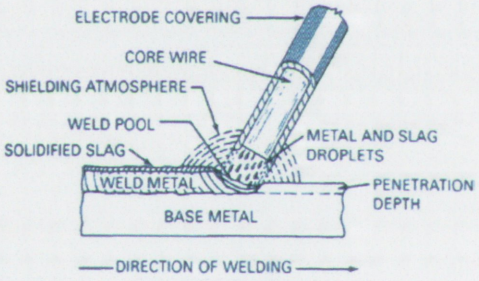


Figure 1.6: Schematic set-up for shielded metal arc welding process

Gas metal arc welding process (GMAW)

In this process, an electric arc is struck between a continuously fed consumable electrode wire and the workpiece material as shown in Figure 1.7. The electrode wire is automatically fed from a spool into the weld pool by a wire feed system. The wire feeder draws the electrode through the welding torch. The shielding is supplied by an inert gas which flows around the wire through a gas cap attached to the torch.

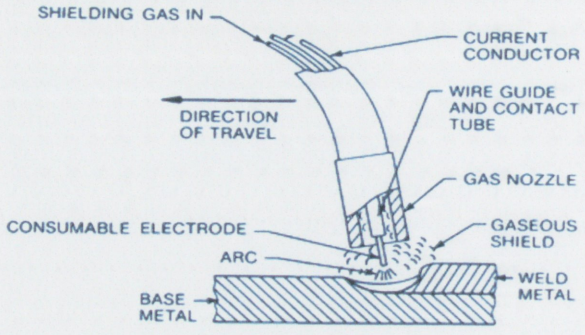


Figure 1.7: Schematic set-up for gas metal arc welding process.

3G E-LEARNING

Submerged Arc Welding Process (SAW)

Submerged arc welding is almost similar to gas metal arc welding process to the fact that an electric arc is created between a continuously fed consumable solid or tubular electrode wire and workpiece materials. However, the arc and the molten weld pool is submerged under a blanket of granular fusible flux consisting of lime, silica, manganese oxide, calcium fluoride, and other compounds, which are being fed continuously ahead of the welding electrode. Furthermore, the molten flux being electrically conductive provides a current path between the electrode and the workpiece. The thick layer of flux completely covers the molten metal thus preventing spatter and sparks. The process is simple to mechanize and easily automated, and can be used on a wide variety of materials. Figure 1.8 schematically depicts a set-up for typical submerged arc welding process.

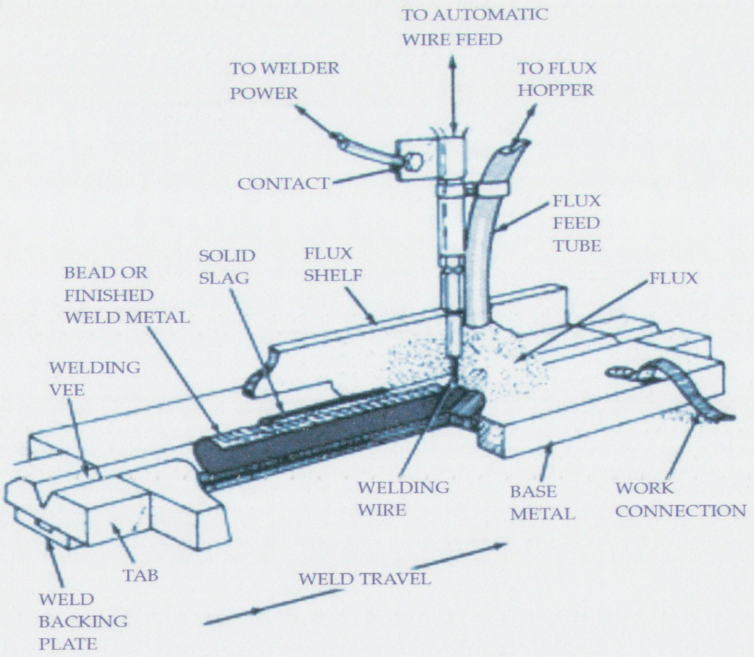


Figure 1.8: Schematic set-up for submerged arc welding process.

Gas Tungsten Arc Welding Process (GTAW)

In the gas tungsten arc welding (GTAW) process, the arc is established between the tip of a non-consumable tungsten electrode and the workpiece. Often an extra filler

material is used if joint filling is important. Because the arc is created between a shaped (conical) non-consumable tungsten electrode and the workpiece, GTAW process provides a concentrated arc leading to very high heat energy density. An inert shielding gas protects the molten weld pool and the non-consumable tungsten electrode. Figure 1.9 depicts a schematic set-up for GTAW process.

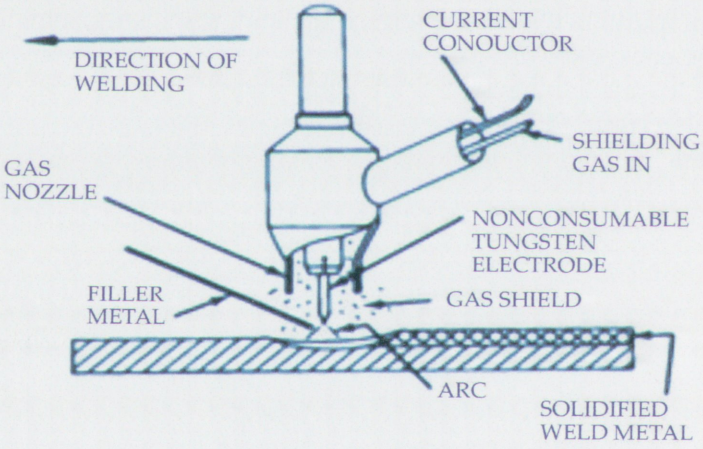


Figure 1.9: Schematic set-up for gas tungsten arc welding process.

Plasma Arc Welding Process (PAW)

The objective of the Plasma Arc Welding (PAW) process is to increase the intensity of the of the arc plasma in a controlled manner such that greater thickness can be welded with the minimum spread of the welding arc. This objective is achieved by providing a special gas nozzle around a tungsten electrode operating on direct current electrode negative (DCEN) polarity. The constricted plasma formed is highly ionized and concentrated. Two variants of the Plasma Arc Welding (PAW) process are commonly used. One is referred to as the transferred arc process and the second is referred to as the non-transferred arc process. In the transferred arc process, the workpiece is connected to the negative polarity so that the arc plasma irradiated on the workpiece has greater intensity. In the non-transferred arc process, the gas nozzle forms part of the electric circuit and hence, the arc plasma is formed between the tungsten electrode and the nozzle. The tail of the arc plasma that irradiates on the workpiece is therefore of lesser intensity. Figure 1.10 schematically shows the set-ups for transferred arc and non-transferred arc PAW processes.

3G E-LEARNING

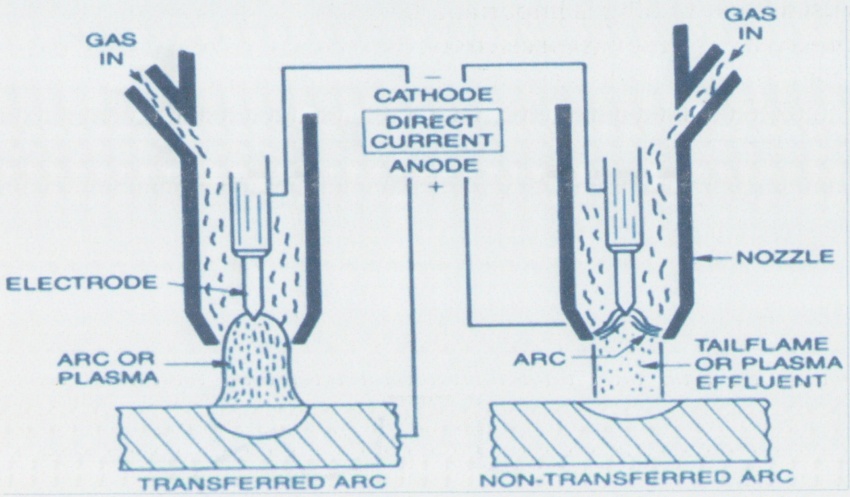


Figure 1.10: Schematic set-up for plasma arc welding process.

1.2.5 Surface Finishing Processes

Surface finishing processes are utilized for imparting intended surface finish on the surface of a job. By imparting a surface finishing process, dimension of part is not changed functionally; either a very negligible amount of material is removed from the certain material is added to the surface of the job. These processes should not be misunderstood as metal removing processes in any case as they are primarily intended to provide a good surface finish or a decorative or protective coating on to the metal surface. Surface cleaning process also called as a surface finishing process.

Some of the commonly used surface finishing processes are:

- Honing,
- Lapping,
- Super finishing,
- Belt grinding,
- Polishing,
- Tumbling,
- Organic finishes,
- Sanding,
- Deburring,
- Electroplating,

- Buffing,
- Metal spraying,
- Painting,
- Inorganic coating,
- Anodizing,
- Sheradising,
- Parkerizing,
- Galvanizing,
- Plastic coating,
- Metallic coating,
- Anodizing and
- Sand blasting.

1.2.6 Casting Processes

Most of the manufactured parts start its journey with casting process. In a typical casting process, metal is first heated in a furnace until it melts and then the molten metal is poured into a mold so that the liquid metal takes the shape of the mold cavity, which is the final shape of the part. Once the liquid metal in the mold cavity solidifies, the mold is broken or opened to take the final part out of the mold cavity.

The metal casting process involves three sequential steps:

- liquefying of metallic material by properly heating it in a suitable furnace,
- pouring of hot molten metal into a previously made colder mold cavity,
- extraction of the solidified cast from the mold cavity

Though casting is one of the oldest manufacturing processes, it is still preferred over other processes due to several advantages given as:

- It is economical with very little wastage. Even the extra metal produced during each casting can be re-melted and reused.
- It can produce parts with complex geometrical features such as internal cavities, hollow sections with fair dimensional accuracy.
- Casting can be used to make very small to extremely large and complex parts.
- It is possible to cast metallic materials with very low to reasonably high melting temperatures. Further, the mechanical properties of a cast are usually isotropic

Classification of Casting Processes

The casting processes can be classified into two broad categories – expendable mold

casting processes and permanent mold casting processes. In expendable mold casting processes, the mold is usually broken to free the solidified cast whereas the mold can be reused in case of permanent mold casting. The pattern used to prepare the molds can also be permanent and expendable, and subsequently, the expendable mold casting processes are further categorized as expendable-pattern-expendable-mold and permanent-pattern-expendable-mold processes. Figure 1.11 depicts a detailed calcification of the casting processes.

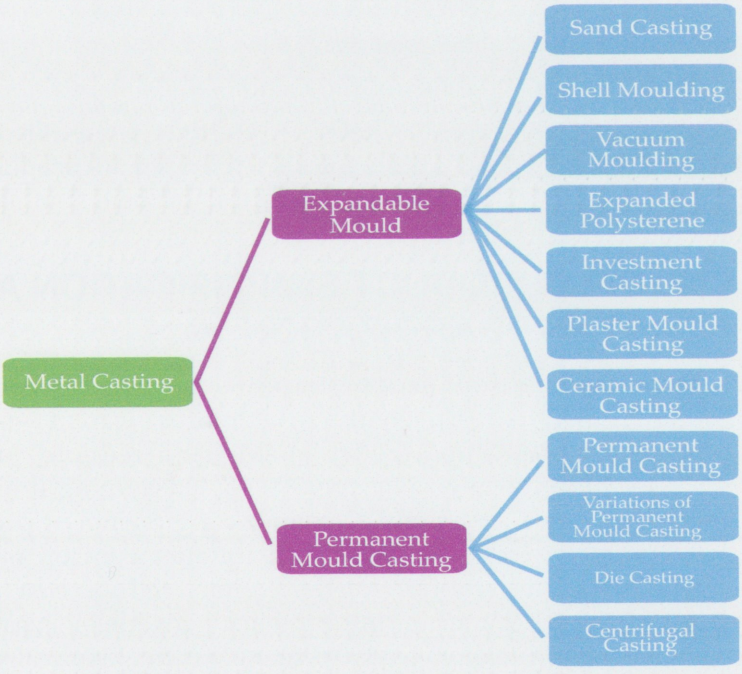


Figure 1.11: Classification of casting processes.

1.2.7 Processes Effecting Change in Properties

Processes effecting change in properties are generally employed to provide certain specific properties to the metal work pieces for making them suitable for particular operations or use. Some important material properties like hardening, softening and grain refinement are needed to jobs and hence are imparted by heat treatment. Heat treatments affect the physical properties and also make a marked change in the internal structure of the metal. Similarly the metal forming processes effect on the physical properties of work pieces similarly shot peening process, imparts fatigue resistance to work pieces.

A few such commonly used processes are given as under:

- Annealing,
- Normalizing,
- Hardening,
- Case hardening,
- Flame hardening,
- Tempering,
- Shot peeing,
- Grain refining and
- Age hardening. In addition, some allied manufacturing activities are also required to produce the finished product such as measurement and assembly.



REMEMBER

A tolerance outlines the geometric accuracy that must be achieved in the manufacturing process. The "tightness" of the tolerances, or in other words the allowed variance between the manufactured product and the ideal product, is a function of the particular application of the product.

1.3 PRODUCT SIMPLIFICATION AND STANDARDIZATION

The technique of simplification and standardization of product is closely inter-related that leads to higher efficiency in production, better quality and reduced production cost. Simplification is a process of determining limited number of grades, types and sizes of a components or products or parts in order to achieve better quality control, minimize waste, simplify production and, thus, reduce cost of production. By eliminating unnecessary varieties, sizes and designs, simplification leads to manufacture identical components or products for interchangeability and maintenance purposes of assembly of parts. Standardization is the important step towards interchangeable manufacture, increased output and higher economy. The technique of standardization comprises of determining optimal manufacturing processes, identifying the best possible engineering material, and allied techniques for the manufacture of a product and adhering to them very strictly so long as the better standards for all these are not identified. Thus definite standards are set up for a specified product with respect to its quality, required equipment, machinery, labor, material, process of manufacture and the cost of production. The identified standard with time for a specified product should never be taken as final forever because improvement is always possible. It must accommodate the outcome of all the

new researches in the manufacturing areas in order to keep pace with increasing global competition. Improvements over the existing standards in all respects should always be welcomed. The different standards prevailing in different industries may be of the types of managerial, design, manufacturing and technical needs. Managerial standards are applicable to administrative functions within industry. These include the company policy, accounting procedures, personnel policies, performance evaluation, control of expenditures, safety aspects, security procedures and regulations, etc. whereas design, manufacturing and technical standards are needed for manufacturing concepts of the industry. These include design and manufacturing techniques, practices, materials and parts, supplies, methods of testing, drafting method, abbreviations and symbols, specifications and nomenclature, etc.

1.3.1 Inspection and Quality Control

A product is manufactured to perform desired functions. It must have a specified dimension such as length, width, height, diameter and surface smoothness to perform or accomplish its intended function. It means that each product requires a defined size, shape and other characteristics as per the design specifications. For manufacturing the product to the specified size, the dimensions should be measured and checked during and after the manufacturing process. It involves measuring the size, smoothness and other features, in addition to their checking. These activities are called measurement and inspection respectively. In the era of globalization, every industry must pay sufficient attention towards maintaining quality because it is another important requirement or function of a production unit. If a manufacturing concern wants to survive for longer time and to maintain its reputation among the users, it should under all condition apply enough efforts not only to keep up the standard of quality of its products once established but to improve upon the same from time to time. For this, every manufacturing concern must maintain a full-fledged inspection and quality control department which inspects the product at different stages of its production. Vigilant inspection of raw materials and products depends upon the entire process of standardization. The production unit of manufacturing concern must produce identical products. However a minor variation may be allowed to a predetermined amount in their finished dimensions of the products. The two extremities of dimensions of the product are called limits. All the parts of which the finished dimensions lie within these limits are acceptable parts. This facilitates easy and quicker production, easy inspection, requires less skill on the part of worker and accommodates a slight inaccuracy in the machine as well, resulting in an overall reduction in the production cost of the part.

1.3.2 Mechanization and Automation

Mechanization means something is done or operated by machinery and not by hand. Mechanization of the manufacturing means is milestone oriented trend towards

minimizing the human efforts to the extent of its possibility, by adopting mechanical and electrical means or methods for automating the different manufacturing processes. Such a trend may be in the area of automating and mechanizing the processes of material handling, loading and unloading of components, actual operations performed on the job or transportation, etc. But, no feedback is provided by the process, operation or machinery. Extension of mechanization of the production process is termed as automation and it is controlled by a closed loop system in which feedback is provided by the sensors. It controls the operations of different machines automatically. The automatic control may be applied for some operations or for all the operations of a machine or group of machines. Accordingly the machine will be known as semi-automatic or fully automatic. The term was identified shortly after the World War II at the Ford Motor Company to describe the automatic handling of materials and parts between the process operations. The word 'automation' is derived from the Greek word *automatos* meaning self-acting. Automation can also be defined as the process of following a predetermined sequence of operations with little or no human intervention, using specialized equipment and devices that perform and control the manufacturing process. Automation is a word that has many meanings in the industry today. Automatic machines of all kinds existed long before the term automation was conceived. But, it should be noted that all automatic machines do not come under the category of automation. Automation is a technology concerned with the application mechanical, electronic, and computer based systems to operate and control production. Every machine should involve some automation, may be to a lesser degree or to a higher extent to which is mainly governed by economic considerations. Automation means a system in which many or all of the processes in the production, movement, and inspection of parts and material are performed under control by the self-operating devices called controllers. This implies that the essential elements of automation comprise of mechanization, sensing, feedback, and control devices.

DID YOU KNOW?

Forming processes are particular manufacturing processes which make use of suitable stresses to cause plastic deformation of the materials to produce required shapes.

The reasons why one should go for automation are:

- Increased productivity

- Reduced cost of labor and dependence on labor shortages
- Improved quality
- Reduced in-process inventory
- Reduced manufacturing time
- Reduced dependence on operator skills
- Increased safety or reduced risk of humans.

Automation can be classified into three categories, viz.

Fixed automation

Programmable automation

Flexible automation.

Fixed Automation

It is also known as hard automation which is utilized to produce a standardized product such as gears, nuts and bolts, etc. Even though the operating conditions can be changed, fixed automation is used for very large quantity production of one or few marginally different components. Highly specialized tools, devices, equipment, special purpose machine tools, are utilized to produce a product or a component of a product very efficiently and at high production rates with as low unit costs as possible relative to other alternative methods of manufacturing.



Computer-aided Manufacturing is the use of software to control machine tools and related ones in the manufacturing of workpieces.

Programmable Automation

In programmable automation, one can change the design of the product or even change the product by changing the program. Such technique is highly useful for the low quantity production of large number of different components. The equipments used for the manufacturing are designed to be flexible or programmable. The production normally carried out in batches.

Flexible Automation

There is a third category possible between fixed automation and programmable automation that is called flexible automation using Computer Aided Design (CAD) and **Computer Aided**

Manufacturing (CAD/CAM) activities. This is also called as flexible manufacturing system (FMS). It allows producing different products on the same equipment in any order or mix. One important example of programmable automation, in discrete manufacturing, is numerical control. Robot is another example of programmable automation. Robot being integral part of FMS and Computer Integrated Manufacturing (CIM) system can do a large number of manufacturing tasks for replacing the human labor. In the present globalized manufacturing scenario, the advancements of hardware and software concepts using the mechatronics for fast mechanization and automation of manufacturing processes have become essential to be incorporated in the manufacturing areas.

1.3.3 Computer Aided Manufacturing (CAM)

The computer aided manufacturing implies manufacturing itself, aided or controlled by computers. In a wider sense, it denotes all the activities in the manufacturing environment like use of computers in inventory control, project management, material requirement planning, data acquisition, testing and quality control. Improved reliability in view of the better manufacturing methods and controls at the manufacturing stage, the products thus manufactured as well as of the manufacturing system would be highly reliable. Since most of the components of a CAM system would include integrated diagnostics and monitoring facilities, they would require less maintenance compared to the conventional manufacturing methods. Because of the Computer Numerical Control (CNC) machines used in production and the part programs being made by the stored geometry from the design stage, the scrap level would be reduced to the minimum possible and almost no rework would be necessary. Since all the information and controlling functions are attempted with the help of the computer, a better management control on the manufacturing activity is possible. All the above advantages when properly translated, would mean a lower total cost and consequently, higher final earnings. Therefore any manufacturing activity in a production unit (job shop production or mass scale manufacture) can get the benefits of Computer Aided Manufacturing. However, better results can be obtained when the design and manufacturing activities are properly integrated. Also, when there is a large variety of products or minor changes required in the existing production programme, CAM can easily manage the necessary changes or alterations. Following are the main advantages of using CAM.



Greater Design Freedom

Any changes that are required in design can be incorporated at any design stage without worrying about any delays, since there would hardly be any in an integrated CAM environment.

Increased Productivity

In view of the fact that the total manufacturing activity is completely organized through the computer, it would be possible to increase the productivity of the plant.

Greater Operating Flexibility

CAM enhances the flexibility in manufacturing methods and changing of product lines.

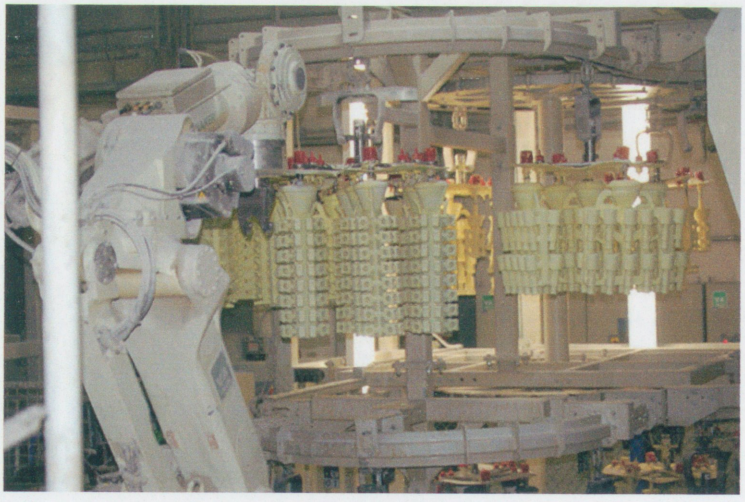
Shorter Lead Time

Lead times in manufacturing would be greatly reduced. The integration of CAD and CAM systems is called computer integrated manufacturing (CIM) system. The role of computer in manufacturing may be in two major groups namely computer monitoring and control of the manufacturing process and manufacturing support applications, which deal essentially with the preparations for act of manufacturing and post manufacture operations. Computers are used in controlling machine tools and other material handling equipments.

CASE STUDY

COMPARING COST AND QUALITY OF A COMPLEX PUMP IMPELLER CASTING MADE FROM WAX AND QUICKCAST PATTERNS

Tech Cast LLC is a leading supplier of high quality investment castings. One of their specialties is large complex pump impeller castings weighing up to 350 pounds and measuring up to 30 inches in diameter. Designing a pump impeller that performs well is a challenge. The fluids being pumped are often multi-component and the flow velocities and volumes are high. Current analytical tools will give a rough estimate of pump performance, but actual performance is only determined experimentally. Consequently, achieving optimum performance is an iterative process: create a design, build the impeller, test its performance, tweak the design, and repeat the process until an optimum design is reached.



In practice, however, optimizing performance in this manner has been prohibitively expensive. Tooling costs, especially for large impellers like those that Tech Cast manufactures, can be very high and lead times long. The tools often require cores, either soluble or ceramic, to create the internal flow paths, requiring that two tools be built. It simply isn't practical to repetitively modify or rebuild tooling to evaluate design changes. As a result, pump manufacturers only iterate until they achieve acceptable performance. They can't afford either the time or cost required for the extra iterations to achieve optimum performance. Tech Cast has pioneered a process that drastically reduces both the cost and time required per iteration, so that pump manufacturers can

go through several versions in less time than they previously could go through a single casting in the past, and spend less money in the process. Tech Cast uses QuickCast patterns to eliminate the need to create or modify tooling for each iteration. QuickCast patterns were the first direct pattern

(patterns created via a 3D printing process) and are by far the most popular direct pattern technology in North America. With Quickcast patterns, castings can be created without the time-consuming process of creating tooling to produce wax patterns, allowing the design to be evaluated in days instead of months.

The cost of QuickCast patterns is typically a small fraction of what tooling costs, and they are available in less than a week, so fully machined impellers are available within three weeks. The resin-based patterns from Quickcast are hollow with a unique internal honeycomb structure that allows the pattern to collapse internally as it expands with temperature. It also minimizes the material in the pattern, resulting in an almost ash-less burn that enables a cast to be created quickly and without a lot of additional steps.

Recently, Tech Cast and 3D Systems worked together on a study to quantify the advantages of their process. A double suction impeller about 15 inches in diameter (pictured above) was chosen for the study.

Castings were created both with molded wax patterns and with QuickCast pattern supplied by 3D Systems. Costs and timing were recorded at each step of the casting process so that an accurate comparison could be made

The first step is to create a CAD model of the casting. The customer typically defines the machined impeller. The foundry must then scale the impeller up to compensate for shrinkage of the metal in casting, add machine stock and add gates. The CAD modeling typically takes a week and is required for both the conventional process and the Tech Cast process.

In the conventional process, the file is then sent to the tool shop where a tool is created in which wax patterns will be molded. For this impeller, the tool cost $40,000 and required 7-9 weeks to create.

For the Tech Cast process, the model is sent to 3D Systems where a QuickCast pattern is created. The cost of the pattern in this case is $3150 and requires one week

In the conventional process, once the tool is received back in the shop, patterns can be molded and impellers cast using Tech Cast's conventional investment casting process. The majority of labor in the process is in molding the pattern and creating the assembly.

Once the QuickCast pattern is received, a minor variation of the conventional investment casting process is used to create the casting. Additional venting is used in the casting process and the pattern must be burned out of the shell rather than melting out. Because there is no labor in molding the pattern, there is actually less

labor content in the casting process for a QuickCast pattern, but it requires a few additional hours for the process variations.

The following table compares the Tech Cast process to the conventional process for this impeller.

	Conventional process	Tech Cast process
Total time to finished casting	10-12 weeks	4 weeks
Labor cost (at $60/hr.)	Base	Base - $81
Purchases	$40,000	$3,150

The Tech Cast process provides an impeller in roughly one third of the time required for the conventional process and at one-tenth the cost. In addition, the casting from the QuickCast pattern has $81 less labor content (assuming a $60/hr. burdened labor rate) than the conventional casting.

The customer can go through at least two iterations in the time it would take to get the first casting from the conventional process.

Assume that when the first casting is tested, the performance is not acceptable. The manufacturer will make an engineering change to improve the performance and request a second impeller to test. The foundry will then create the casting model of the modified design. Because only a change is made, it won't require the full week the first modeling did. We will assume a half week to incorporate the design change into the casting model.

In the conventional process, the tool must be modified to incorporate the change. The cost and time required to make the change will depend on how extensive the change is, but a reasonable average would be 15% of the tool cost and two weeks for a relatively minor change. The modified tool will then be used to mold a new pattern.

In the Tech Cast process, the updated model will be used to create a new QuickCast pattern which will then be cast.

With the conventional process, if the impeller performance is acceptable after the design revision, the manufacturer is likely to go into production. The project is already behind schedule and the pressures to get to market outweigh the need to improve performance.

With the Tech Cast process, if a tool is ordered after the second impeller it adds 7-9 weeks and $40,000, meaning the time and cost to get to production is nearly identical to the conventional process.

If the decision to go into production is made after the third impeller, the Tech Cast process would be a week ahead of the conventional process and roughly $2,500 less expensive.

One of the advantages of the Tech Cast process is that several design variations can be evaluated at one time. If the manufacturer had chosen instead to try all three

of the designs at once and choose the best to go to production, the results would look like this:

	Conventional process	Tech Cast process
Total time to finished casting	17-19 weeks	4 weeks
Labor cost (at $60/hr.)	Base	Base - $243
Purchases	$52,000	$9,450

If the manufacturer chose the best performing design to go to production, and ordered the tool, he would get to production 6 weeks sooner than the conventional process and save $2,500 in the process.

Another advantage of the Tech Cast process is that while the tool is being built, castings can continue to be built from QuickCast patterns. That will allow the manufacturer to build field test units, and initial production pumps before the tool is available, and get to market even faster.

The Tech Cast process also works with impellers that require ceramic cores. Tech Cast can have ceramic cores built by an additive manufacturing process so that the design can be optimized before going to tooling.

SUMMARY

- Manufacturing Engineering is one of the streams of engineering which deals with various manufacturing processes. It also focuses on research and development process, machines, tools and equipments.
- Castings need re-melting of scrap and defective ingots in cupola or in some other melting furnace and then pouring of the molten metal into sand or metallic molds to obtain the castings.
- Primary shaping processes are manufacturing of a product from an amorphous material.
- The secondary processes require the use of one or more machine tools, various single or multi-point cutting tools (cutters), job holding devices, marking and measuring instruments, testing devices and gauges etc.
- Forming processes encompasses a wide variety of techniques, which make use of suitable force, pressure or stresses, like compression, tension and shear or their combination to cause a permanent deformation of the raw material to impart required shape.
- The liquid state joining processes involve localized melting and solidification of workpiece materials with or without the addition of external filler material.
- The electrode wire is automatically fed from a spool into the weld pool by a wire feed system.
- Submerged arc welding is almost similar to gas metal arc welding process to the fact that an electric arc is created between a continuously fed consumable solid or tubular electrode wire and workpiece materials.

KNOWLEDGE CHECK

1. In shaper machine tool, workpiece ..... and tool .....

a. reciprocates, rotates

b. remains stationary, rotates

c. remain stationary, reciprocates

d. rotates, reciprocates

2. Arc blow occurs in ..... Welding.

a. AC

b. DC

c. Gas

d. Resistance

3. **During welding, when the weld reduces the cross sectional thickness of the base metals it is called .....**

a. lack of penetration

b. spattering

c. undercutting

d. blow hole

4. **Which of the following is not a function of flux that is added during casting of cast iron?**

a. absorb impurities

b. replenishes material loss

c. protects casting from oxidation

d. forms slag

5. **Plastic bottles are manufactured using the process of**

a. blow molding

b. injection molding

c. atomizing

d. die casting

REVIEW QUESTIONS

1. How do you classify the manufacturing processes?
2. Discuss primary shaping processes.
3. Explain the secondary or machining processes.
4. What do you understand from the terms manufacturing, process plan, maintenance?
5. Define the mechanical joining processes and solid state joining process.

CHECK YOUR RESULT

1. (c) 2. (b) 3. (c) 4. (c) 5. (a)

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CHAPTER

2

METAL CASTING PROCESSES

LEARNING OBJECTIVES

After studying this chapter, you will be able to:

1. Understand by pattern casting
2. Discuss the metal casting

INTRODUCTION

Metal casting is a metalworking technique in which molten metal is poured into a mold and allowed to set before being removed to reveal a metal piece which can be finished with grinding, sanding, and polishing before being sold. This is one of the oldest metalworking techniques in the world, with evidence of cast metal pieces being found at archaeological sites all over the world, sometimes demonstrating a very high level of skill. This technique continues to be utilized today in a broad range of industries.

A wide variety of materials can be used to make molds for metal casting, depending on the metal being worked. The material needs to be strong and durable enough to withstand the hot metal, while being workable enough to be to be carved or worked into a mold. Wood, limestone, plaster of Paris, and ceramic have all been used for

molds, and crude metal casting has been performed by pouring molten metal into forms made by hollowing out sand or clay. Re-usable molds for metal casting click together, holding the metal while it sets and then pulling apart.

Some molds are made by carving a form from wax, including a high level of detail so that the piece will be as finished as possible. The wax can be inserted into a wet ceramic or plaster of Paris block and then fired, leaving the shape of the mold behind while the wax flows out. This technique is known as "lost wax casting," and it is simple enough to be taught in elementary school art classes.



Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify.

To do metal casting, people usually need access to a foundry, a facility which has been specially outfitted for work with hot metals. Foundries include a very hot furnace or fireplace known as a forge which can be used to work metal directly for blacksmithing, or to melt metals for metal casting. Once metal is molten, it can also be alloyed with other metals to bring out desired properties, and then carefully poured into molds for casting.

Different metals require unique levels of skill to work with, as indicated by the terms "Bronze Age," "Iron Age," and so forth for different periods in human history. Some foundries are equipped to handle a range of metals, including metals which need a very high temperature for working, while others are cruder, and designed to be used with softer metals which are easier to work. Metal casting can also be accomplished with fine metals like silver and gold to make cast jewelry.

2.1 PATTERN CASTING

The pattern is the principal tool during the casting process. It is the replica of the object to be made by the casting process, with some modifications. The main modifications are the addition of pattern allowances, and the provision of core prints. If the casting is to be hollow, additional patterns called cores are used to create these cavities in the finished product. The quality of the casting produced depends upon the material of the pattern, its design, and construction. The costs of the pattern and the related equipment are reflected in the cost of the **casting**. The use of an expensive pattern is justified when the quantity of castings required is substantial.

Functions of the Pattern

- A pattern prepares a mold cavity for the purpose of making a casting.
- A pattern may contain projections known as core prints if the casting requires a core and need to be made hollow.
- Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.
- Patterns properly made and having finished and smooth surfaces reduce casting defects.
- A properly constructed pattern minimizes the overall cost of the castings.

Pattern Material

Patterns may be constructed from the following materials. Each material has its own advantages, limitations, and field of application. Some materials used for making patterns are: wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins.

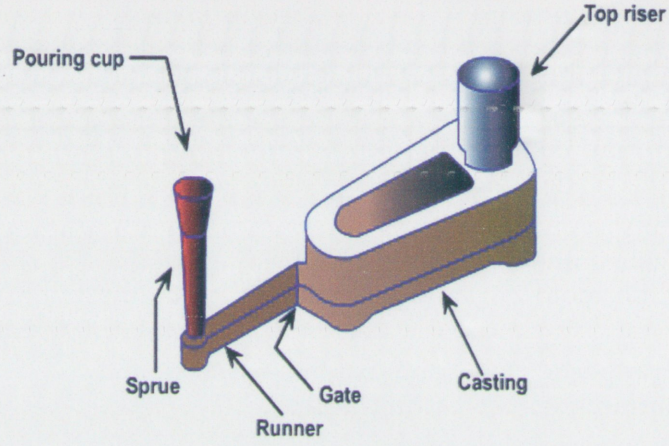
To be suitable for use, the pattern material should be:

- Easily worked, shaped and joined
- Light in weight
- Strong, hard and durable
- Resistant to wear and abrasion
- Resistant to corrosion, and to chemical reactions
- Dimensionally stable and unaffected by variations in temperature and humidity
- Available at low cost

The usual pattern materials are wood, metal, and plastics. The most commonly used pattern material is wood, since it is readily available and of low weight. Also, it can be easily shaped and is relatively cheap. The main disadvantage of wood is its absorption of moisture, which can cause distortion and dimensional changes. Hence, proper seasoning and upkeep of wood is almost a pre-requisite for large-scale use of wood as a pattern material.



The pattern needs to be incorporate suitable allowances for shrinkage; these are called contraction allowances, and their exact values depend on the alloy being cast and the exact sand casting method being used. Some alloys will have overall linear shrinkage of up to 2.5%, whereas other alloys may actually experience no shrinkage or a slight "positive" shrinkage or increase in size in the casting process.



Pattern Allowances

Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting. Thus, when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specification can be made. The selection of correct allowances greatly helps to reduce machining costs and avoid rejections.

The allowances usually considered on patterns and core boxes are as follows:

- Shrinkage or contraction allowance
- Draft or taper allowance
- Machining or finish allowance
- Distortion or camber allowance
- Rapping allowance

All most all cast metals shrink or contract volumetrically on cooling.

The metal shrinkage is of two types:

- *Liquid Shrinkage*: It refers to the reduction in volume when the metal changes from liquid state to solid state at the solidus temperature. To account for this shrinkage; riser, which feed the liquid metal to the casting, are provided in the mold.
- *Solid Shrinkage*: It refers to the reduction in volume caused when metal loses temperature in solid state. To account for this, shrinkage allowance is provided on the patterns.

The rate of contraction with temperature is dependent on the material.

For example, steel contracts to a higher degree compared to aluminum. To compensate

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the solid shrinkage, a shrink rule must be used in laying out the measurements for the pattern. A shrink rule for cast iron is 1/8 inch longer per foot than a standard rule. If a gear blank of 4 inch in diameter was planned to produce out of cast iron, the shrink rule in measuring it 4 inch would actually measure 4 -1/24 inch, thus compensating for the shrinkage. The various rate of contraction of various materials are given in Table 2.1.

Table 2.1: Rate of contraction of various metals

Material	Dimension	Shrinkage allowance (inch/ft)
Grey Cast Iron	Up to 2 feet	0.125
	2 feet to 4 feet	0.105
	over 4 feet	0.083
Cast Steel	Up to 2 feet	0.251
	2 feet to 6 feet	0.191
	over 6 feet	0.155
Aluminum	Up to 4 feet	0.155
	4 feet to 6 feet	0.143
	over 6 feet	0.125
Magnesium	Up to 4 feet	0.173
	Over 4 feet	0.155

2.1.1. Types of Pattern

A pattern is an element used for making cavities in the mould, into which molten metal is poured to produce a casting. The type of pattern to be used for a particular casting depends upon many factors like design of casting, complexity of shape, number of casting required [bulk of casting], mould process, surface finish and accuracy.

The requirements of a good pattern are:

- Secure the desired shape and size of the casting
- Cheap and readily repairable
- Simple in design for ease of manufacture
- Light in mass and convenient to handle
- Have high strength and long life in order to make as many molds as required

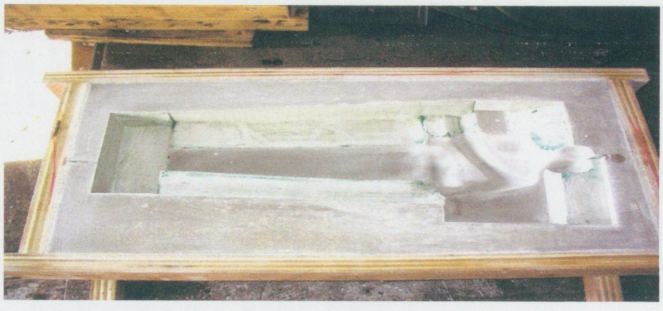
- Retain its dimensions and rigidity during the definite service life
- Its surface should be smooth and wear resistant
- Able to withstand rough handling

The following patterns are commonly used:

1. Solid or single piece pattern
2. Split or two piece patterns
3. Gated pattern
4. Match plate pattern
5. Skeleton pattern
6. Sweep pattern
7. Loose piece pattern
8. Cope and drag pattern
9. Follow board pattern
10. Segmental pattern

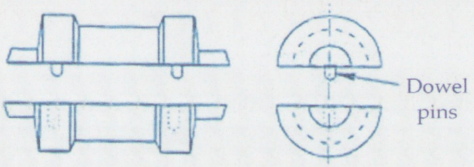
Solid or Single Piece Pattern

It is the simplest of all patterns is made in one piece and carries no joints, partition or loose pieces. The pattern is cheap and it is best suited for limited production only. Since its molding involves a large number of manual operations like gate cutting, providing runner and risers so, such patterns are used for producing a few large castings for example, stuffing box of steam engine.



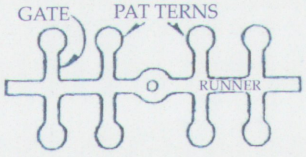
Split or Two Piece Patterns

These patterns are used for intricate casting of usual shapes. They are made in two parts and these two parts of the pattern are joined together with the help of dowel pins. While molding one of the patterns is contained by the drag and other by the cope. For a more complex casting, the pattern may be split in more than two parts.



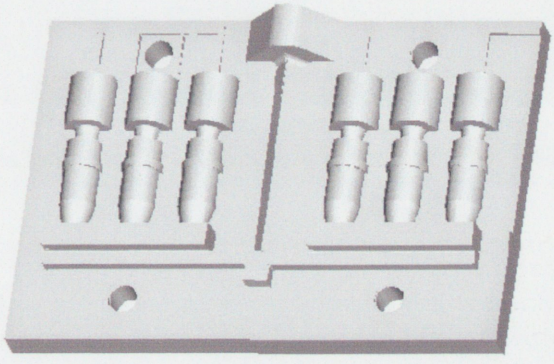
Gated Pattern

They are used in mass production for such castings multi cavity molds are prepared i.e., a single sand mould carries a number of cavities patterns and these castings are connected to each other by means of gate formers. Which provides suitable channels or gates in sand for feeding all the cavities. Gated patterns reduce the molding time somewhat. Because of their higher cost, these patterns are used for producing small castings in mass production systems and on molding machines.



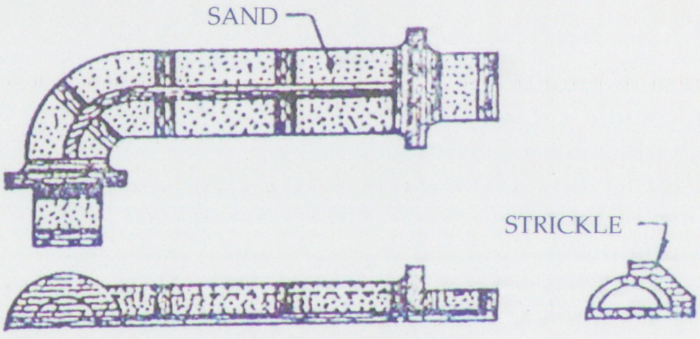
Match Plate Pattern

These are used for mass production these patterns find a great favor in machine molding. A match plate pattern is a split pattern having the cope and drags portions mounted on opposite sides of a plate (usually metallic), called the "match plate" that conforms to the contour of the parting surface. The gates and runners are also mounted on the match plate, so that very little hand work is required. This results in higher productivity.



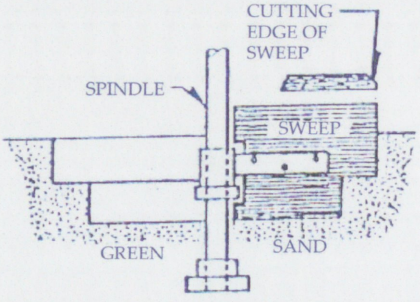
Skeleton Pattern

For large castings having simple geometrical shapes, skeleton patterns are used. Just like sweep patterns, these are simple wooden frames that outline the shape of the part to be cast and are also used as guides by the molder in the hand shaping of the mould. This type of pattern is also used in pit or floor molding process.



Sweep Pattern

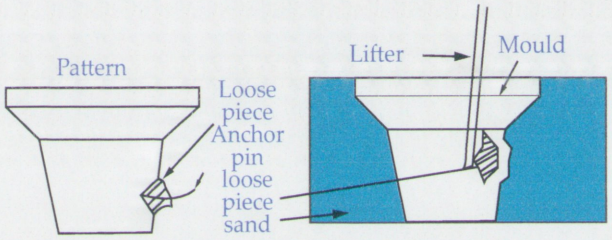
Sweeps can be advantageously used for preparing molds of large symmetrical castings. This effects a large saving in time, labor and material. A sweep is a section or board (wooden) of proper contour that is rotated about one edge to shape mould cavities having shapes of rotational symmetry. This type of pattern is used when a casting of large size is to be produced in a short time.



Loose Piece Pattern

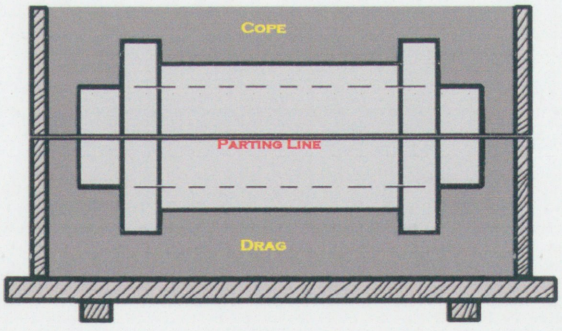
Some patterns usually single piece are made to have loose pieces in order to enable their easy with drawl from the mould. These pieces form and integral part of the pattern

during molding. After the mould is complete, the pattern is withdrawn leaving the pieces in the sand, which are later withdrawn separately through the cavity formed by the pattern.



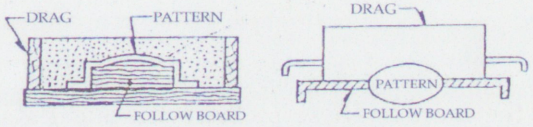
Cope and Drag Pattern

When very large casting are to be made, the complete pattern becomes too heavy to be handled by a single operator. Such pattern is made in two parts which are separately molded in different molding boxes. After completion of the molds, the two boxes are assembled to from the complete cavity. It is similar to two-piece pattern.



Follow Board Pattern

A follow board is a wooden board used for support a pattern during molding. It acts as a seat for the pattern. In the former case, the follow board is provided with a cavity corresponding to the shape of the pattern in which the pattern is seated for molding.



Segmental Pattern

The segmental pattern is functionally similar to sweep pattern in the sense, that both employ a part of the pattern instead of a complete pattern, for getting the required shape of the mould. The segmental pattern is in the form of a segment, and is used for molding parts having circular shapes. To create the mould, it is rotated about the post in the same way as in sweep pattern. But it is not revolved continuously about the post to prepare the mould. Rather, it prepares the mould by parts.

2.1.2. Moulding Sands

Sand casting is a process of using sand as the primary material to mold various metallic products. This molding method is very efficient because sand is a refractory material, which means it can withstand very high temperatures. It is also a very economical process, as it requires less cost and technology.

The first step in the process of sand casting is to prepare the molding container. The container can be made of either wood or metal, in which an embossed pattern is placed. The sand is then poured over the pattern. Other elements such as water and clay are usually added to make the sand more compact and solid.

There are two common methods of solidifying the sand. The first approach is using green sand. The word "green" does not refer to its color, but is used as an indication of its wetness. To avoid the sand from being too runny, only 2 to 4 % of water is used. A green sand casting generally produces a rough surface on the finished metal product.

The air-set approach of sand casting is more commonly used, especially in factories and foundries. This method uses dry sand, along with other ingredients such as clay and adhesive, to produce a cast. As the mixture is poured in the container, it is frequently compressed to avoid holes. Sometimes, the container is even vibrated to make a smooth and even casting. Many manufacturers prefer air-set casting because it creates a smoother texture on the finished product.

For three-dimensional or irregular figures such as a cube or a metal hammer, a two-part casting mold is used. Both the upper and the bottom part of the mold contain halves of the pattern. When the parts are sealed together, the hot metal is poured through a hole called the "gate," and the metal is contained in the compartment until it cools and solidifies.

The sand casting is usually destroyed after each use, but the sand itself can be recycled to produce another casting. This long process becomes a disadvantage if a product is to be produced in great quantities in a short period. Usual metals that are cast are aluminum, cast iron, tin, and steel. Even bronze and copper can be sand-cast. Many metal tools, plumbing, and even car parts are made using sand casting. Reports in 2003 show that more than 70 % of metal castings are created by sand casting.

Some sands only need to withstand 650 °C (1,202 °F) if casting aluminum alloys, whereas steel needs a sand that will withstand 1,500 °C (2,730 °F). Sand with too low refractoriness will melt and fuse to the casting.



Classification of molding sands

According to their use in the foundry, molding sands are classified into following categories:

1. Green sand
   - It is sand used in the wet condition for making the mould. It is mixture of silica sand with 15-25 %clay and 6-8 % water
   - As explained green sand molds are not dried and metal is poured in them in the wet condition
   - Being damp the sand can be easily worked with hand to give it any desired shape
   - This sand is used for producing small to medium sized molds which are not very complex
2. Dry sand
   - Dry sand is the green sand that has been dried or baked after preparing the mould.
   - Drying sand gives strength to the mould so that it can be used for larger castings
3. Loam sand
   - Loam sand is sand containing up to 50 % clay which has been worked to the consistency of builder mortar.
   - This sand is used for loam sand molds for making very heavy castings usually with the help of sweeps and skeleton patterns.
4. Parting sand
   - This sand is used during making of the mould to ensure that green sand does not stick to the pattern and the cope and drug parts can be easily separated for removing the pattern without causing any damage to the mould.
   - Parting sand consists of fine grained clay free dried silica sand, sea sand or burnt sand with some parting compounds.

- The parting compounds used include charcoal, ground bone and limestone, groundnut shells, talc and calcium phosphate.

5. Facing sand
   - Facing sand is the sand which covers the pattern all around it. The remaining box is filled with ordinary floor sand.
   - Facing sand forms the face of the mould and comes in direct contact with the molten metal when it is poured.
   - High strength and refractoriness are required for this sand.
   - It is made of silica sand and clay without the addition of any used sand.
   - Graphite, mollases, plumbago etc. may be added to the facing sand. Thickness of the sand layer varies from 20 to 30 mm.
6. Backing sand
   - Backing sand is the bulk of the sand used to back up the facing sand and to fill up the volume of the flask.
   - It consists mainly of old, repeatedly used molding sand which is generally black in color due to addition of coal dust and burning on contact with hot metal.
   - Because of the color backing sand is also sometimes called black sand.
   - The main purpose for the use of backing sand is to reduce the cost of molding.
7. *System sand*
   - This is the sand used in mechanized foundries for filling the entire flask.
   - No separate facing sand in used in a mechanized foundry.
   - Sand, cleaned and reactivated by the addition of water and binders is used to fill the flask. Because of the absence of any fresh sand, system sand must have more strength, permeability and refractoriness compared to backing sand.
8. Core sand
   - Core sand is the sand used for making cores. This is silica sand mixed with core oil. That is why it is also called oil sand.
   - The core oil consists of linseed oil, resin, light mineral oil with some binders.
   - For larger cores, sometimes pitch or flour and water may also be used to save on cost.

2.1.3. Properties and Sand Testing

A large variety of molding materials is used in foundries for manufacturing molds and cores. They include molding sand, system sand or backing sand, facing sand, parting

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sand, and core sand. The choice of molding materials is based on their processing properties. The properties that are generally required in molding materials are:

Refractoriness

It is the ability of the molding material to resist the temperature of the liquid metal to be poured so that it does not get fused with the metal. The refractoriness of the silica sand is highest.

Permeability

During pouring and subsequent solidification of a casting, a large amount of gases and steam is generated. These gases are those that have been absorbed by the metal during melting, air absorbed from the atmosphere and the steam generated by the molding and core sand. If these gases are not allowed to escape from the mold, they would be entrapped inside the casting and cause casting defects. To overcome this problem the molding material must be porous. Proper venting of the mold also helps in escaping the gases that are generated inside the mold cavity.

Green Strength

The molding sand that contains moisture is termed as green sand. The green sand particles must have the ability to cling to each other to impart sufficient strength to the mold. The green sand must have enough strength so that the constructed mold retains its shape.

Dry Strength

When the molten metal is poured in the mold, the sand around the mold cavity is quickly converted into dry sand as the moisture in the sand evaporates due to the heat of the molten metal. At this stage the molding sand must possess the sufficient strength to retain the exact shape of the mold cavity and at the same time it must be able to withstand the metallostatic pressure of the liquid material.

Hot Strength

As soon as the moisture is eliminated, the sand would reach at a high temperature when the metal in the mold is still in liquid state. The strength of the sand that is required to hold the shape of the cavity is called hot strength.

Collapsibility

The molding sand should also have collapsibility so that during the contraction of the

solidified casting it does not provide any resistance, which may result in cracks in the castings. Besides these specific properties the molding material should be cheap, reusable and should have good thermal conductivity.

2.1.4. Moisture Content Test

Moisture is the property of the molding sand it is defined as the amount of water present in the molding sand. Low moisture content in the molding sand does not develop strength properties. High moisture content decreases permeability.



Procedures are:

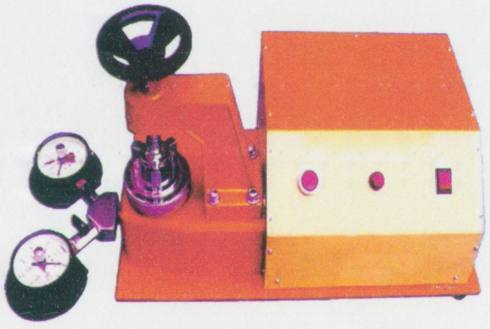
1. 20 to 50 gms of prepared sand is placed in the pan and is heated by an infrared heater bulb for 2 to 3 minutes.
2. The moisture in the molding sand is thus evaporated.
3. Moulding sand is taken out of the pan and reweighed.
4. The percentage of moisture can be calculated from the difference in the weights, of the original moist and the consequently dried sand samples.



Where, W1-Weight of the sand before drying,
W2-Weight of the sand after drying.

Clay content test

Clay influences strength, permeability and other molding properties. It is responsible for bonding sand particles together



Procedures are:

1. Small quantity of prepared molding sand was dried
2. Separate 50 gms of dry molding sand and transfer wash bottle.
3. Add 475cc of distilled water + 25cc of a 3% NaOH.
4. Agitate this mixture about 10 minutes with the help of sand stirrer.
5. Fill the wash bottle with water up to the marker.
6. After the sand etc., has settled for about 10 minutes, Siphon out the water from the wash bottle.
7. Dry the settled down sand.
8. The clay content can be determined from the difference in weights of the initial and final sand samples.

Percentage of clay content = (W1-W2)/ (W1) * 100

Where, W1-Weight of the sand before drying,

W2-Weight of the sand after drying.

Grain fitness test

The grain size, distribution, grain fitness are determined with the help of the fitness testing of molding sands. The apparatus consists of a number of standard sieves mounted one above the other, on a power driven shaker.

The shaker vibrates the sieves and the sand placed on the top sieve gets screened and collects on different sieves depending upon the various sizes of grains present in the molding sand.

The top sieve is coarsest and the bottom-most sieve is the finest of all the sieves. In between sieve are placed in order of fineness from top to bottom.



Procedures are:

1. Sample of dry sand (clay removed sand) placed in the upper sieve
2. Sand is vibrated for definite period
3. The amount of same retained on each sieve is weighted.
4. Percentage distribution of grain is computed.

Permeability test:

The quantity of air that will pass through a standard specimen of the sand at a particular pressure condition is called the permeability of the sand.

Following are the major parts of the permeability test equipment:

1. An inverted bell jar, which floats in a water.
2. Specimen tube, for the purpose of hold the equipment
3. A manometer (measure the air pressure)



Steps involved are:

1. The air (2000cc volume) held in the bell jar is forced to pass through the sand specimen.
2. At this time air entering the specimen equal to the air escaped through the specimen
3. Take the pressure reading in the manometer.
4. Note the time required for 2000cc of air to pass the sand
5. Calculate the permeability number
6. Permeability number (N) = ((V x H) / (A x P x T))

Where,

V-Volume of air (cc)

H-Height of the specimen (mm)

A-Area of the specimen (mm^2)

P-Air pressure (gm / cm^2)

T-Time taken by the air to pass through the sand (seconds)

2.1.5. Core materials and Core Making

Anyone with more than a passing interest in advanced composites will be aware of the benefits that various core materials can bring to a composite construction, whether it be honeycomb cores extensively used in F1 car monocoques to foam cores in refrigerated vehicle body construction. Easy Composites stock a range of core materials including aluminum honeycomb, closed cell foam and coremat which all essentially serve the purpose of adding thickness (and thus deflection resistance) whilst adding minimum weight to a composite.

Core making is an important branch in any foundry and the choice of core making depends on various factors. To name them are depending on type of metal to be cast, depending on the size of casting, choice based on complexity involved in a casting process, depending on the requirement of quality in final product, depends on equipment used for production and energy source.

Common Technologies in Core Making:

There are six most common technologies involved in core making.

They are:

- Oil as the sand binder
- Green sand
- Hotbox
- Cold box
- No bakes
- Shell process

In each of the above technologies there are various advantages and drawbacks.

Requirements and Features of Common Technologies in Core Making

When each of the technology is ranked based on the usage of energy per unit of product ranking from greatest to lowest amount the order is oil as the sand binder being the highest followed by green sand, hotbox, cold box, no bakes and shell process being lowest usage of energy in ranking.

That is when rated in percentage the technology of oil as the sand binder uses the maximum energy of hundred percentage and green sand used 85% followed by hotbox with 75%, cold box with 58%, no bakes with 38%. The least energy usage is made by shell process technology with 35% recorded as usage.

The oil as the sand binder as well as the green sand technology uses high energy because it needs high temperatures for the process of curing and refractory coating and pasting has to be carried out on cores. The hotbox technology gives output as solid

cores and needs hot curing for the process of binder setting. The technology of cold box is carried out with the usage of heated sand and amine gas mixture.

No bakes technology operates at accurately controlled setting. The least usage of energy is by shell process technology in which no coating is necessary.

In a similar way per actions towards energy consumption must be made for achieving system efficiency, which must also focus on step towards consistent usage of such energy consumed to be used efficiently.

Some of the steps suggested for workforce in this aspect are avoiding wastages of shell sand, usage of equipment's producing heat only when needed, analyzing and taking steps towards vital defects, making economical usage by switching of unwanted machineries.

Some of the process improvements that could be made at reduced cost towards this direction are taking steps for oven insulation, going for moisture sensors installation, taking steps towards process improvements like reviewing for reusable products like steel cores which increase productivity and helps in achieving greater quality with cost cutting.

The high cost up gradations that could be taken in the direction for system efficiency are going for improvements in drying process by making use of either infrared heating or microwave heating, making use of technique of continuous drying, reuse of heat recovered, taking steps towards heat recovery like recovery of heat from exhausts attached in the drying or baking oven.



REMEMBER

Process change to any foundry must be taken only after careful projection on various factors being taken into account. Some to name in this direction are processing change results on costs like fixed and variable, investment or capital cost, payback needed and so on.

2.1.6. Dry and Loam sand Molding

Dry sand molding is the green sand practice modified by baking the mold at 400-600F (204-316C). Some foundries use dry sand molds to produce intricate parts which are difficult to cast to exact size and dimensions. Molds are generally dried (or baked) in large mold drying or with large mold heaters. Castings of large or medium size and of complex configuration such as frames, engine cylinders, rolls, large gears and housings are often made using the dry sand technique. Both ferrous and nonferrous metals are cast in this type of mold.



Foundry is a factory that produces metal castings.

Advantages

Dry sand molds are generally stronger than green sand molds and therefore can withstand much additional handling.

Better dimension control than if they were molded in green sand.

The improved quality of the sand mixture due to the removal of moisture can result in a much smoother finish on the castings than if made in green sand molds. Where molds are properly washed and sprayed with refractory coatings, the casting finish improved.

Disadvantages

This type of molding is much more expensive than green sand molding and is not a high-production process. Correct baking (drying) times are essential.

Loam is one type of clay which is made with sand mixed with water to form a thin plastic mixture from which molds are made. Loam sand also contains ganisters or fire clay. The loam must be sufficiently adhesive so that it can cling to the vertical surface. It always requires special provision to secure adequate ventilation. The object is opened out pores in the otherwise compact, closely knit mass, by artificial means. There are various kinds of organic matter such as chopped straw, and particularly horse manure, is mixed up with the sand, a typical loam sand mixture is given below:

1.	Silica Sand	22 vol.
2.	Clay	5 vol.
3.	Coke	10 %
4.	Moisture	18-20 vol.

This applied as plaster to the rough structure of the mould usually made of brick work and the exact shape is given by a rotating sweep around a central spindle. Cast iron plates and bars are used to reinforce the brick work which retains the molding material. Loam molds also be prepared by the use of skeleton pattern made of wood. The surfaces of loams are blackened and are dried before being assembled. Loam molds are employed chiefly in the making of large casting

for which it would be expensive to use full pattern and ordinary flasks equipment. Objects such as large cylinders, chemical pans, large gears, round bottoms, kettles and other machining parts are produces in the loam molding.

2.1.7. Pit and floor Moulding

The nature of this industry and its resulting intense demands concerning casting quality has influenced our attention to quality. Customers like pulp, paper and board mills have very demanding operating environments that accelerate ageing. In addition, many of the components are quite massive.

We operate with furan and cement sand cores and molds for rolls, cylinders and shafts.

Max weight of the castings up to 100 000 kg (150 tn with special arrangements)

Pits: 15 m deep and lifting height 20 m

Sawing: Bandsaw Gantry, max diameter 2000 mm

Furan sand mixers:

- Bay 7: IMF 10 tn/h
- Bay 6: IMF 10 tn/h
- Bay 4: Axmann 10 tn/h, IMF 20 tn/h

Several core mixers, core ovens, core forming device

Crane capacity up to 140 tons

Hand molded casting: up to 70 ton.

- Castings for paper machines, wind power, marine- and investment industry.
- Typical castings: cylinder blocks, hubs, frames, planer carriers, gearboxes and flywheels.

Several core mixers, furan sand mixers, cold box core shooters.

Shake-out table 3500 - 7000 mm (50 tons).

Furan sand molds and cores

Overhead cranes up to 90 tons.

Weight range of castings from 500 kg to 70 000 kg

Batch sizes vary between one and hundreds per year.

2.1.8. Shell Mold Casting

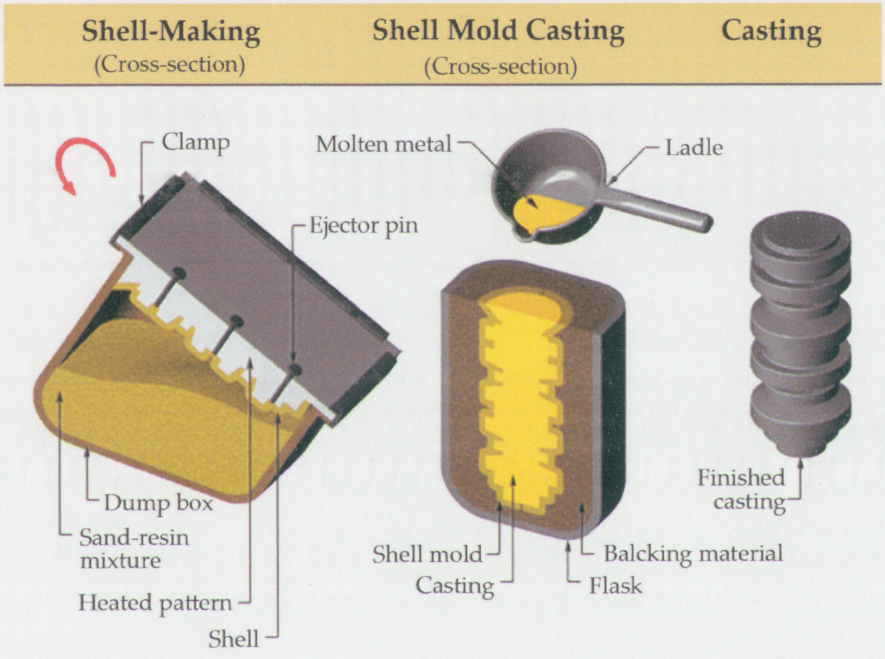
Shell mold casting is a metal casting process similar to sand casting, in that molten metal is poured into an expendable mold. However, in shell mold casting, the mold

is a thin-walled shell created from applying a sand-resin mixture around a pattern. The pattern, a metal piece in the shape of the desired part, is reused to form multiple shell molds. A reusable pattern allows for higher production rates, while the disposable molds enable complex geometries to be cast. Shell mold casting requires the use of a metal pattern, oven, sand-resin mixture, dump box, and molten metal.

Shell mold casting allows the use of both ferrous and non-ferrous metals, most commonly using cast iron, carbon steel, alloy steel, stainless steel, aluminum alloys, and copper alloys. Typical parts are small-to-medium in size and require high accuracy, such as gear housings, cylinder heads, connecting rods, and lever arms.

The shell mold casting process consists of the following steps:

- *Pattern creation* - A two-piece metal pattern is created in the shape of the desired part, typically from iron or steel. Other materials are sometimes used, such as aluminum for low volume production or graphite for casting reactive materials.
- *Mold creation* - First, each pattern half is heated to 175-370°C (350-700°F) and coated with a lubricant to facilitate removal. Next, the heated pattern is clamped to a dump box, which contains a mixture of sand and a resin binder. The dump box is inverted, allowing this sand-resin mixture to coat the pattern. The heated pattern partially cures the mixture, which now forms a shell around the pattern. Each pattern half and surrounding shell is cured to completion in an oven and then the shell is ejected from the pattern.
- *Mold assembly* - The two shell halves are joined together and securely clamped to form the complete shell mold. If any cores are required, they are inserted prior to closing the mold. The shell mold is then placed into a flask and supported by a backing material.
- *Pouring* - The mold is securely clamped together while the molten metal is poured from a ladle into the gating system and fills the mold cavity.
- *Cooling* - After the mold has been filled, the molten metal is allowed to cool and solidify into the shape of the final casting.
- *Casting removal* - After the molten metal has cooled, the mold can be broken and the casting removed. Trimming and cleaning processes are required to remove any excess metal from the feed system and any sand from the mold.



2.1.9. Permanent Mold Castings

Permanent mold castings, while not as flexible as sand castings in allowing the use of different patterns (different part designs), lower the cost of producing a part. At a production run of 1000 or more parts, **permanent mold castings** produce a lower piece cost part. Of course, the break-even point depends on the complexity of the part. More complex parts being favored by the use of permanent molds

The usual considerations of minimum wall thicknesses (such as 3mm for lengths under 75 mm), radius (inside radius = nominal wall thickness, outside radius = 3 x nominal wall thickness), draft angles (1 to 3º on outside surfaces, 2 to 5º on inside surfaces) etc. all apply. Typical tolerances are 2 % of linear dimensions. Surface finish ranges from 2.5 μm to 7.5 μm (100 μin to 250 μin).

Typical part sizes range from 50 g to 70 kg (1.5 ounces to 150 lb). Typical materials used are small and medium sized parts made from aluminum, magnesium and brass and their alloys. Typical parts include gears, splines, wheels, gear housings, pipefittings, fuel injection housings, and automotive engine pistons.

Other Permanent Mold Castings

Slush Casting: Slush Casting is a special type of permanent mold casting, where the

molten metal is not allowed to completely solidify. After the desired wall thickness is obtained, the not yet solidified molten metal is poured out. This is useful for making hollow ornamental objects such as candlesticks, lamps, statues etc.

Corthias Casting: Corthias Casting is another variation of the permanent mold casting, where a plunger is used to pack down the molten metal form the sprue hole. This allows for thinner walls and greater details to be produced.

Low Pressure Permanent Mold Casting: Low pressure permanent mold casting is yet another variation of the permanent mold casting. Here, instead of using gravity to assist in the metal pour and flow in the mold, a low pressure of up to 1 atmosphere gas is applied to the molten metal. This maintenance of pressure on the melt causes complete fill of the mold and compensates for any shrinkage on cooling. Thin wall castings can be made. Mechanical properties are about 5 % superior to permanent mold casting. Since no riser is used (unlike a regular casting), the yield is generally higher since the metal in the pressurized feed tube is still molten and the mold is ready for the next shot right away.



Permanent mold casting is metal casting process that employs reusable molds ("permanent molds"), usually made from metal.

Vacuum Permanent Mold Casting: Vacuum permanent mold casting is yet another variation of the permanent mold casting. This is similar to the low-pressure permanent mold casting, where a vacuum is used instead of a pressure. Thin wall castings can be made as in the low-pressure permanent mold casting. In addition, the yields are high since no risers are used. Since vacuum is used instead, the purity of the metal is maintained. The mechanical properties of the casting are 10 to 15 % superior to the traditional permanent mold casting. Castings range in size from 200 g to 4.5 kg (6 oz to 10 lb).

2.1.10. Carbon Dioxide Moulding

Co_2 Casting is a kind of sand casting process. In this process the sand molding mixture is hardened by blowing gas over the mold. This process is favored by hobby metal casters because a lot of cost cutting can be done. In addition, one can be sure of getting dimensionally accurate

Process: The Mold for Co_2 casting is made of a mixture of sand and liquid silicate binder which is hardened by passing Co_2 gas over the mold. The equipment of the molding process

include Co_2 cylinder, regulator, hoses and hand held applicator gun or nozzle. Carbon di oxide molding deliver great accuracy in production.

Any existing pattern can be used for the molding purpose which can be placed in the mold before the mold is hardened. This method helps in producing strong mold and cores that can be used for high end applications. If the process is carefully executed then casting can be as precise as produced by the shell casting method.

Carbon di oxide casting is favored both by the commercial foundry men and hobbyist for a number of reasons. In commercial operations, foundry men can assure customers of affordable castings which require less machining. The molding process which can be fully automated is generally used for casting process that require speed, high production runs and flexibility. In home foundries this is one of the simplest process that improves the casting quality.

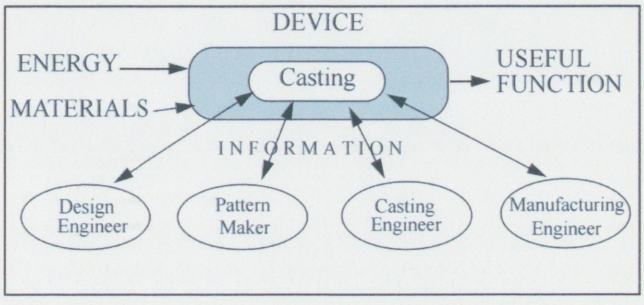
***Applications*:** Co_2 casting process is ideal where speed and flexibility is the prime requirement molds and cores of a varied sizes and shapes can be molded by this process.

***Advantages*:** This process has many advantages in comparison to other forms of castings some of them are as follows:

- Compared to other casting methods cores and molds are strong
- Reduces fuel cost since gas is used instead of to other costly heating generating elements
- Reduces large requirement for number of mold boxes and core dryers
- Provides great dimensional tolerance and accuracy in production
- Moisture is completely eliminated from the molding sand
- This process can be fully automated.

2.2. METAL CASTING

Metal castings form integral components of devices that perform useful functions for human beings, an idea shown schematically follows:



The cast component has a shape, size, chemical composition and metallurgical microstructure which is determined by engineering decisions arrived at by:

A. Design engineers (mechanical engineers)

B. Pattern makers (skilled craftsman, CAD)

C. Casting engineers (metallurgical engineers)

D. Manufacturing engineers (mechanical, metallurgical engineers)

The engineering professionals that carry out this process work together, sharing information so that the casting will perform as intended in a timely and cost effective manner. It should be noted that the casting may only be a small part of the useful device (usually in more sophisticated devices like an automobile where there may be hundreds of components), or it may be the entire device (simple device like a frying pan).



Typical industries served include metal casting parts for: firefighting equipment, plumbing parts, value parts, electrical hardware, precision machinery, water hydrants, gears, decorative hardware, bronze plaques, military transportation, and other industries.

2.2.1. Metal Casting Design

The principles of successful casting design involve a systematic blend of experience and engineering basics to allow the creation of a successful casting, from inception through production.

The major components of the design process are outlined in the six steps listed and described graphically and schematically.

Casting Design Steps

1. Physical design of part to be cast

Purpose of casting (size, shape), tolerances (manufacturing and engineering), dimensional change in processes, relationship of this part to others to optimize its design (concurrent engineering)

2. Material selection for part to be cast

Mechanical and physical properties, cast ability, section size sensitivity, fluid flow properties

3. Pattern production for molds and cores

Gating and riser design, fluid flow and heat transfer

4. Casting process selection, casting production

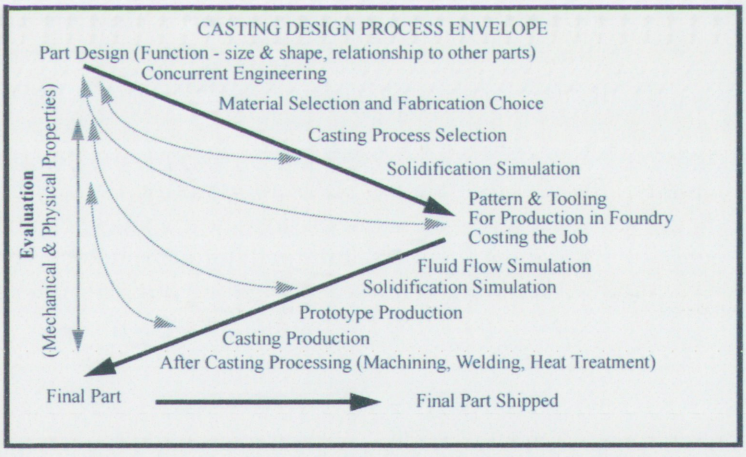
Limitations due to metal cast, casting size, dimensional requirements cost to produce

5. After casting processing

Machining, heat treating, welding

6. Evaluation of cast product

The casting design process is an iterative procedure, requiring excellent communication in all steps of the process. This communication is illustrated through the use of arrows in the schematic follows:



Clearly the designer of the casting needs to understand the fundamental material properties of the casting, its limitations as a material, and the limitations on the potential processes needed to produce that casting.

General considerations by designers include: minimize section size changes; eliminate sharp corners; understand the mechanical property requirements of the casting, the machining requirements, telebanking, the locating requirements, the handling requirements, the process limitations, and how statistical methods can be used in process control. It is important for the design engineer to always question the "old way" of making parts, to be aware of new technology so that the "design envelope" can be stretched to its ultimate. Once the material to be cast has been selected and the casting process chosen, the designer will send drawings (CAD) to the foundry to answer the question, "Can this part be produced in a cost effective way as a casting?" Experienced pattern makers with the help of fluid flow and heat transfer experts will proceed to lay out the requirements for the molds and the cores necessary to produce the part. At this point in the process, or even in the design stage, simulation of the solidification

of the proposed part is a desirable activity. Modern computers are currently being used with powerful software packages to give a preview of solidification, illustrating in color and in real time the path of solidification in the casting.

2.2.2. Melting Furnaces



Casting process simulation was initially developed at universities starting from the early '70s, mainly in Europe and in the U.S., and is regarded as the most important innovation in casting technology over the last 50 years. Since the late '80s, commercial programs (such as AutoCAST and MAGMA) are available which make it possible for foundries to gain new insight into what is happening inside the mold or die during the casting process.

A melting furnace is an appliance capable of heating materials to such a high temperature that they melt, which from a chemical perspective basically means that they reach the critical threshold temperature at which they convert from a solid to a liquid. Not all materials will melt, and those that do often have different melting points. As such, most furnaces are intended for handling certain types of jobs. Most are adjustable which allows for some flexibility and internal control. There can be a wide variety in terms of **furnace** size and capabilities, with some intended for more or less personal use, as in a private shop or garage, whereas as others are much larger and are used industrially. Still, all usually fall within one of four major types or formats: cupola furnaces, electric arc furnaces, induction furnaces, and crucible furnaces. Each has a slightly different style and use profile, but the overarching goal is usually the same no matter the specifics.

Understanding the Basics

Metals are far and away the most common material that people melt down in furnaces. Melted or liquefied metal is much more malleable, and can be formed, molded, and reconfigured with relative ease. This applies both to things like stainless steel and aluminum as well as precious metals like gold and silver. Melting makes it possible to shape and repurpose these raw elements into something useful, and a furnace is usually the most controlled and efficient way to proceed.

The furnace is a tool that has been used by people for a very long time. The earliest furnace is believed to have originated with the Indus Valley Civilization of the Indian subcontinent, and has been dated to somewhere between 2500 and 1800 BC. The melting furnace is an industrial version of this concept, and is typically used for the production of specific materials or as a heat source.

Cupola Models

Some industrial scholars consider the cupola furnace to be the most historically popular form of melting furnace for ferrous, or iron-based, materials. The device is at its core a vertical shaft that resembles a smoke stack. The inside is usually lined with refractory bricks. The most primitive models are little more than basic enclosed towers, usually with a system of shelves and trays for catching the product. More modern examples have temperature controls and a more formalized melt-and-catch system. Air blowing nozzles, used to increase heat, can also be found inside the shaft in many cases. The cupola furnace can be used for various tasks, such as producing liquid ore and melting cast iron or bronzes.



Furnace is a device used for high-temperature heating.

Electric Arcs

Electric arc furnaces are also very popular for re-melting steel scrap. Smaller units are sometimes used for producing cast-iron products, too. As the name implies, this model uses an electric arc to generate heat. The arc creates an electrical breakdown of gas that causes what's known as "plasma discharge," which leads to more rapid melting. Inside the furnace unit, material is put in direct contact with the arc which, in some units, can reach temperatures of up to 3275° Fahrenheit (1800° Celsius). A lot depends on the size of the furnace and what exactly is being melted.

Induction Method

The induction furnace is generally used for melting both ferrous and non-ferrous alloys. It usually employs a water-cooled copper helical coil into which a crucible is installed. When alternating current passes through the coil, the crucible is heated. This model is generally praised for its energy efficiency and the lack of pollution it causes. Induction furnaces tend to be a lot more contained and as a result tend to make less of a mess, as well. Most iron foundries now use the induction furnace instead of the cupola furnace because of these advantages; it is also popular in a number of industrial settings where efficiency and cleanliness are concerns.

Crucible Furnaces

The crucible furnace is considered to be the oldest type of melting furnace, and also the most primitive. It is still used in many more traditional settings and is common for a number of small projects, but tends to be less popular in industry. Its basic design consists of a refractory crucible into which the material to be heated is placed. The material is then heated from outside the crucible wall. Gas-fired versions of this often use a burner to generate heat, while electric models use heating elements.

2.2.3. Rotary Furnace

A rotary furnace, also called a rotary kiln, is a long tube that is used as a continuous plug flow reactor in the mineral industry. The mineral feed is introduced to the reactor portion and is transported down the length of the tube while the tube slowly rotates around its central axis. The materials are mixed as well as heated. The original designs were applied to the calcination treatment in the production of Portland cement and in the extraction of mercury from ores. These reactors are used frequently for the recovery of valuable metals.

A typical rotary furnace is made from a single sheet of steel wrapped into a cylinder with a diameter of about 3 ft to 6 ft (0.9 m to 1.8 m) and a length of about 30 ft to 60 ft (9.1 m to 18.3 m). In one common drive configuration, the tube is rolled on smooth stainless steel rings that rest on two stainless steel rotating rollers. Usually, there are multiple heat zones. The heat may be applied via the hot gas discharge from the fuel, or the fuel may be fired directly into the tube. The transformed product is discharged after being cooled in a cooling section where heat is recovered and sent back to the combustion air.

Screw conveyors or simple threaded rods can be used in a separate rotary furnace design in which more mixing is desired. Another configuration consists of a reverberating design in which material is shaken down the tube. The rotary furnace design is modified by a tilt mechanism that allows liquid metal to drain from the reactor. This design is very useful in the extraction of metals from ores or from recycled materials, such as copper, gold, and mercury.

Fuel is limited to high-energy content fuels, such as oil, gas, or fluidized coal since high temperatures are required. The high-energy requirement to melt metals also explains the use of direct contact with the combustion flame in some designs. The combustion gases are generally passed counter-current to the material flow. Controls include feed rates, temperature zones, and rotation speeds. Many companies now provide complete systems that are either of standard design or custom engineered for the applications.

A variation of the rotary furnace is a batch process that consists of a rotating vessel that is titled on its side. The heat is supplied through the free space above the liquid.

3G E-LEARNING

When the metal is melted, the vessel is tilted, and the metal is poured into molds. This is a common design for the recycling of aluminum cans, as the cans are primarily aluminum and organic materials that can be burned off during the melting process.

2.2.4. Cupola Furnace

A cupola furnace is a cylindrical device that is used to heat and melt metals such as iron and bronze. These blast furnaces are typically between 1.5 and 13 feet (about 0.5 to four meters) in diameter, and have the outward appearance of a smokestack. In order to operate a cupola furnace, the cylinder is usually filled with alternating layers metal and coke, and flux materials, such as lime or carbon adjuncts, can also be added. When the metal melts, it flows down and can be released from a tap on the front of the furnace. After the run is complete, these furnaces can be emptied and prepared for future use by opening a dump gate on the bottom to remove remaining coke and other materials.

Archaeological evidence suggests that cupola designs may have been used in China during the third century BCE. Early examples of cupola furnaces were used in China during the Chunqiu period to cast bronze. Cupola furnaces were also used for cast iron in Europe from the 17th Century on. Until the middle of the 20th Century, the cupola furnace remained the primary method of casting iron. Most foundries eventually switched over to induction furnaces, though cupolas are still used in some instances.

When a cupola furnace is in use, it is typically referred to as a campaign. At the start of a campaign, coke is placed into the furnace and then ignited. Ports called tuyeres are used to introduce air to the burning coke, which creates a type of blast furnace. The introduction of air to the coke results in it becoming very hot, at which point metal can be set into the furnace. Additional layers of coke are added so that the heating process will continue, and lime or other fluxing agents can be added to reduce oxidation.

Heat from the lower layers of burning coke typically rises through the cylinder, heating the upper layers of metal and melting them. Carbon from the coke can bond with the liquid metal as it runs through the lower layers and pools at the bottom. Adjuncts such as silicon carbide may be added to increase carbon content. After enough molten metal has pooled in the bottom part of a cupola furnace, the operator can open a spigot to drain it into a collection vessel. There is typically another spigot at a higher point on the back of the device that can drain slag materials.

Induction Furnaces

The principle of induction melting is that a high voltage electrical source from a primary coil induces a low voltage, high current in the metal, or secondary coil. Induction heating is simply a method of transferring heat energy. Induction furnaces are ideal

for melting and alloying a wide variety of metals with minimum melt losses, however, little refining of the metal is possible. There are two main types of induction furnace: coreless and channel.

Coreless Induction Furnaces

The heart of the coreless induction furnace is the coil, which consists of a hollow section of heavy duty, high conductivity copper tubing which is wound into a helical coil. Coil shape is contained within a steel shell and magnetic shielding is used to prevent heating of the supporting shell. To protect it from overheating, the coil is water-cooled, the water bing recirculated and cooled in a cooling tower. The shell is supported on trunnions on which the furnace tils to facilitate pouring.

The crucible is formed by ramming a granular refractory between the coil and a hollow internal former which is melted away with the first heat leaving a sintered lining.

The power cubicle converts the voltage and frequency of main supply, to that required for electrical melting. Frequencies used in induction melting vary from 50 cycles per second (mains frequency) to 10,000 cycles per second (high frequency). The higher the operating frequency, the greater the maximum amount of power that can be applied to a furnace of given capacity and the lower the amount of turbulence induced.

When the charge material is molten, the interaction of the magnetic field and the electrical currents flowing in the induction coil produce a stirring action within the molten metal. This stirring action forces the molten metal to rise upwards in the center causing the characteristic meniscus on the surface of the metal. The degree of stirring action is influenced by the power and frequency applied as well as the size and shape of the coil and the density and viscosity of the molten metal. The stirring action within the bath is important as it helps with mixing of alloys and melting of turnings as well as homogenizing of temperature throughout the furnace. Excessive stirring can increase gas pick up, lining wear and oxidation of alloys.

The coreless induction furnace has largely replaced the crucible furnace, especially for melting of high melting point alloys. The coreless induction furnace is commonly used to melt all grades of steels and irons as well as many non-ferrous alloys. The furnace is ideal for remelting and alloying because of the high degree of control over temperature and chemistry while the induction current provides good circulation of the melt.

Channel Induction Furnaces

The channel induction furnace consists of a refractory lined steel shell which contains the molten metal. Attached to the steel shell and connected by a throat is an induction unit which forms the melting component of the furnace. The induction unit consists of

an iron core in the form of a ring around which a primary induction coil is wound. This assembly forms a simple transformer in which the molten metal loops comprises the secondary component. The heat generated within the loop causes the metal to circulate into the main well of the furnace. The circulation of the molten metal effects a useful stirring action in the melt.

Channel induction furnaces are commonly used for melting low melting point alloys and or as a holding and superheating unit for higher melting point alloys such as cast iron. Channel induction furnaces can be used as holders for metal melted off peak in coreless induction units thereby reducing total melting costs by avoiding peak demand charges.

Electric Arc Furnaces

Electric arc furnaces may be categorized as direct arc or indirect arc. Both types of units are suited for the melting of high melting point alloys such as steels. They may be lined with acid or basic refractories.

Direct arc furnaces

Direct arc furnaces are very popular for the melting of alloy steels and range in size from a few kilograms, for laboratory units, to in excess of 100 tons per batch. Typically units found in foundries are in the range of 1 to 10 tons. The furnace generally consists of a cylindrical steel shell which is lined with acid or basic refractories. The roof which can normally swing away to facilitate charging, generally contains three carbon electrodes operating on a high tension three-phase power supply. These electrodes protrude vertically through the roof and an electric current passes directly through them and into the metal bath. The distance between the electrodes and the metal bath is automatically controlled and determines the power input into the bath.

These furnaces generally have a door at the back for alloying, oxygen lancing and slag removal purposes, and a pouring spout at the front. The entire unit is capable of being tilted for discharge of the melt through the pouring spout. Some of the advantages of direct arc furnaces include high melt rates, high pouring temperatures and excellent control of melt chemistry.

Indirect Arc Furnaces

Generally consist of a horizontal barrel shape steel shell lined with refractories. Meltin is effected by the arcing between two horizontally opposed carbon electrodes. Heating is via radiation from the arc to the charge. The barrel shaped shell is designed to rotate and reverse through approximately 180°C in order to avoid excessive heating of the refractories above the melt level and to increase the melting efficiency of the unit. Indirect arc furnaces are suitable for melting a wide range of alloys but are particularly

popular for the production of copper base alloys. The units operate on a single-phase power supply and hence the size is usually limited to relatively small units.

2.2.5. Casting Defects



Casting defect is an undesired irregularity in a metal casting process.

A casting defect is a functional or aesthetic flaw in a piece of cast metal. There are a number of types of flaws people can observe in cast metal, and it is possible take steps to prevent flaws or address them once they arise. Using skilled personnel and appropriate equipment is an important step in making the casting process as successful as possible, as many flaws are the result of not handling materials properly during casting, and people can avoid them with proper training.

Sometimes, tiny bubbles form during casting, making the metal porous. This creates weak points that may fail under stress. Larger air pockets can also form and are sometimes not readily visible because they are inside the metal, rather than along the edges of the finished piece where people can easily see them. Metal may fail to fill a mold, creating a gap, or can overflow, making an overrun that someone will have to trim.

A casting defect can also involve differential cooling rates in the mold, creating lines where metal did not fully fuse. These are weak, and if the metal is under stress, it can bend or snap at those points. Contamination in the mold may also contribute to casting defects, leaving flecks of other materials in the finished product or creating a weak point by triggering chemical reactions that change the composition of the product while the metal is in a liquid state. People working with alloys can run into problems with poor mixtures or contamination, leading to bad performance in the mold and a subsequent casting defect.

Creating pieces of cast metal requires using appropriate molds, heating metals to the correct temperature, and handling the molds properly during the casting process. Many errors can lead to a **casting defect**. Sometimes, they are simply unpleasant to look at, and do not interfere with the function of the finished piece. Others may create a problem by weakening the metal. Casters use materials testing to check on the quality of products after they finish, looking for any defects that might make it necessary to discard the piece.

If it is possible to refinish or work the piece to fix the casting defect without compromising the integrity of the metal, a technician may consider this option. This must be weighed against the cost of tasking someone to fix the problem. Discards may be melted down and recycled, sold as seconds to people who do not need perfect pieces, or sold to recycling companies for another facility to use.

Different Types of Castings defects

A properly designed casting, a properly prepared mould and correctly malted metal should result in a defect free casting. However, if proper control is not exercised in the foundry-sometimes it is too expensive - a variety of defects may result in a casting.

These defects may be the result of:

(a) Improper pattern design,

(b) Improper mould and core construction,

(c) Improper melting practice,

(d) Improper pouring practice and

(e) Because of molding and core making materials.

(f) Improper gating system

(g) Improper metal composition

(h) Inadequate melting temp and rate of pouring

It creates a deficiency or imperfection.

Exceeding quality limits imposed by design and service casting defects are mainly 3 categories. These are:

(1) Major or most severe defects

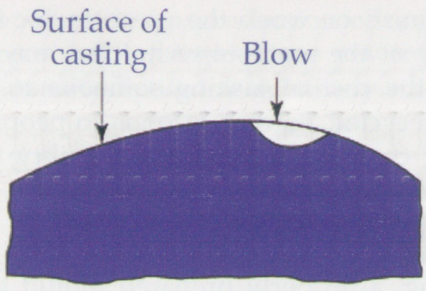
(2) Intermediate defects

(3) Minor defects

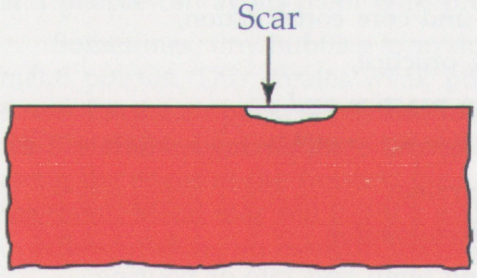
Surface Defects

Due to design and quality of sand molds and general cause is poor ramming.

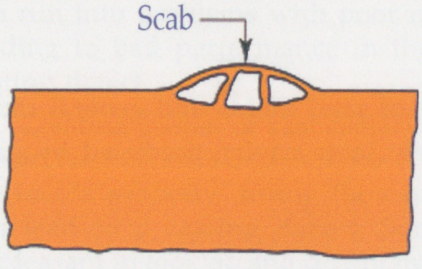
Blow: Blow is relatively large cavity produced by gases which displace molten metal form.



Scar: Due to improper permeability or venting. A scare is a shallow blow. It generally occurs on flat surf; whereas a blow occurs on a convex casting surface. A blister is a shallow blow like a scar with thin layer of metal covering it,



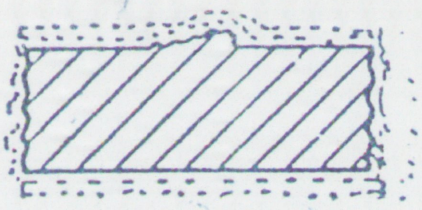
Scab: This defect occurs when a portion of the face of a mould lifts or breaks down and the recess thus made is filled by metal. When the metal is poured into the cavity, gas may be disengaged with such violence as to break up the sand which is then washed away and the resulting cavity filled with metal. The reasons can be: - to fine sand, low permeability of sand, high moisture content of sand and uneven molds ramming.



Drop: Drop or crush in a mould is an irregularly shaped projection on the cope surface of a casting. This defect is caused by the break-away of a part of mould sand as a result of weak packing of the mould, low strength of the molding sand, malfunctioning of molding equipment, strong jolts and strikes at the flask when assembling the mould.

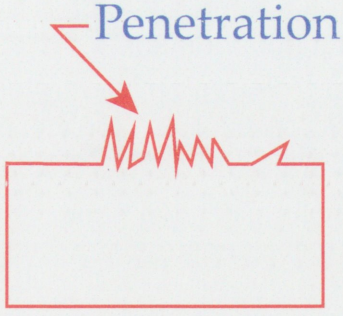
3G E-LEARNING

The loose sand that falls into the cavity will also cause a dirty casting surface, either on the top or bottom surface of the casting, depending upon the relative densities of the sand and the liquid.



Penetration: It is a strong crust of fused sand on the surface of a casting which results from insufficient refractoriness of molding materials, a large content of impurities, inadequate mould packing and poor quality of mould washes.

When the molten metal is poured into the mould cavity, at those places when the sand packing is inadequate, some metal will flow between the sand particles for a distance into the mould wall and get solidified. When the casting is removed, this lump of metal remains attached to the casting. Of course, it can be removed afterwards by chipping or grinding.



Buckle: A buckle is a long, fairly shallow, broad, vee depression that occurs in the surface of flat castings. It extends in a fairly straight line across the entire flat surface.

It results due to the sand expansion caused by the heat of the metal, when the sand has insufficient hot deformation. It also results from poor casting design providing too large a flat surface in the mold cavity.

Buckling is prevented by mixing cereal or wood flour to sand.



Internal defects:

Blow holes: Blow holes, gas holes or gas cavities are well rounded cavities having a clean and smooth surface. They appear either on the casting surface or in the body of a casting.

These defects occur when an excessive evolved gas is not able to flow through the mould. So, it collects into a bubble at the high points of a mould cavity ad prevents the liquid metal from filling that space.

This will result in open blows. Closed, cavities or gas holes are formed when the evolved gases or the dissolved gases in the molten metal are not able to leave the m ass of the molten metal as it solidifies and get trapped within the casting.

These defects are caused by:

i) Excessive moisture content (in the case of green sand molds) or organic content of the sand, moisture on chills, chaplets or metal inserts,

ii) Inadequate gas permeability of the molding sand (due to fine grain size of sand, high clay content, hard ramming),

iii) Poor venting of mould, insufficient drying of mould and cores, cores not properly vented, high gas content of the molten metal,

iv) Low pouring temperature and incorrect feeding of the casting etc.

Pin holes: Pin holes are small gas holes either at the surface or just below the surface. When these are present, they occur in large numbers and are fairly uniformly dispersed over the surface.

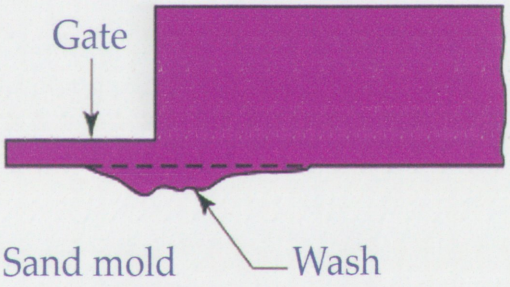
This defect occurs due to gas dissolved in the alloy and the alloy not properly degassed.



Visible Defects

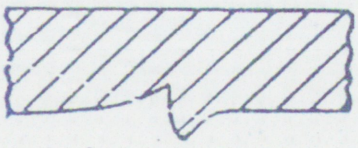
Wash: A cut or wash is a low; projection on the drag face of a casting that extends along the surface, decreasing in height as it extends from one side of the casting to the other end.

It usually occurs with bottom gating castings in which the molding sand has insufficient hot strength, and when too much metal is made to flow through one gate into the mold cavity,



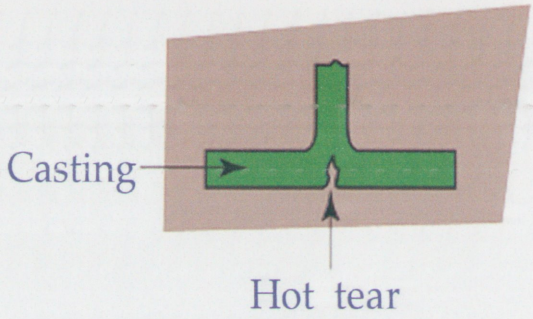
Rat tail: A rat tail is a long, shallow, angular depression in the surface of a flat rating and resembles a buckle, except that, it is not shaped like a broad vee.

The reasons for this defect are the same for buckle

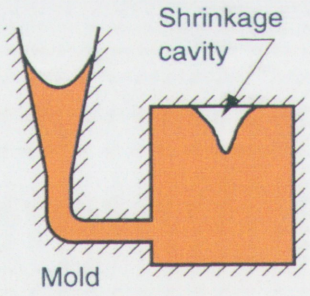


Hot tear: Hot tears are hot cracks which appear in the form of irregular crevices with a dark oxidized fracture surface. They arise when the solidifying met does not have sufficient strength to resist tensile forces produced during solidification.

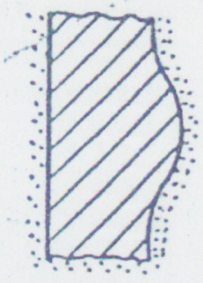
They are chiefly from an excessively high temperature of casting metal, increased metal contraction incorrect design of the gating system and casting on the whole (causing portions of the casting to be restrained from shrinking freely during cooling which in turn causes excessive high intern resistance stresses), poor deformability of the cores, and non-uniform cooling which gives rise t internal stresses. This defect can be avoided by improving the design of the casting and by having a mould of low hot strength and large hot deformation.



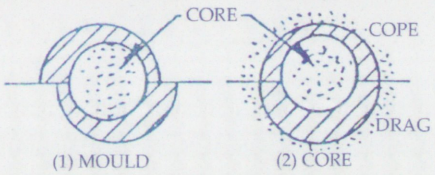
Shrinkage: A shrinkage cavity is a depression or an internal void in a casting that results from the volume contraction that occurs during solidification.



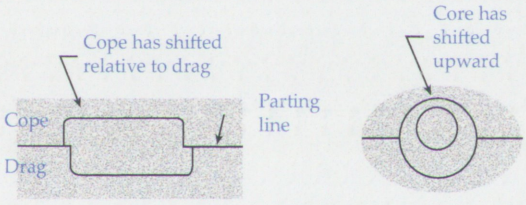
Swell: A swell is a slight, smooth bulge usually found on vertical faces of castings, resulting from liquid metal pressure. It may be due to low strength of mould because of too high a water content or when the mould is not rammed sufficiently.



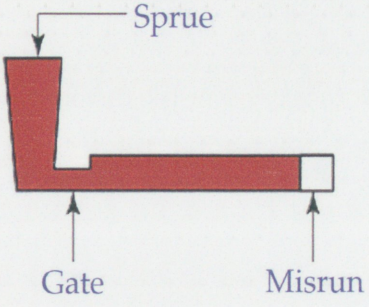
Shift: Mold shift refers to a defect caused by a sidewise displacement of the mold cope relative to the drag, the result of which is a step in the cast product at the parting line.



Core shift is similar to mold shift, but it is the core that is displaced, and (he dis-placement is usually vertical. Core shift and mold shift are caused by buoyancy of the molten metal



Misrun or cold sheet or short run: This defect is incomplete cavity filling. The reasons can be: - inadequate metal supply, too- low mould or melt temperature, improperly designed gates, .or length to thickness ratio of the casting is too large. When molten metal is flowing from one side in a thin section, it may loose sufficient heat resulting in loss of its fluidity, such that the leading edge of the stream may freeze before it reaches the end of the cavity.



DID YOU KNOW?

Clay molds were used in ancient China since Shang Dynasty (c. 1600 to 1046 BC). The famous Houmuwu ding (c. 1300 BC) was made using clay molding.

SUMMARY

- A pattern is an element used for making cavities in the mold, into which molten metal is poured to produce a casting.
- Sand casting is a process of using sand as the primary material to mold various metallic products.
- Moisture is the property of the molding sand it is defined as the amount of water present in the molding sand.
- Shell mold casting is a metal casting process similar to sand casting, in that molten metal is poured into an expendable mold.
- The principles of successful casting design involve a systematic blend of experience and engineering basics to allow the creation of a successful casting, from inception through production.
- A melting furnace is an appliance capable of heating materials to such a high temperature that they melt, which from a chemical perspective basically means that they reach the critical threshold temperature at which they convert from a solid to a liquid.
- A rotary furnace, also called a rotary kiln, is a long tube that is used as a continuous plug flow reactor in the mineral industry.
- A casting defect is a functional or aesthetic flaw in a piece of cast metal there are a number of types of flaws people can observe in cast metal, and it is possible take steps to prevent flaws or address them once they arise.

KNOWLEDGE CHECK

1. **The distortion in casting cannot be prevented by**
   a. Modification of casting design
   b. Providing distortion allowance
   c. Providing sufficient machining allowance to cover the distortion effect
   d. Providing proper shrinkage allowance
2. **The machining allowance provided to ferrous castings for making small and average sized casting is**
   a. 1.5mm
   b. 3mm
   c. 4.5mm
   d. 6mm

3. **The low permeability in sand can cause which of the following defects in casting**
   a. Rough surface
   b. Blow holes
   c. Hot tears
   d. Drop
4. **In a centrifugal casting method**
   a. core is made of sand
   b. no core is used
   c. core is made of ferrous metal
   d. core is made of non-ferrous metal
5. **In casting, gating ratio is defined as the ratio of**
   a. Sprue area: total area: total gate area
   b. Total gate area: sprue area: total area
   c. Total area: sprue area: total gate area
   d. Total area: total gate area: sprue area

REVIEW QUESTIONS

1. List and explain the considerations involved in selecting pattern materials.
2. What differences, if any, would you expect in the properties of castings made by permanent mold vs. sand-casting methods'?
3. Explain the difference in the importance of drafts in green-sand casting vs. permanent mold casting.
4. What kind of metal is used in castings?
5. Differentiate between expendable mold and permanent mold.

CHECK YOUR RESULT

1. (d) 2. (d) 3. (b) 4. (d) 5. (a)

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CHAPTER

3

METAL JOINING PROCESSES

LEARNING OBJECTIVES

After studying this chapter, you will be able to:

1. Discuss about welding
2. Understand by gas welding
3. Explain resistance welding

INTRODUCTION

Metal joining is a controlled process used to fuse metals. There are several techniques of metal joining of which welding is one of the more basic forms. Expertise and technological advances have enabled metal joining innovations, which in turn have led to component advances in many industrial sectors, including aerospace.

It is required when the desired component cannot be made by means of metal forming or machining.

The essential metal- joining operations are:

- Welding,
- Soldering,
- Adhesive bonding,
- Riveting,
- Bolting



Metal joining includes specialized processes such as electron beam welding, vacuum, and honeycomb brazing – complex operations requiring a fusion of expertise and technology.

Joining two or more elements to make a single part is termed as fabrication method. A fairly large number of industrial components are made by fabrication processes. Common examples are aircraft and ship bodies, bridges, building trusses, welded machine frames, sheet-metal parts, etc. The fabrication is often the most economical method, and relies on raw material obtained from one of the primary manufacturing processes such as rolling and extrusion. Hence it may be regarded as secondary manufacturing processes. The various fabrication processes are classified as:

- Mechanical joining process
- Adhesive bonding process
- Welding process, brazing and soldering process

3.1 WELDING

Welding is the process of joining metals by melting the parts and then using a filler to form a joint. It can be done using different energy sources, from a gas flame or electric arc to a laser or ultrasound.

Welding is a joining process for metals wherein the work pieces to be joined as well as the welding or filler material used experience some melting. A common method for welding, known as arc welding, consists of generating an electric arc between an electrode (which contains the welding or filler material) and the work pieces to be welded together. The arc generates enough heat to melt the electrode and the areas of the work pieces were the welding is performed.

As the electrode passes over a region while the arc is present, molten metal from the electrode and molten base metal from the work pieces all get mixed together, solidifying to form a strong joint upon cooldown. The electrode contains some flux material, the purpose of which is to stabilize the arc formed by generating gases (carbon dioxide, carbon monoxide, water vapor) that shield the arc from the surrounding atmosphere.

There are different welding processes used in modern times:

- Arc welding is done through the use of an electrical current, and can be performed by using inexpensive equipment.
- Gas welding is widely used for repair work, especially in anything involving pipes and tubes. It is common in the jewelry industry, as well as for connecting plastics and other materials that cannot stand higher temperatures.
- Resistance welding involves the use of additional sheets of metal to encase the pieces to be welded together. It is the most environmentally-friendly of all methods, but it requires costly equipment that cannot be used in all situations
- Energy beam welding, also known as laser beam welding, is one of the most modern techniques used. This method is fast and accurate, but the high equipment cost makes it prohibitive for many industries.

Welding cannot be done with all types of metals, as some materials, such as stainless steel, are prone to cracking and distortion when overheated. Alloys are particularly problematic, since it is hard to know the exact chemical composition of the metal. Welding has become highly automatized over the last



Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques.

decade, and the use of robots is now commonplace in certain industries, such as the automotive manufacturing plants.

It is possible to weld items in unusual conditions, including underwater and in outer space. Underwater **welding** is widely used in the repair of pipelines and ships, while that performed in space is currently being researched as a possible way to put together space stations and other structures.

3.1.1 Welding Process

Welding process is a material joining process in which two or more parts are coalesced (joined together) at their contacting surfaces by a suitable application of heat and pressure. Sometimes parts are united together by application of pressure only without external heat. In some welding process a filler material is added to facilitate coalescence. Welding process is most commonly associated with metallic parts but plastics also it is used.



A weld is made when separate pieces of material to be joined combine and form one piece when heated to a temperature high enough to cause softening or melting. Filler material is typically added to strengthen the joint.

Requirements of Welding Process

- At the interface where welding is to be done should be clean from dust, oil , paint, grease etc. otherwise joint will be very weak.
- To remove the oily substance from the surface, the organic solvents such as acetone and carbon tetrachloride may be used.
- The heavier oxide films may be removed by acid pickling, wire brushing or emery.
- After the complete evaporation of the organic solvent welding process should be done. Incomplete evaporation may lead to formation of phosgene at the time of welding which may be hazardous.
- Oxide at the surface should be removed with proper fusing; hence they are to be eliminated by the use fluxes. A flux is a material is a material used to prevent, dissolve, or facilitate removal of oxides and other undesirable surface substances.

The following are the definitions of some of the welding terms that are generally used in welding process:

- *Backing* – It is the material support provided at the root side of a weld to aid in the control penetration.
- *Base Metal* – The metal to be joined or cut is known as base metal.
- *Weld Bead* – Bead is the metal added during the single pass of welding. The bead appear as separate material from the base metal.
- *Crater* – In the arc welding, a crater is the depression in the weld metal pool at the point arc strikes the base metal plate.
- *Deposition Rate* – The rate at which the weld metal is deposited per unit times and is expressed in kg/h.
- *Penetration* – It is the depth up to which weld metal combines with the base metal and measured from the surface of the joint.
- *Fillet Weld* – The metal fused into corner of the joint made of two pieces placed at approximately 900 to each other.
- *Puddle* – the portion of the weld joint that melted by the heat of welding is called puddle.
- *Root* – It is the point at which the two pieces to be joined by welding is nearest.
- *Track Weld* – A small weld, generally used to temporarily hold the two pieces together during actual welding process.
- *Torch* – In gas welding, the torch mixes the fuel and oxygen and controls its delivery to get the desired flames
- *Weld Face* – It is the exposed surface of the weld.
- *Weld Metal* – The metal that is solidified in the joint is called weld metal. It may be only base metal or mixer of base metal and filler metal.
- *Weld Pass* – A single movement of the welding torch or electrode along the length of the joint, which results in a bead, is a weld pass.

Types of Welding Processes

There are some types of welding processes, such as:

- Solid state welding process
- Liquid state (fusion) welding process

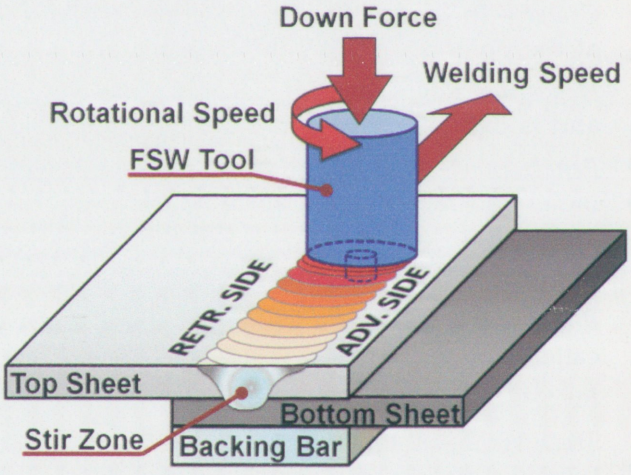
Solid State Welding Process

Solid state welding the surfaces to be joined is brought into close proximity by:

- Heating the surfaces without causing melting and applying normal pressure

- Providing relative motion between the two surfaces and applying light normal pressure
- Applying high pressure without heating

In these processes the materials remain in solid state and welding is achieved through the application of heat and pressure, or high pressure only.



Examples solid state welding processes are: forge welding, explosion welding, friction welding, diffusion welding, ultrasonic welding and roll welding.



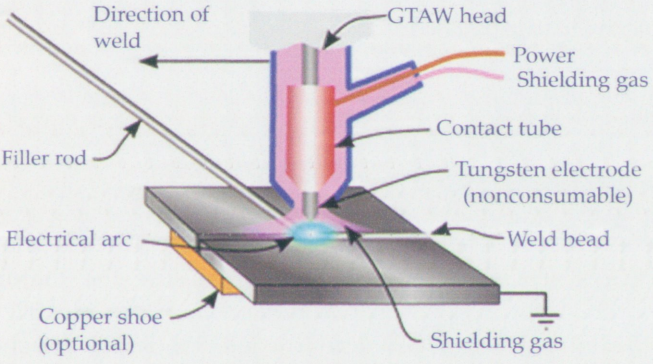
It may use to clad a metal substrate, such as steel, with a protective layer of a dissimilar metal, such as aluminum. Since the materials do not melt, two metals with significantly different melting points can be successfully welded by explosion welding. The force and speed of the explosion are directed to cause a series of progressive shock waves that deform the faying surfaces at the moment of impact. A magnified section of the joint reveals a true weld with an interlocking wave shape and, usually, some alloying.

Liquid State (Fusion) Welding Process

In fusion welding process base metal is melted and joint with or without application of pressure.

The following welding process comes into fusion welding:

- **Arc welding**
- Resistance welding
- Ox-fuel gas welding
- Other processes



There are two inherent problems with fusion welding:

- Effect of localized heating and rapid cooling on the microstructure and properties of the parent metals.
- Effect of residual stresses developed in the parent metals due to restrained expansion or contraction.



Arc welding is a type of welding that uses a welding power supply to create an electric arc between an electrode and the base material to melt the metals at the welding point.

Defects of Welding Process

There are some defects of welding process, such as:

- *Cracks* – This causes significant reduction in the strength of weldment. Welding cracks are caused by embrittlement or low ductility of the weld and/or base metal combined with high restraint during contraction.
- *Cavities*– These includes porosity and shrinkage voids.
- *Solid inclusions*– These are metallic or non-metallic solid material particles entrapped in the weld metal. The most common form is slag inclusion or metallic oxides.
- *Incomplete fusion* – A similar defect is lack of penetration.
- *Imperfect shape*

- Miscellaneous defects like arc strike, excessive spatter

3.1.2 Types of Arc Welding

There are some types of welding, such as:

- Stick - Shielded metal arc welding (SMAW)
- TIG - Gas tungsten arc welding (GTAW)
- MIG - Gas metal arc welding (GMAW)
- Flux-Cored arc welding (FCAW)

Stick - Shielded Metal Arc Welding (SMAW)

Shielded metal arc welding, commonly called stick, is a welding process that uses an electrode (welding rod) to carry the electric current and provide the majority of the weld metal. The electrode consists of a core wire coated in flux. An electric arc is created across the gap when the energized circuit and the electrode tip touches the work piece and is withdrawn, yet still within close contact, generating temperatures of approximately 6500°F. This heat melts both the base metal and the electrode creating the weld. During this process, the molten metal is protected from oxides and nitrides in the atmosphere by a gaseous shield created by the vaporizing of the flux coating. The electrode produces a slag covering on the finished weld.



Advantages

There are some advantages of stick - shielded metal arc welding (SMAW), such as:

- Low cost equipment
- Portability
- No need for shielding gas (can be used outside during rain or wind)
- Works on dirty or rusty metal

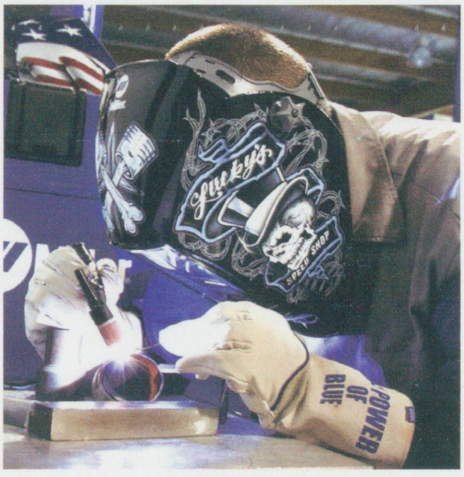
Disadvantages

There are some disadvantages of stick - shielded metal arc welding (SMAW), such as:

- Lower consumable efficiency (waste is produced)
- Difficult to use on thin materials
- High operator skill required

TIG - Gas Tungsten Arc Welding (GTAW)

Gas tungsten arc welding, commonly called TIG or Heli-arc, is a welding process that uses a non-consumable tungsten electrode to heat the base metal and to create a molten weld puddle. An autogenous (no filler metal) weld can be created by melting two pieces of metal together. An external filler rod can be added into the molten puddle to create the weld bead and increase mechanical properties. Like the GMAW process, the molten weld puddle needs to be shielded by an external gas supply. The most commonly used shielding gas is argon, but argon/helium mixtures can be used on heavy aluminum. GTAW can be used to weld most alloys.



Advantages

There are some advantages of TIG - gas tungsten arc welding (GTAW), such as:

- Clean, high quality welds
- Ability to weld very thin materials
- Wide range of alloys can be welded
- Spatter free welds
- Highly aesthetic weld beads

Disadvantages

There are some disadvantages of TIG - gas tungsten arc welding (GTAW), such as:

- High operator skill required
- High cost equipment
- Lower deposition rates
- Need external shielding gas
- Material must be free of rust and dirt



GMAW is commonly known as MIG (metal inert gas) welding. Since fluxes are not used the welds produced are sound, free of contaminants, and as corrosion-resistant as the parent metal. The filler material is usually the same composition (or alloy) as the base metal.

MIG - Gas Metal Arc Welding (GMAW)

Gas metal arc welding, commonly called MIG welding, is a process that uses a continuously fed, solid wire electrode through a welding "gun." The operator pulls a trigger on the welding gun, which feeds the consumable electrode through. An electric arc forms between the electrode and the base material, which heats the base material, causing it to melt, and join. The molten weld metal is protected from oxides and nitrides in the atmosphere by an externally supplied shielding gas. The most commonly used gas is carbon dioxide or a mixture of argon and carbon dioxide. The GMAW process can be used to weld a wide range of alloys including carbon steel, stainless steel, magnesium, nickel, copper, silicon bronze and aluminum.



DID YOU KNOW?

In the 1940s the tungsten-inert gas process, using a no consumable tungsten electrode to perform fusion welds, was introduced. In 1948 a new gas-shielded process utilized a wire electrode that was consumed in the weld.

Advantages

There are some advantages of MIG - gas metal arc welding (GMAW), such as:

- Higher electrode efficiency (less waste)
- Lower heat inputs
- Minimal weld clean up
- Reduced welding fumes
- Easiest to learn

Disadvantages

There are some disadvantages of MIG - gas metal arc welding (GMAW), such as:

- Need external shielding gas
- Limited positions (no vertical or overhead)
- High cost equipment

- Cannot weld thick materials
- Material must be free of rust and dirt

Flux-Cored Arc Welding - (FCAW)

Flux-cored arc welding is a welding process similar to GMAW, in that it uses a continuously fed electrode, but uses a tubular wire filled with flux instead of a solid wire. There are two types of flux-cored wire, self-shielded and dual shield. Self-shielded is used without the aid of an external gas shield and uses the flux to shield the molten weld puddle. Dual shield uses the flux and an external shielding gas to protect the molten weld puddle. Typical shielding gases are carbon dioxide and argon/carbon dioxide mixes. Self-shielded wires are optimal for outdoor use, even in windy situations. Both wires produce a slag covering on the finished weld.



Advantages

There are some advantages of Flux-cored arc welding - (FCAW), such as:

- Higher electrode efficiency (less waste)
- Lower heat inputs
- Minimal weld clean up
- Reduced welding Fumes
- No need for external shielding gas

Disadvantages

There are some disadvantages of **Flux-cored arc welding** - (FCAW), such as:

- Creates slag
- Not recommended for thin materials
- A lot of smoke is generated
- High cost equipment



Flux-cored arc welding is a semi-automatic or automatic arc welding process.

3.1.3 Principle of Welding

A weld can be defined as a coalescence of metals produced by heating to a suitable temperature with or without the application of pressure, and with or without the use of a filler material.

Soldering

Soldering is a joining process that is similar to brazing, except that it is performed at much lower temperatures than brazing. Thus, soldering is also a process of joining two work pieces together with a filler metal, such that only this filler metal undergoes melting that is, the work pieces do not experience any melting. Brazing materials are those that melt above 450 °C, so soldering materials would be those that melt at less than 450 °C.

Common soldering materials include tin-lead, tin-zinc, lead-silver, and cadmium-silver alloys. Like welding and brazing, soldering also employs flux materials to clean the surface to be soldered and improve metallurgical bonding. Residues from fluxes, however, must be removed after soldering to reduce the risk of the occurrence of corrosion.

In semiconductor manufacturing, one common application of soldering as a joining method is in eutectic die attach. This is a process for mounting the die on the package cavity using a metal preform that forms a eutectic alloy with the die.

Brazing

Brazing is a process for joining two work pieces together with a filler metal that is sandwiched between them, wherein only this filler metal undergoes melting that is., the work pieces do not experience any melting. The temperature at which brazing is done must therefore be high enough to melt the filler material, but not the work pieces. Materials used as fillers

for brazing are those that melt above 450 °C. Flux is also used during brazing for the purpose of eliminating oxide films from the surfaces of the work pieces and preventing oxidation. This would ensure a good metallurgical bond between the work pieces and the filler once the brazing process is completed.

Once melted, the brazing material fills up the spaces between the surfaces being joined, and even manages to get into tight spaces by capillary action. A strong joint is obtained after the brazing material has cooled down.



Brazing is a metal-joining process in which two or more metal items are joined together by melting and flowing a filler metal into the joint, the filler metal having a lower melting point than the adjoining metal.

In the semiconductor industry, a common application of **brazing** is in the attachment of leads to certain ceramic packages (such as 'side-brazed packages'). To allow brazing of metal features to a ceramic package, the mating surfaces of the package must first be coated with a thin film of refractory metal (*for example*. molybdenum, tantalum, etc.). This is usually done by applying the metal to the ceramic package in powder form and then heating it. The resulting metal film is then electroplated with copper. The feature for attachment to the package may then be brazed to this copper plated areas.

Adhesive Bonding

Adhesive bonding is a process for joining parts using bonding chemicals or materials known as adhesives. It is employed to join polymers and polymer-matrix composites, as well as polymers to metals, metals to metals, and ceramics to metals. Adhesive-bonded joints can withstand shear, tensile, and compressive stresses, but they do not exhibit good resistance against peeling. To overcome the weakness of adhesive bonding against peeling, joints mated together by adhesives must have a good design that is., the adhesion area is maximized and mechanical interlocking is employed.

High adhesive bond strength is achieved if chemical bonds are formed between the adhesive and the base material, or adherent. However, compared to welding, brazing, and soldering, it is not easy to achieve primary bonding (ionic, covalent, and metallic) in adhesive bonds because of the relatively larger interfacial gaps between the adhesive and the adherent. Secondary bonds, which do not involve electron transfer or electron sharing but instead rely on coulombic forces of attraction, is therefore more likely to form in adhesive

bonding. To maximize adhesive bonding strength, surfaces to be joined by adhesives must be cleaned thoroughly. This, in essence, minimizes the interfacial gap between the adhesive and the adherent. Making the surfaces 'rough' also improves adhesive bond strength because of the mechanical interlocking that the 'roughness' provides.

Adhesive bonding is also widely used in semiconductor manufacturing, a common application of which is adhesive die attach.

Diffusion Bonding

Diffusion bonding, or **diffusion welding**, is a solid-state joining process wherein the joined parts undergo no more than a few percent macroscopic deformation. It can be accomplished at temperatures higher than half the absolute melting point of the base material. Diffusion bonding generally occurs in two stages: 1) deformation processes that result in the surfaces to be joined coming into intimate contact; and 2) formation of bonds by diffusion-controlled mechanisms such as grain boundary diffusion and power law creep. Diffusion bonding is capable of joining a vast array of combinations and sizes of metal and ceramic parts.



Diffusion welding is a solid state welding process by which two metals (which may be dissimilar) can be bonded together.

Mechanical Joining

Mechanical joining is a process for joining parts through mechanical methods, which often involve threaded holes. Joining parts using screws or nuts and bolts are common examples of mechanical joining. The threaded holes employed for mechanical joining are vulnerable to fractures. In ductile materials, the fracture can come from fatigue, while in brittle materials, the fracture can simply result from mechanical overloading. Thus, mechanical joints must be designed with fatigue failure and brittle fracture in mind. Another issue to be considered when designing mechanical joints is galvanic corrosion, which is a type of corrosion that affects different types of metals that are in contact with each other.

3.2 GAS WELDING

Gas welding, also called oxy-fuel welding, is a system of

welding that uses one of various gases and oxygen to ignite a torch. Welding is defined as the process of combining two materials, usually metal, by heating them until both ends become molten. Filler materials are generally added into this molten material, and the two ends are joined together and allowed to cool, forming one solid piece.

Common gases used in gas welding include natural gas, propane, hydrogen, MAPP gas, liquefied petroleum, propylene, and acetylene, with acetylene being the most common. In many cases, one gas is not beneficial over another, although in some situations a specific gas may be preferable.

For example, one gas may heat higher or lower than another, making it more convenient to use with certain metals.

A variety of metals can be joined using gas welding techniques, although a skilled torch operator is necessary in order to ensure a smooth weld. Not all metals melt at the same temperature, so the welder must know how long to heat varying types of materials. There is also a certain level of skill required for gas welding, to ensure that the weld is flawlessly done. Less experienced welders may end up with a joint that is lumpy or uneven.

The gas welder is generally constructed using two tanks. One holds a specific type of gas, which is usually unique for each manufacturer. The other holds oxygen. These two gases combine as they enter the torch and help to maintain a consistent flame.



There are other uses for the oxy-fuel torch, many them involving materials other than metal. Gas welding torches can be used to cut metal and to flame stone for decorative purposes. There are also specialized water welders that are used for welding very small and delicate objects like jewelry. Other uses can include fire polishing glass and, formerly, to heat quicklime in order to create a bright light used in magic shows and other productions.

Another type of gas welding involves the use of a single gas without the use of oxygen. This method is generally not preferable for many types of metal, but is commonly used in soldering. Soldering is an easier form of welding that is performed by melting solder and using the molten material to join two pieces of metal. This differs from traditional welding because the two pieces are not melted, but are only conjoined by solder. The soldering method is not recommended for large items or welds that need to withstand high levels of pressure, but it works well for the inner workings of electronics and other small materials.



REMEMBER

Oxy-fuel is one of the oldest welding processes, besides forge welding. Still used in industry, in recent decades it has been less widely utilized in industrial applications as other specifically devised technologies have been adopted.

3.2.1 Types of Gas Welding

Gas welding involves the use of a gas-fed flame torch to heat the metal work piece and the filler material to create a weld. The gas is generally a mixture of a fuel gas and oxygen to create a clean, hot flame. Many different gases can be used as fuel for gas welding, and electricity is not needed to power the welding system, resulting in a flexible and portable fabrication method. All gas welding techniques require proper safety equipment for the welder and storage of the welding gases.

Oxy-Acetylene Welding

Oxy-acetylene welding uses a mixture of acetylene gas and oxygen gas to feed the welding torch. Oxy-acetylene welding is the most commonly used gas welding technique. This gas mixture also provides the highest flame temperature of available fuel gases, however acetylene is generally the most expensive of all fuel gases. Acetylene is an unstable gas and requires specific handling and storage procedures.

Oxy-Gasoline Welding

Pressurized gasoline is used as a welding fuel where fabrication costs are an issue, particularly in locations where acetylene canisters are not available. Gasoline torches can be more effective than acetylene for torch-cutting thick steel plates. The gasoline can be hand-pumped from a pressure cylinder, a common practice by jewelry makers in impoverished areas.

MAPP Gas Welding

Methylacetylene-propadiene-petroleum (MAPP) is a gas mixture that is much more inert than other gas mixtures, making it safer for hobbyists and recreational welders to use and store. MAPP can also be used at very high pressures, allowing it to be used in high-volume cutting operations.

Butane/Propane Welding

Butane and propane are similar gases that can be used alone as fuel gases or mixed together. Butane and propane have a lower flame temperature than acetylene, but are less expensive and easier to transport. Propane torches are more frequently used for soldering, bending and heating. Propane requires a different type of torch tip to be used than an injector tip because it is a heavier gas.

Hydrogen Welding

Hydrogen can be used at higher pressures than other fuel gases, making it especially useful for underwater welding processes. Some hydrogen welding equipment works off electrolysis by splitting water into hydrogen and oxygen to be used in the welding process. This type of electrolysis is often used for small torches, such as those used in jewelry making processes.

3.2.2 Oxy-fuel Cutting - Process

Oxy-Fuel gas cutting is functional for use with low carbon and low alloy steels, with a carbon content generally restricted to 1/10 to 3/10 of 1%. The various alloy elements found in steel affect the ability of the oxygen to cut the metal. Elements such as manganese, silicon, phosphorus, and sulfur have very little effect in normally found levels. Other elements such as chromium, nickel, molybdenum, and carbon generally reduce the ability of oxygen to sever the material up to the various limits of each.

Prior to attempting to flame cut a piece of material, you must study it and consider the elements it contains as well as the combinations of these elements, just as you would if you studied the metal for physical properties for heat treatment, flame

hardening, etc. A cutting torch diverts the oxygen and mixes part of it with the fuel gas to create the preheat flame, forming the ring of flame around the cutting tip. This preheat flame will reach a temperature of 440°F to 6000°F, depending on the fuel gas used as well as the ratio of oxygen to fuel gas.



The oxy-fuel process is the most widely applied industrial thermal cutting process because it can cut thicknesses from 0.5mm to 250mm, the equipment is low cost and can be used manually or mechanized. There are several fuel gas and nozzle design options that can significantly enhance performance in terms of cut quality and cutting speed.

Process Fundamentals

The cutting process is illustrated in Figure 3.1. Basically, a mixture of oxygen and the fuel gas is used to preheat the metal to its 'ignition' temperature which, for steel, is 700°C - 900°C (bright red heat) but well below its melting point.

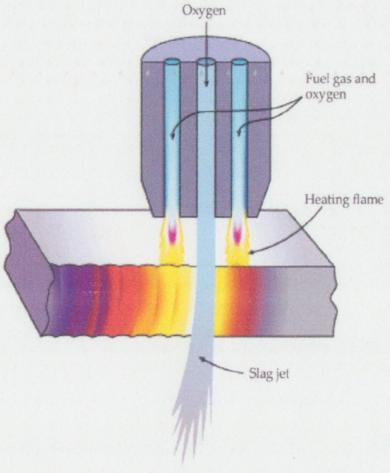


Figure 3.1: Diagram of oxyacetylene cutting process

A jet of pure oxygen is then directed into the preheated area instigating a vigorous exothermic chemical reaction between the oxygen and the metal to form iron oxide or slag. The oxygen jet blows away the slag enabling the jet to pierce through the material and continue to cut through the material.

There are four basic requirements for oxy-fuel cutting:

- The ignition temperature of the material must be lower than its melting point otherwise the material would melt and flow away before cutting could take place
- The oxide melting point must be lower than that of the surrounding material so that it can be mechanically blown away by the oxygen jet
- The oxidation reaction between the oxygen jet and the metal must be sufficient to maintain the ignition temperature
- A minimum of gaseous reaction products should be produced so as not to dilute the cutting oxygen

As stainless steel, cast iron and non-ferrous metals form refractory oxides that is. The oxide melting point is higher than the material, powder must be injected into the flame to form a low melting point, fluid slag.

Purity of oxygen

The cutting speed and cut edge quality are primarily determined by the purity of the oxygen stream. Thus, nozzle design plays a significant role in protecting the oxygen stream from air entrainment.

The purity of oxygen should be at least 99.5%. A decrease in purity of 1% will typically reduce the cutting speed by 25% and increase the gas consumption by 25%.

Choice of fuel gas

Fuel gas combustion occurs in two distinct zones. In the inner cone or primary flame, the fuel gas combines with oxygen to form carbon monoxide and hydrogen which for acetylene, the reaction is given by

$$2C_2H_2 + 2O_2 \rightarrow 4CO + 2H_2$$

Combustion also continues in the secondary or outer zone of the flame with oxygen being supplied from the air.

$$4CO+2H_2 +3O_2 \rightarrow 4CO_2 +2H_2O$$

Thus, fuel gases are characterized by their

- flame temperature - the hottest part of the flame is at the tip of the primary flame (inner cone)
- fuel gas to oxygen ratio - the amount of fuel gas required for combustion but this will vary according to whether the flame is neutral, oxidizing or reducing
- heat of combustion - heat of combustion is greater in the outer part of the flame

The five most commonly used fuel gases are acetylene, propane, MAPP (methylacetylene-propadiene), propylene and natural gas. The properties of the gases are given in the Table. The relative performance of the fuel gases in terms of pierce time, cutting speed and cut edge quality, is determined by the flame temperature and heat distribution within the inner and out flame cones.

Acetylene

Acetylene produces the highest flame temperature of all the fuel gases. The maximum flame temperature for acetylene (in oxygen) is approximately 3,160°C compared with a maximum temperature of 2,828°C with propane. The hotter flame produces more rapid piercing of the materials with the pierce time being typically one third that produced with propane.

The higher flame speed (7.4m/s compared with 3.3m/s for propane) and the higher calorific value of the primary flame (inner cone) (18,890kJ/m^3 compared with 10,433 kJ/m^3 for propane) produce a more intense flame at the surface of the metal reducing the width of the Heat Affected Zone (HAZ) and the degree of distortion.

Propane

Propane produces a lower flame temperature than acetylene (the maximum flame temperature in oxygen is 2,828°C compared with 3,160°C for acetylene). It has a greater total heat of combustion than acetylene but the heat is generated mostly in the outer cone (*see Table*). The characteristic appearance of the flames for acetylene and propane are shown in Figures 3.2 and 3.3 where the propane flame appears to be less focused. Consequently, piercing is much slower but as the burning and slag formation are effected by the oxygen jet, cutting speeds are about the same as for acetylene.

Propane has a greater stoichiometric oxygen requirement than acetylene; for the maximum flame temperature in oxygen, the ratio of the volume of oxygen to fuel gas are 1.2 to 1 for acetylene and 4.3 to 1 for propane.

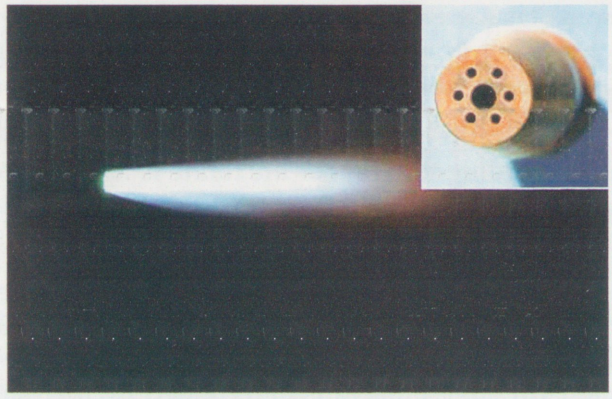


Figure 3.2: Ocyacetylene gas jet and nozzle design

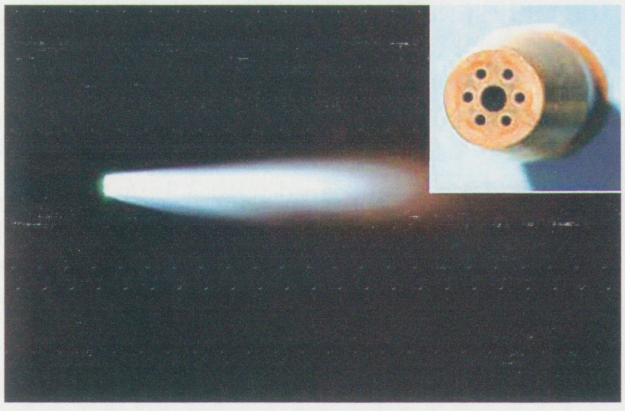


Figure 3.3: Propane gas jet and nozzle design

MAPP

MAPP gas is a mixture of various hydrocarbons, principally, methylacetylene and propadiene. It produces a relatively hot flame (2,976°C) with a high heat release in the primary flame (inner cone) (15,445kJ/m^3), less than for acetylene (18,890kJm^3) but much higher than for propane (10,433kJm^3). The secondary flame (outer cone) also gives off a high heat release, similar to propane and natural gas. The combination of a lower flame temperature, more distributed heat source and larger gas flows compared with acetylene results in a substantially slower pierce time. As MAPP gas can be used at a higher pressure than acetylene, it can be used for underwater cutting in deep water

as it is less likely to dissociate into its components of carbon and hydrogen which are explosive.

Propylene

Propylene is a liquid petroleum gas (LPG) product and has a similar flame temperature to MAPP (2896°C compared to 2,976°C for MAPP); it is hotter than propane, but not as hot as acetylene. It gives off a high heat release in the outer cone (72,000kJ/m^3) but, like propane, it has the disadvantage of having a high stoichiometric fuel gas requirement (oxygen to fuel gas ratio of approximately 3.7 to 1 by volume).

Natural Gas

Natural gas has the lowest flame temperature similar to propane and the lowest total heat value of the commonly used fuel gases, *for example* for the inner flame 1,490kJ/m^3 compared with 18,890kJ/m^3 for acetylene. Consequently, natural gas is the slowest for piercing.

Table 3.1: Fuel gas characteristics

Fuel Gas	Maximum Flame Temperature °C	Oxygen to fuel gas Ratio (vol)	Heat distribution kJ/m^3	
			Primary	Secondary
Acetylene	3,160	1.2:1	18,890	35,882
Propane	2,828	4.3:1	10,433	85,325
MAPP	2,976	3.3:1	15,445	56,431
Propylene	2,896	3.7:1	16,000	72,000
Hydrogen	2,856	0.42:1	-	-
Natural Gas	2,770	1.8:1	1,490	35,770

3.3 RESISTANCE WELDING

Resistance welding refers to processes that use electrically generated heat and pressure to create bonds between materials. Such processes usually pertain to connecting metals but the term resistance welding may also be used in plastic bonding. This type of welding is regarded as quick and efficient when done properly. Mistakes during such a process can result in problems such as cracking, deformed surface appearance, and

cavities. The machines normally used for resistance welding utilize copper electrodes. These are used to inject the materials with electrically generated heat. The machine's operator can control the amount of heat and the heating period. After a sufficient amount of heat is injected, the materials may be cooled on the outside while the inner, molten materials are left to cool more gradually. When this phase is complete, bonds should be formed.

Generally, the higher the melting point of the metal, the less heat that is needed. A metal that conducts heat well, such as aluminum, requires more heat for resistance welding. This is because the heat tends to spread through the material instead of being trapped at the melting point.

DID YOU KNOW?

Resistance welding, invented in 1877 by Elihu Thomson, was accepted long before arc welding for spot and seam joining of sheet.

Resistance welding also requires force. Pressure is used to hold layers of metal together while they are cooling. If this is not done, cohesion may never occur. The necessary pressure is usually applied by the machine that supplies the electrical current. The machine's operator can also usually control the amount of pressure.

Spot welding is an example of a resistance welding process. It can be used to connect multiple layers of metal without filler materials. Since copper is an excellent conductor of heat, pointed, copper electrodes, are used to clamp the metal together and send electrical currents through them.

Many metals do not conduct heat well. The heat created within the layers of the project is therefore trapped and results in melting. Pressure from the electrodes then causes the layers to connect.

Seam welding is similar to spot welding. Instead of creating bonds at various points, however, this process allows the creation of long, continuous bonds. Round electrodes are used in this process to roll over the outsides of the materials, feeding them with electrical current and applying pressure.

There are several types of resistance welding bonds. Fusion bonding involves materials that bind because their melting points are reached, allowing the molten materials to mix together. A solid state bond, on the contrary, is one that involves minimal melting.

3.3.1 Resistance Welding Process

The resistance welding processes differ from many of the other more popular welding processes such as MIG, Stick and TIG. Filler metal is rarely used and fluxes are not employed.

Three factors involved are:

- The amount of current that passes through the work
- The pressure that the electrodes transfer to the work
- The time the current flows through the work.

Heat is generated by the passage of electrical current through a resistance circuit. The force applied before, during, and after the current flow forces the heated parts together so that coalescence will occur. Pressure is required throughout the entire welding cycle to assure a continuous electrical circuit through the work.

Resistance welds are made very quickly; however, each process has its own time cycle.

- Resistance welding operations are automatic.
- The pressure is applied by mechanical, hydraulic, or pneumatic systems.
- Motion, when it is involved, is applied mechanically.
- Current control is completely automatic once the welding operator initiates the weld.
- Resistance welding equipment utilizes programmers for controlling current, time cycles, pressure, and movement.
- Welding programs for resistance welding can become quite complex.

How it Works

- *Bulk Resistance*: Metals have what is called a PTC or positive temperature coefficient. This means that their resistance increases as temperature increases.
- *Contact Resistance*: When two surfaces come in contact, microscopically the surfaces are rough, where some points come in contact on the surface and some do not. At the points where contact is made and assuming the two pieces of metal are pressed together with some pressure, the oxide layer breaks forming a limited number of metal-to-metal bridges. The weld current is then passed over a large area as it moves through the bulk metal. Since the current is forced through a limited number of bridges this "necking down" increases the current density, generating heat which causes melting. As melting occurs, new bridges are formed. Molten metal also has higher resistance than non-molten metal, forcing the current toward newer bridges. The process proceeds until the entire surface is molten.

Weldability

The weldability, also known as join ability, of a material refers to its ability to be welded. Weldability is controlled by three factors:

- Resistivity
- Thermal conductivity
- Melting temperature

Metals with a high resistance to current flow and with a low thermal conductivity and a relatively low melting temperature would be easily wieldable. Ferrous metals all fall into this category. Metals that have a lower resistivity but a higher thermal conductivity will be slightly more difficult to weld. This includes the light metals, aluminum and magnesium. The precious metals comprise the third group. These are difficult to weld because of very high thermal conductivity. The fourth group is the refractory metals, which have extremely high melting points and are more difficult to weld.

These three properties can be combined into a formula which will provide an indication of the ease of welding a metal.

This formula is:

$$W = \frac{R}{Fkt} \times 100$$

In this formula, W equals weldability, R is resistivity, and F is the melting temperature of the metal in °C, and Kt is the relative thermal conductivity with copper equal to 1.00. If weldability (W) is below 0.25, it is a poor rating. If W is between 0.25 and 0.75, weldability becomes fair. Between 0.75 and 2.0, weldability is good. Above 2.0 weldability is excellent. In this formula, mild steel would have a weldability rating of over 10. Aluminum has a weldability factor of from 1 to 2 depending on the alloy and these are considered having a good weldability rating. Copper and certain brasses have a low weldability factor and are known to be very difficult to weld.

Welding Heat and Current

Welding heat is proportional to the square of the welding current. If the current is doubled, the heat generated is quadrupled. Welding heat is proportional to the total time of current flow, thus, if current is doubled, the time can be reduced considerably. The welding heat generated is directly proportional to the resistance and is related to the material being welded and the pressure applied. The heat losses should be held to a minimum. It is an advantage to shorten welding tire. Mechanical pressure which forces the parts together helps refine the grain structure of the weld.

3G E-LEARNING

Heat is also generated at the contact between the welding electrodes and the work. This amount of heat generated is lower since the resistance between high conductivity electrode material and the normally employed mild steel is less than that between two pieces of mild steel. In most applications, the electrodes are water cooled to minimize the heat generated between the electrode and the work.

Advantages

The automotive and appliance industries choose resistance welding for manufacturing because of the great advantages this process has to offer. The first advantage is speed. When over 5000 welds need to be made in a typical car, a process where each weld takes less than a second is of great importance. The process is also adaptable to robotic manipulation so the speed is extremely fast. It is excellent for the sheet metals used in automotive construction, and because no filler metal is needed, the complex wire feed systems in many arc welding processes are avoided.

Higher speeds, <.1 seconds for automotive spot welding, short process time

- Excellent for sheet metal applications <1/4 inch
- No filler metals or consumables required
- Relatively safe due to low voltage requirements
- Environmentally friendly clean process
- Joint formed is reliable

Disadvantages

Several disadvantages are associated with this process. Resistance welding equipment is more expensive than arc welding equipment. The process lacks the portability of arc welding. Although individual spot welding guns may have limited movement on the assembly line, the power source is fixed.

Parts to be joined are limited to a thickness of less than 1/4 of an inch due to current requirements. Thicker base materials have a greater ability to dissipate heat away from the weld area. Also, the resistance welding process is limited to overlapping joints, which requires more material than a butt joint.

The process can produce unfavorable power line demands, particularly with single-phase as opposed to 3-phase transformers. Short time, high power demands can cause lights to dim and computers to reset if the electrical system in a factory is not properly prepared for the introduction of resistance welding equipment.

The lack of a simple, in-process nondestructive testing technique for resistance spot and seam welding is also a limitation. Because resistance welds are produced between overlapping sheets, there can be no visual examination if the finished weld. Also, the time required for ultrasonic inspection of individual spot welds would be

unacceptable in a high production environment such as the automotive industry. Spot welds have low tensile and fatigue strength; the notch around the periphery of the nugget between the sheets acts as a stress concentrator. Electrode wear acts to increase the diameter of the electrode face. During production, current values must slowly rise to compensate for the decreased current density, else nugget size drops.

- Power requirements
- Nondestructive testing
- Low fatigue and tensile strength
- Is not portable
- High levels of electrode wear
- If uses a lap joint, it requires additional metal

3.3.2 Types of Resistance Welding

Resistance welding uses heat and pressure to create a bond between two materials. With this type of welding, the heat is generated by electricity. Usually the materials that are bonded together by resistance welding will be metal, but plastics can also be bonded using resistance welding methods. If done properly, resistance welding is a fast and efficient way to bond two pieces of material together, but if done improperly the weld can crack, break and cause many other problems.

Spot

Spot welding is a method of resistance welding that is used in small projects and for making repairs. Spot welding is also used to bond thin sheets of metal together. In spot welding, electricity is passed between two copper electrodes, causing heat that melts and binds the metal sheets together. The heat creates, which also aids in the bonding of the metal sheets. Another aspect of spot welding is that, as the name implies, the welds are in small strategically placed spots instead of long welds all along the edges where the two pieces of material come together.

Joining two pieces of metal together by spot welding can be quick and efficient, but the resulting join will not be adequate for all purposes. It can be weak or deformed, particularly if the method is not used correctly. Spot welding basically joins two pieces of metal using the heat from an electric current. The two pieces of metal are pressed together with electrodes on either side. The electrodes are connected via a small spot. The current must be applied for the correct amount of time in order to get a strong join. The exact timing will depend on the types and thickness of metals being joined.

Disadvantages

The electrodes have to be able to reach both sides of the pieces of metal that are being joined together. A particular spot welding machine will be able to hold only a certain thickness of metal--usually 5 to 50 inches--and although the position of the electrodes can be adjusted, there will be only a limited amount of movement in most electrode holders. The size and shapes of the electrodes will determine the size and strength of the weld. The join forms only at the spot where the electrodes are in contact with the metal. If the current is not strong enough, hot enough or the metal is not held together with enough force, the spot weld may be small or weak.

Warping and a loss of fatigue strength can occur around the point where metal has been spot welded. The appearance of the join is often rather ugly, and there can be cracks. The metal may also become less resistant to corrosion.

Advantages

Spot welding is quick and easy. There is no need to use any fluxes or filler metal to create a join by spot welding, and there is no dangerous open flame. Spot welding can be performed without any special skill. Automated machines can spot weld in factories to speed up production. The machines used in car factories produce as many as 200 spot welds in six seconds. Spot welding can be used to join many different metals, and can join different types to each other. Sheets as thin as 1/4 inch can be spot welded, and multiple sheets may be joined together at the same time.

Limitations

Spot welding is useful in many circumstances, although there are certain limitations. It can create only localized joins, which may not be particularly strong. The strength of a spot weld depends on the force and temperature that has been applied and on the cleanliness of the electrodes and metal. The difficulty of attaching the electrodes to oddly shaped pieces of metal can be avoided by using a portable spot welder. This has electrodes that are attached to long cables so they can reach inaccessible places.

Flash Butt

Flash butt welding is used for making butt joints for bar type or tubular components. *For example*, where two pieces of heavy gauge metal come together this is the type of weld that would be used. For many people this is the type of joint they think of when they think of welding. This type of weld is used in the construction of large buildings, in some places on cars and in other applications where large pieces of metal come together. This is a solid joint weld that is very strong if done properly. This type of welding requires high temperatures to accomplish.

Seam

Seam welding is used to seal the seam between two pieces of metal. With this type of welding two wheel-shaped electrodes are needed. The wheel shape of the electrodes allow for long continuous welds that reinforce the metals, making the weld as strong as possible. Many types of welding need to be done by a person in order for the weld to be done properly, but seam welds are often done by machines. This makes for quick, accurate welds that are extremely strong. After the product comes out of the machine it will be checked manually and any mistakes will be fixed manually using spot welds.

CASE STUDY

OIL AND GAS WELDING

Renown Engineering Ltd has over 25 years' experience in welding and fabrication complex and heavy projects in various materials. The following project exemplifies the depth of welding capability, and the willingness to take on challenging projects.



The Project

Renown Engineering were tasked to weld 100mm thick eye beams to a base plate for an oil and gas application. Renown were required to turn the project around quickly as the customer had already been let down by a supplier who could not fulfill the welding demands.

Issues to Overcome

The original subcontractor machined the items, meaning any distortion during the welding process would ruin the project. The machining was also so acute that access for welding was impossible.

Renown's Approach

To overcome the difficulties of allowing access for welding, Renown redesigned and re-machined the weld preparation to enable access for welding to take place. Renown

qualified a welding procedure to cover the thickness range (200mm) and qualified welders against the procedure. When the welding began, pre-heat was critical, therefore Renown used STORK for pre-heating equipment. Heating pads then needed to come off every other shift to allow the job to be rotated, staggering the welding to minimize distortion. Renown also manufactured a frame to hold the component during the welding process. Due to the speed of response, Renown was able to deliver to the customer's specifications and on time.

SUMMARY

- Welding is the process of joining metals by melting the parts and then using a filler to form a joint. It can be done using different energy sources, from a gas flame or electric arc to a laser or ultrasound.
- Welding process is a material joining process in which two or more parts are coalesced (joined together) at their contacting surfaces by a suitable application of heat and pressure.
- Shielded metal arc welding, commonly called Stick, is a welding process that uses an electrode (welding rod) to carry the electric current and provide the majority of the weld metal.
- Gas metal arc welding, commonly called MIG welding, is a process that uses a continuously fed, solid wire electrode through a welding "gun."
- Diffusion bonding, or diffusion welding, is a solid-state joining process wherein the joined parts undergo no more than a few percent macroscopic deformation.
- Gas welding, also called oxy-fuel welding, is a system of welding that uses one of various gases and oxygen to ignite a torch.

KNOWLEDGE CHECK

1. **The process of joining two pieces of metal with a different fusible metal applied in a molten state is called as**
   a. welding
   b. soldering
   c. both (a) and (b)
   d. None of the above.
2. **Which of the following statements is/are true for welding process?**
   a. General welding equipments are very costly
   b. Welding results in residual stresses and distortion of workpiece
   c. Two dissimilar metals cannot be joined by welding
   d. All of the above.
3. **The metal joined is never brought to a molten stage in:**
   a. pressure welding
   b. fusion welding

c. thermit welding

d. None of the above.

4. **Which of the following is an example of fusion welding?**

a. Atomic hydrogen welding

b. Flash welding

c. Seam welding

d. Spot welding

5. **In resistance electric welding, the current passed through two joining metal pieces is:**

a. 230 to 440 volts, at a high amperage

b. 230 to 440 volts, at a low amperage

c. 2 to 8 volts, at a high amperage

d. 2 to 8 volts, at a low amperage

REVIEW QUESTIONS

1. What is welding?
2. Define defects of welding process.
3. Explain types of arc welding.
4. What do you understand by gas welding?
5. Write short note on "resistance welding."

CHECK YOUR RESULT

1. (b) 2. (b) 3. (a) 4. (a) 5. (d)

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CHAPTER

4

METAL SHAPING AND FORMING

LEARNING OBJECTIVES

After studying this chapter, you will be able to:

1. Understand overview of metal forming
2. Explain bulk deformation process
3. Discuss about sheet-forming processes

INTRODUCTION

Metal forming is a very important manufacturing operation. It enjoys industrial importance among various production operations due to its advantages such as cost effectiveness, enhanced mechanical properties, flexible operations, higher productivity, considerable material saving.

The objects and articles that we use in our daily life are man-made, engineered parts, which are obtained from some raw material through some manufacturing process. All these objects are made of a number of small components assembled into finished product.



Manufacturing of finished parts and components from raw materials is one of the most important steps in production. Production encompasses all types of manufacturing processes. Manufacturing refers to the conversion of raw materials into finished products employing suitable techniques. There are several methods of manufacturing such as metal casting, metal forming, metal machining, metal joining and finishing.

4.1 OVERVIEW OF METAL FORMING

Metal forming is a general term for a large group that includes a wide variety of manufacturing processes. Metal forming processes are characteristic in that the metal being processed is plastically deformed to shape it into a desired geometry. In order to plastically deform a metal, a force must be applied that will exceed the yield strength of the material. When low amounts of stress are applied to a metal it will change its geometry slightly, in correspondence to the force that is exerted. Basically it will compress, stretch, and/or bend a small amount. The magnitude of the amount will be directly proportional to the force applied. Also the material will return to its original geometry once the force is released. Think of stretching a rubber band, then releasing it, and having it go back to its original shape. This is called elastic deformation. Once the stress on a metal increases past a certain point, it no longer deforms elastically, but starts to undergo plastic deformation. In plastic deformation, the geometric change in the material is no longer directly proportional to stress and geometric changes remain after the stress is released; meaning that the material does not recover its shape. The actual level of stress applied to a metal where **elastic deformation** turns to plastic deformation is called the proportional limit, and is often difficult to determine exactly. The .002 offset convention is usually used to determine the yield point, which is taken for practical purposes as the stress level where plastic deformation, (yielding), begins to occur.

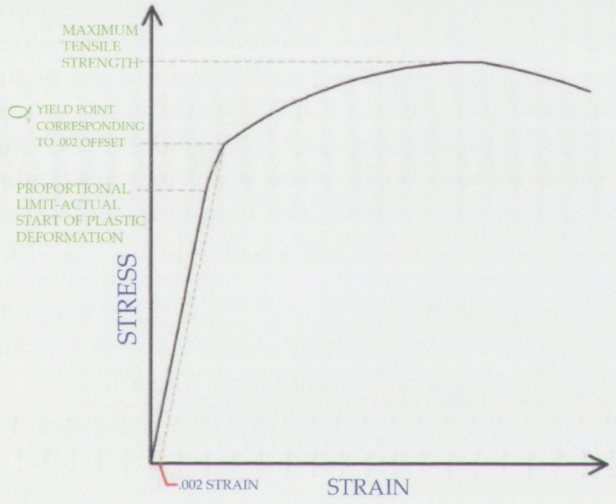


Figure 4.1: Stress strain diagram for typical metal.

It can be seen by the stress-strain graph that once the yield point of a metal is reached and it is deforming plastically, higher levels of stress are needed to continue its deformation. The metal actually gets stronger, the more it is deformed plastically. This is called strain hardening or work hardening. As may be expected, strain hardening is a very important factor in metal forming processes. Strain hardening is often a problem that must be overcome, but many times strain hardening, when used correctly, is a vital part of the manufacturing process in the production of stronger parts.



Elastic deformation is a change in shape of a material at low stress that is recoverable after the stress is removed.

4.1.1. Material Considerations

Forming is the process of obtaining the required shape and size on the raw material by subjecting the material to plastic deformation through the application of tensile force, compressive force, bending or shear force or combinations of these forces.

Flow Stress

During a metal forming operation, it is important to know the force and power that will be needed to accomplish the necessary deformation. The stress-strain graph shows us that

the more a work piece is deformed plastically, the more stress is needed. The flow stress is the instantaneous value of the force necessary to continue the yielding and flow of the work material at any point during the process. Flow stress can be considered as a function of strain. The flow stress value can be used to analyze what is going on at any particular point in the metal forming process. The maximum flow stress may be a critical measurement in some metal forming operations, since it will specify the force and power requirements for the machinery to perform the process. The force needed at the maximum strain of the material would have to be calculated in order to determine maximum flow stress.

For different types of metal forming processes, the flow stress analysis may be different. For a process like forging, the maximum flow stress value would be very important. However, for a process like extrusion, where the metal is continuously being deformed and the different stages of the metal's deformation are occurring simultaneously, it is of interest to analyze the mean flow stress value.



REMEMBER

Forging can produce a piece that is stronger than an equivalent cast or machined part. As the metal is shaped during the forging process, its internal grain deforms to follow the general shape of the part.

Strain Rate

The strain rate for any particular manufacturing metal forming process is directly related to the speed at which deformation is occurring. A greater rate of deformation of the work piece will mean a higher strain rate. The specific process and the physical action of the equipment being used has a lot to do with strain rate. Strain rate will affect the amount of flow stress. The effect strain rate has on flow stress is dependent upon the metal and the temperature at which the metal is formed. The strain rate with relation to flow stress of a typical metal at different temperatures is shown in Figure 4.2.

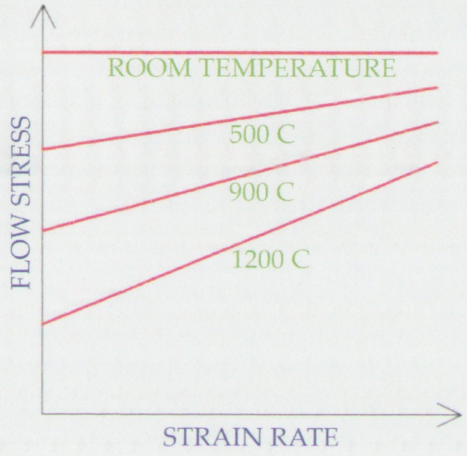


Figure 4.2: Flow stress verses strain rate for a typical metal at different temperatures.

4.1.2. Temperature in Metal Forming

Properties of a metal change with an increase in temperature. Therefore, the metal will react differently to the same manufacturing operation if it is performed under different temperatures and the manufactured part may possess different properties. For these reasons, it is very important to understand the materials that is to be used in manufacturing process. This involves knowing their behavior at various temperature ranges. In industrial metal forming manufacture, there are three basic temperature ranges at which the metal can be formed, cold working, warm working, and hot working.

Cold Working

Cold working, (or cold forming), is a metal forming process that is carried out at room temperature or a little above it. The yield point of a metal is also higher at the lower temperature range of cold forming. Hence, the force required to shape a part is greater in cold working than for warm working or hot working. At cold working temperatures, the ductility of a metal is limited, and only a certain amount of shape change may be produced. Surface preparation is important in cold forming. Fracture of the material can be a problem, limiting the amount of deformation possible. In fact, some metals will fracture from a small amount of cold forming and must be hot formed. One main disadvantage of this type of process is a decrease in the ductility of the part's material, but there are many advantages. The part will be stronger and harder due to strain hardening. Cold forming causes directional grain orientation, which can be controlled to produce desired directional strength properties. Also, work manufactured

by cold forming can be created with more accurate geometric tolerances and a better surface finish. Since low temperature metal forming processes do not require the heating of the material, a large amount of energy can be saved and faster production is possible. Despite the higher force requirements, the total amount of energy expended is much lower in cold working than in hot working.



REMEMBER

If cold working is higher than certain limits, the metal will fracture before reaching the desired shape and size.

Warm Working

Warm working, (or warm forming), is a metal forming process carried out above the temperature range of cold working, but below the recrystallization temperature of the metal. Warm working may be preferred over cold forming because it will reduce the force required to perform the operation. Also, the amount of annealing of the material that may have been necessary for the cold formed part may be less for warm working.

Hot Working

Hot working, (or hot forming), is a metal forming process that is carried out at a temperature range that is higher than the recrystallization temperature of the metal being formed. The behavior of the metal is significantly altered, due to the fact that it is above its recrystallization temperature. Utilization of different qualities of the metal at this temperature is the characteristic of hot working.

Although many of these qualities continue to increase with increasing temperature, there are limiting factors that make overly high temperatures undesirable. During most metal forming processes the die is often cold or slightly heated. However, the metal stock for hot working will usually be at a higher temperature relative to the die. In the design of metal forming process, it is critical to consider the flow of metal during the forming of the work. For metal forming manufacturing, in general, the temperature gradient between the die and the work has a large effect on metal flow during the process. The metal nearer to the die surfaces will be cooler than the metal closer to the inside of the part, and cooler metal does not flow as easily. High temperature gradients, within the work, will cause greater differences in flow characteristics

of different sections of the metal, these could be problematic. For example, metal flowing significantly faster at the center of the work compared to cooler metal near the die surfaces that is flowing slower, can cause part defects. Higher temperatures are harder to maintain throughout the metal forming process. Work cooling during the process can also result in more metal flow variations. Another consideration with hot forming manufacture, with regard to the temperature at which to form the part, is that the higher the temperature the more reactive the metal is likely to be. Also if a part for a hot working process is too hot then friction, caused during the process, may further increase heat to certain areas causing melting, (not good), in localized sections of the work. In an industrial hot metal working operation, the optimum temperature should be determined according to the material and the specific manufacturing process.

When above its **recrystallization** temperature a metal has a reduced yield strength, also no strain hardening will occur as the material is plastically deformed. Shaping a metal at the hot working temperature range requires much less force and power than in cold working. Above its recrystallization temperature, a metal also possesses far greater ductility than at its cold worked temperature. The much greater ductility allows for massive shape changes that would not be possible in cold worked parts. The ability to perform these massive shape changes is a very important characteristic of these high temperature metal forming processes. The work metal will recrystallize, after the process, as the part cools. In general, hot metal forming will close up vacancies and porosity in the metal, break up inclusions and eliminate them by distributing their material throughout the work piece, destroy old weaker cast grain structures and produce a wrought isotropic grain structure in the part. These high temperature forming processes do not strain harden or reduce the ductility of the formed material. Strain hardening of a part may or may not be wanted, depending upon the application. Qualities of hot forming that are considered disadvantageous are poorer surface finish, increased scale and oxides, decarburization, (steels), lower dimensional accuracy, and the need to heat parts. The heating of parts reduces tool life, results in a lower productivity, and a higher energy requirement than in cold working.



Recrystallization is a procedure for purifying an impure compound in a solvent. The method of purification is based on the principle that the solubility of most solids increases with increased temperature.

Selection of Temperature Range for a Metal Forming Operation

Production at each of these temperature ranges has a different set of advantages and disadvantages. Sometimes, qualities that may be undesirable to one process may be desirable to another. Also, many times work will go through several processes. The goal is to design the manufacture of a part in such a way as to best utilize the different qualities to meet or enhance the specifications of the part. To produce a strong part with excellent surface finish, then a cold forming process could be a good choice. However, to produce a part with a high ductility a hot forming process may be best. Sometimes the advantages of both hot forming and cold forming are utilized when a part is manufactured by a series of processes.



Hot working operations may first be performed on a work piece to achieve large amounts of shape change that would not be possible with cold forming due to strain hardening and limited ductility. Then the last process that completes the manufacture of the part is a cold working operation. This process does not require a significant shape change, since most of the deformation was accomplished by the hot forming process. Having a cold forming process last will finish the shape change, while strengthening the part, giving a good surface finish and highly accurate tolerances.

4.1.3. Friction Effects

Metal forming processes are characteristic of high pressures between two contacting surfaces. In hot forming operations, these high pressures are accompanied by extreme temperatures. Friction and die wear are a serious consideration in metal forming manufacturing. A certain amount of friction will be necessary for some metal forming processes, but excessive friction is always undesirable. Friction increases the amount of force required to perform an operation, causes wear on tooling, and can affect metal flow, creating defects in the work.

Where friction is involved, lubricants can usually help. For some metal forming processes and materials no lubrication is used, but for many lubrication is applied to contacting surfaces to reduce friction forces. Lubricants used in industry are different depending upon the type of metal forming process,

the temperature at which the operation occurs, and the type of material formed.

Homogeneous Deformation

If a solid cylindrical workpiece is placed between two flat platens and an applied load P is increased until the stress reaches the flow stress of the material then its height will be reduced from initial value of h_o to h_1. Under ideal homogeneous condition in absence of **friction** between platens and work, any height reduction causes a uniform in-crease in diameter and area from original area of A_o to final area A_f.

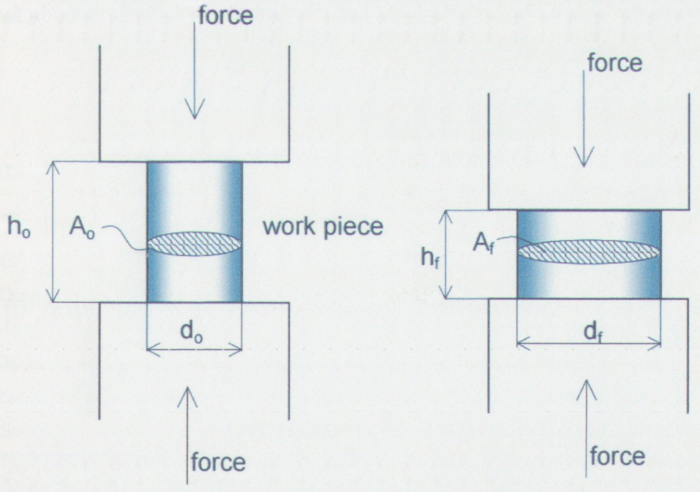


Figure 4.3: Homogeneous deformation.

The load required, i.e. the press capacity, is defined by

$P = Y_f A_f$

Inhomogeneous Deformation

In practice, the friction between platens and workpiece cannot be avoided and the latter develops a "barrel" shape. This is called inhomogeneous deformation and changes the load estimation as follows:



REMEMBER

Lubricants should be effective and not produce any toxic fumes. Lubricants used in manufacturing industry for metal forming processes include, vegetable and mineral oils, soaps, graphite dispensed in grease, water based solutions, solid polymers, wax, and molten glass.

$$P = Y_f k_s A_f = Y_f \left(1 + \frac{\mu d_o}{3h_o}\right) A_f$$

where μ is the frictional coefficient between workpiece and platen, and k_s is the shape factor.



Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.

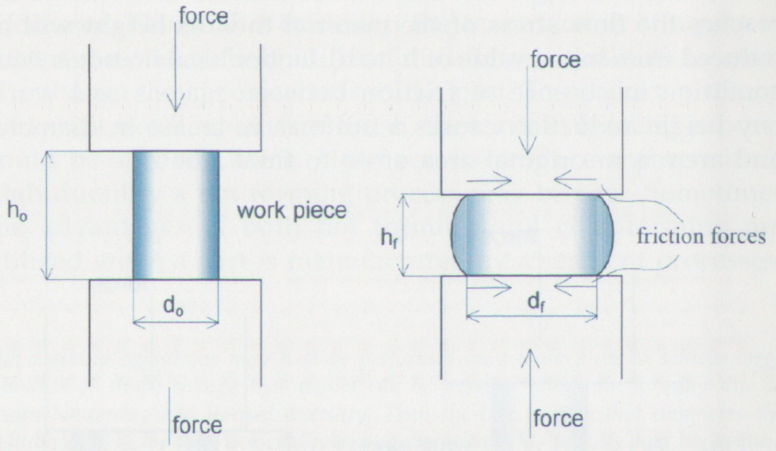


Figure 4.4: Inhomogeneous deformation with barreling of the workpiece.

4.1.4. Classification of Forming

Typically, metal forming processes can be classified into two broad groups. One is bulk forming and the other is sheet metal forming. Bulk deformation refers to the use of raw materials for forming which have low surface area to volume ratio. Rolling, forging, extrusion and drawing are bulk forming processes. In bulk deformation processing methods, the nature of force applied may be compressive, compressive and tensile, shear or a combination of these forces.

Bulk forming is accomplished in forming presses with the help of a set of tool and die. Examples for products produced by bulk forming are: gears, bushed, valves, engine parts such as valves, connecting rods, hydraulic valves, etc.

3G E-LEARNING

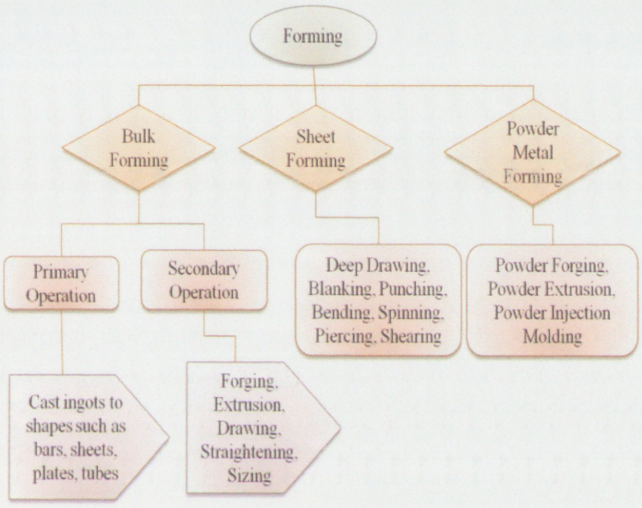


Figure 4.5: Classification of metal forming processes.

Sheet metal forming involves application of tensile or shear forces predominantly. Working upon sheets, plates and strips mainly constitutes sheet forming. Sheet metal operations are mostly carried out in presses – hydraulic or pneumatic. A set of tools called die and punch are used for the sheet working operations. Bending, drawing, shearing, blanking, punching are some of the sheet metal operations.

A new class of forming process called powder forming is gaining importance due to its unique capabilities. One of the important merits of powder forming is its ability to produce parts very near to final dimensions with minimum material wastage. It is called near-net-shape forming. Material compositions can be adjusted to suit the desirable mechanical properties. Formability of sintered metals is greater than conventional wrought materials. However, the challenge in powder forming continues to be the complete elimination or near-complete elimination of porosity. Porosity reduces the strength, ductility and corrosion resistance and enhances the risk of premature failure of components.

Based on the nature of deformation force applied on the material, during forming, metal forming processes are also classified into several types as shown as follows:



REMEMBER

To make the bus routing easier, bus planning should be considered at the floorplanning stage, which is called bus-driven floorplanning.

Forming by compressive stress	Tensile and compressive stresses	Forming under Tensile stress	Bending and shearing stresses
•Open Die Forging	•Deep drawing	•Stretch forming	•Bending
•Closed Die Forging	•Spinning	•Stretching	•Shearing
•Rolling	•Stripping	•Expanding	•Punching
•Coining	•Wrinkle bulging		•Blanking
•Extrusion			

Forming is also classified as cold forming, hot forming or warm forming. Hot forming is the deformation carried out at temperatures above recrystallization temperatures. Typically, recrystallization temperatures for materials ranges from 0.5 Tm to 0.8 Tm, where Tm is melting temperature of material.

4.2 BULK DEFORMATION PROCESS

Bulk deformation is characteristic in that the work formed has a low surface area to volume ratio. These processes involve large amount of plastic deformation. The cross-section of workpiece changes without volume change. The ratio cross-section area/ volume is small. For most operations, hot or warm working conditions are preferred although some operations are carried out at room temperature.

4.2.1. Rolling

Rolling is a direct compression deformation process, which reduces the thickness or changes the cross section of a long workpiece. The process occurs through a set of rolls, which supply the compressive forces needed to plastically deform the metal. Flat rolled products are classified as plate, sheet, or foil, depending on the thickness of the product. A plate has thickness greater than 6 mm, whereas a foil has thickness less than 0.1 mm. A sheet has thickness between that of the plate and the foil. Rolling can be done hot or cold. In many products, initial reductions are performed hot, where the metal can experience large shape changes without fracturing, and the final reductions are performed cold, so that better surface finish and tolerances can be achieved.

Flat rolling reduces the thickness of the metal, producing a product with flat upper and lower surfaces. Shape rolling can also reduce the thickness of the metal but, more importantly, it imparts a more complex cross section shape. Shape rolling can be used to produce bars, rods, I -beams, channels, rails, etc. long rolling can be used to produce a seamless product by reducing the wall thickness of a ring through the action of two rolls. Seamless pipes can be produced and sized by specialized rolling operations such as rotary tube piercing, tube rolling, and **pilgering**. A variety of rolling processes for steel are schematically shown in Figure 4.6.

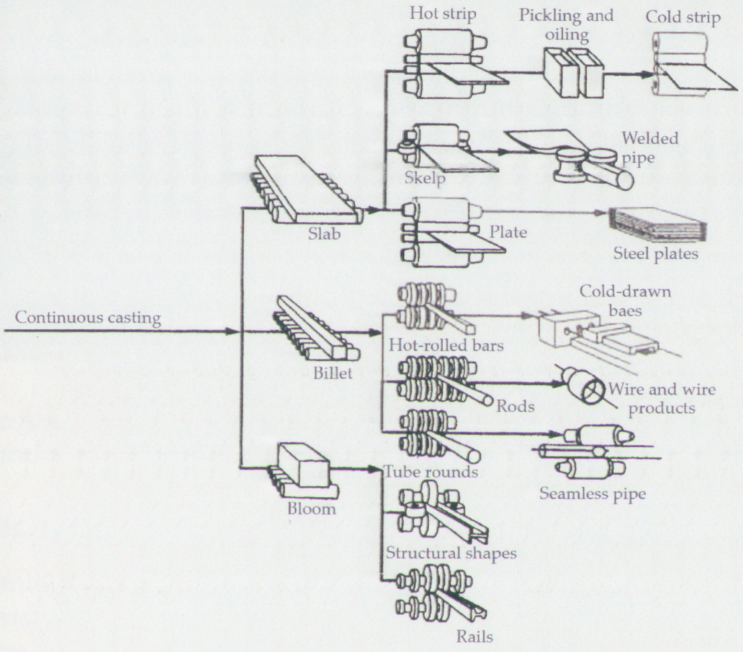


Figure 4.6: Schematics of various rolling processes for steel.

Although large, the rolling mill equipment is relatively simple. A two-high mill consists of two rolls, and a three-high mill consists of three rolls, which also allows reduction to occur on reverse directional flow of the metal. A four-high mill consists of two work rolls in contact with the metal and two back up rolls. A six-high mill is like a four-high mill, but has two additional rolls between the work roll and backup roll called intermediate rolls, which allow in essence some control over the crown and camber of the work rolls. Cluster mills exist usually for the production of thin foil products. A cluster mill will have a pair of small-diameter work rolls and a series of intermediate and backup rolls to support the work rolls. A tandem rolling mill will have a series of rolling stands where each stand imparts a specific amount of reduction. The operation of a tandem mill is challenging due to coupling effects between the stands.

Defects can be present in sheet and plate products if the rolling operation is not performed correctly. Wavy edges, waves along the centerline, zipper cracks along the centerline, or



Pilgering is a cold operation consists of a set of dies that rock back and forth over the outside of the tube.



The first rail rolling mill was established by John Birkenshaw in 1820, where he produced fish bellied wrought iron rails in lengths of 15 to 18 feet.

edge cracks can occur if the reduction is not uniform across the width of that metal. Crowned rolls, six-high mills, and sleeved rolls can be used to correct these types of defects by properly controlling the amount of roll bending that occurs. Small amount of waviness in a sheet product can be eliminated by a post deformation leveling operation, where the sheet passes over a series of rollers while under tension; Alligatoring or fish tails can occur at the front end or back end of the workpiece. Proper alignment of the feed stock into roll gap, proper balancing of the friction between the top and bottom rolls, and proper choice of roll size for reduction can be used to minimize or to eliminate these two types of defects

3G E-LEARNING



ROLE MODEL

JOHN HANBURY: RESPONSIBLE FOR THE INDUSTRIALIZATION AND URBANIZATION OF THE EASTERN VALLEY

John Hanbury, Esq. (1664–1734) was one of a dynasty of ironmasters responsible for the industrialization and urbanization of the eastern valley through which runs the Afon Llwyd (in English "grey river") in Monmouthshire around Pontypool. Hanbury is most notable for patenting the rolling process of tinplating in the early 18th Century.

Background and marriage

Hanbury was born into a family ultimately from Hanbury, Worcestershire and was christened in Gloucester in 1664. Hanbury was the son of Capel Hanbury (1707–1765), who in turn was the third son of the first John Hanbury of Pursall Green. In 1701 he married Albina, daughter of William Selwyn and Albinia daughter of Richard Betenson, and began to enlarge Park House in Pontypool, a property begun by his father in 1659. In December 1701 Hanbury became Member of Parliament for Gloucester, but after the death of Albina in 1702 he left politics for a short period. He regained his seat in December 1702, and in July 1703 he married Bridget, eldest daughter of Sir Edward Ayscough of Stallingborough and South Kelsey. With his marriage to Bridget came a fortune of £10,000 and connections with established political families. Bridget was a close friend of Sarah Churchill, Duchess of Marlborough and Hanbury was introduced to influential politicians.

Ironmaster

When his father died in Jan 1704, Hanbury inherited the estate at Pontypool. The estate included ironworks, some of which had long belonged to members of the family. Soon after his father's death he wrote down his observations about his ironworks. He had a blast furnace, forges (probably two), and mills (including a slitting mill) at Pontypool and a further furnace and forge at Llanelly (then in Breconshire). In 1708, he also became interested in the blast furnace at Melin Cwrt, near Neath. Hanbury continued his Pontypool and Llanelly ironworks for the rest of his life and they passed to his descendants with the rest of his Pontypool estate.

Tinplate

The observations included details of the production costs of iron and "Pontpoole plates". Edward Lhwyd in 1697 described the process for making these as involving a rolling mill. Hanbury's Observations do not include tin among the costs, which suggests that his Pontypool plates were blackplate (plates of iron), not tinplate. This is confirmed by its being sold by the ton, not by the box. This may be to prevent the plates rusting that Thomas Allgood, one of Hanbury's managers, began japanning plates as "Pontypool japan". However, the concept of rolling plate iron was probably brought to Pontypool by Thomas Cooke, probably the son of Thomas Cooke, who had worked at Wolverley for Andrew Yarranton, who found out how to produce tinplate by visiting Saxony.

The first production of tinplate at Pontypool seems to date from 1725, when this commodity first appears in the Gloucester Port Books. This immediately follows the first appearance (in French of Réaumur's *Principes de l'art de fer-blanc*), but prior to a report of it being published in England - millfounded a rolling mill and started a tinplating industry. Hanbury can thus properly be claimed as the progenitor of the British tinplate industry.

Politics

Hanbury lost his Parliamentary seat in 1708, but re-entered politics in 1720 as an MP for the Welsh constituency Monmouthshire. Although a supporter of the Whig party, in his later life he opposed several of Robert Walpole's most important bills. In 1731, he joined with Sir James Lowther and others in opposing the application previously made by William Wood for a royal charter to incorporate a million pound company for his (ineffectve) ironmaking enterprise. Lowther referred to Hanbury as having 'the greatest skill as well as works' (i.e. ironworks).

In 1720 he benefited from the legacy of his friend Charles Williams of Caerleon, and with the £70,000 left to him he bought Colbrook House near Abergavenny, which subsequently passed to John Hanbury's son Charles Hanbury Williams.

3G E-LEARNING

4.2.2. Forging

Forging is a metalworking process where a workpiece is shaped by compressive forces using various dies and tools. The forging process produces discrete parts. Some finishing operations are usually required. Similarly shaped parts can often be produced by casting or powder metallurgy operations, but the mechanical properties of a forged component are usually superior compared to other processing methods. Forging can be done hot or cold. Warm forging is a process that is growing in popularity due primarily to thermal energy costs. Typical forged parts are shown in Figure 4.7.

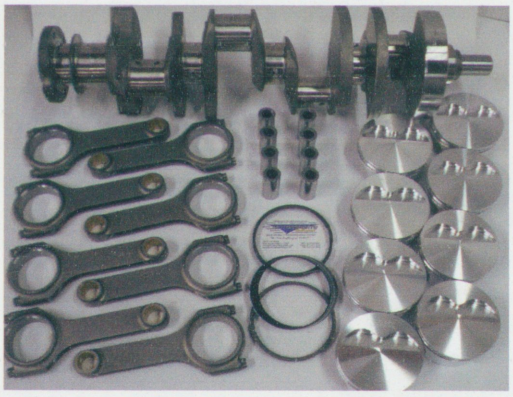


Figure 4.7: Examples of forged parts.

Open die forging consists of dies, with very simple geometry. The dies are usually flat, U-shaped, or v shaped, as seen in Figure 4.8. The shaping of the metal occurs through manipulation of the workpiece and skill of the operator. It is a process that is useful in producing a small number of pieces. It is difficult to hold to close tolerance in this type of forging. Open die forging between two flat dies is often called upsetting. Cogging or drawing out is an open die forging process where the thickness of the workpiece is reduced by successive small strikes along the length of the metal. Open die forging is closely related to blacksmithing.

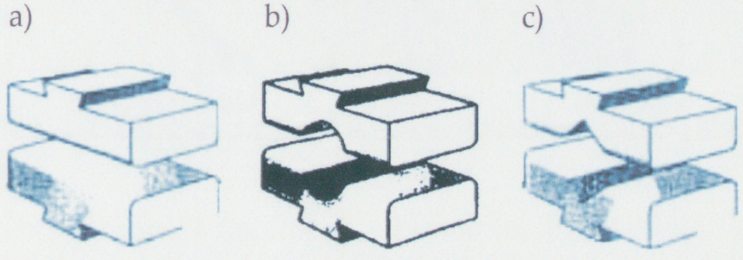


Figure 4.8: Open die forging tools: (a) fiat dies; (b) U-shaped dies; and (c) V-shaped dies.

Closed die or impression die forging consists of a die set with a machined impression, as shown in Figure 4.9. There is good use of metal in this operation as compared to open die forging. Excess metal beyond the size needed for forging is used and flows into the gutter portion of the die set to produce flash. The excess metal helps to insure that the cavities are completely filled at the end of the press stroke. Good tolerances and accuracy of the final forging are attainable. The die costs for closed die forging are fairly high due to their property requirements and machining costs.

Closed die forging often occurs in a sequence of steps. Each step of the operation usually has its own impression in the die block. The first step distributes metals into regions where extra volume is required in the final component. This step often involves editing, where extra metal is gathered, or fullering, where metal is moved away from the local region. In hot forging, the first step is referred to as busting because the scale on the surface of the workpiece is busted off. The second step is blocking, where the part is formed into a rough shape. The third step is finishing, where the final shape of the component is imparted to the workpiece. The fourth step is trimming, where the excess metal in the flash region is trimmed from the component. Figure 4.9 illustrates these various steps.

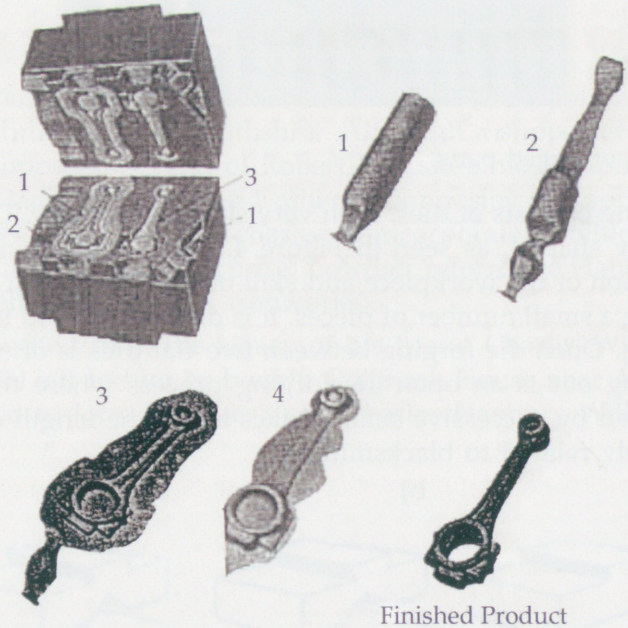


Figure 4.9: Impression forging dies with forging sequence.

3G E-LEARNING

The machines used for forging are hammers and presses. Hammers are energy-limited equipment and can be a simple gravity drop machine where a freefalling ram strikes the workpiece. Augmentation of the energy supplied to the hammer can be done in the form of pressured air, steam or hydraulic fluid. In a hot closed die operation, multiple blows are usually needed during each step, especially the blocking and finishing steps, when using a hammer to forge metal. Table 4.1 provides some numerical details about hammers for a typical gear blank forging.

Table 4.1: Characteristics of hammers for forging a 4.45-lb steel gear blank

Hammer size	Process time (sec)	Minimum part temperature (°F)	Maximum part temperature (°F)	Die temperature (°F)	Load (tons)
4000 lb, 1 blow	0.003	2143	2359	502	850
2500 lb, 3 blows	2	2110	2219	418	874
1500 lb, 6 blows	5	2031	2158	506	818
1000 lb, 12 blows	11	1970	2117	553	389

Temperature buildup in dies is lower than press systems.

A 4000-lb hammer had 40% of initial energy available.

Good uniformity of temperature in part.

Mechanical presses are stroke-limited equipment with a large flywheel powered by an electrical motor. The up-and-down motion of the ram is handled via a connecting rod attached to a crank shaft. The travel distance during each press stroke is controlled by machine design and operation. Hydraulic presses are load-limited equipment where the press will stop once its load capacity is reached. The power comes from pressurized hydraulic fluid. Screw presses, similar to hammers, are energy limited equipment. A large flywheel transmits power through a vertical screw, which causes the ram to move. The ram movement stops when all the energy from the flywheel has dissipated. Table 4.2 provides some numerical details about hydraulic presses to produce the same gear blank as in Table 4.1.

Table 4.2: Characteristics of hydraulic presses for forging a 4.45-lb steel gear blank

Press Size	Process time (sec)	Minimum part temperature (°F)	Maximum part temperature (°F)	Die temperature (°F)	Load (tons)
250 tons, slow	1.6	1458	2159	1233	250
500 tons	0.75	1533	2181	1164	500

1000 tons	0.33	1639	2194	1072	676
2000 tons, fast	0.18	1721	2198	996	705

Two hundred fifty tons press stalled and left underfilled on outer diameter.

Fast 2000 ton press is similar to mechanical or screw press.

Smaller presses resulted in increased die temperature.

In order to be successful in forging a metal, the formability of the metal needs to be understood, especially with regard to temperature and speed. The impression die shape needs to be carefully designed and machined to allow a good flow of metal without seams or laps developing. The die material needs to be carefully chosen to match the metal being shaped and the temperature of the operation.

4.2.3. Extrusion

Extrusion is a method of forming in which metals are forced through a die or series of dies, resulting in a specific shape of constant cross section. With the proper tooling, extrusions may be tapered or stepped. Extrusions can be either very thick in cross section or very thin and be either solid or hollow. The extruded stock, which can be 100 feet in length or longer, is then cut to a convenient stock size and used as specific products, assembly components, or as raw stock material for further processing. Extrusion size is expressed as a circle size which relates to the smallest circle diameter which can enclose an extrusion's cross section.

Metal extrusion processes may be performed hot, warm, or cold. Each method has its own unique operating parameters.

Hot Extrusion

Hot extrusion uses heated feedstock, called a billet that ranges in temperature from 200° to 2,300° Fahrenheit, or 90° to 1,260° Celsius depending on the material.

Aluminum is the most common hot extruded material, with billet temperatures ranging from 575° to 1,100° Fahrenheit, or 300° to 600° Celsius. Hot extrusion is always performed at temperatures much higher than the recrystallization temperature of the material to be extruded. The heated billet is confined in a container, force is applied and the billet is extruded through a die or dies.

Hot extrusion is used to produce close tolerance dimensions as well as smooth, fine surfaces. Additionally, and depending on the metal used, improved microstructures are obtained. The process is also very economical in that most of the metal extruded is usable. The primary type of hot extrusion is direct, or forward, extrusion. Direct extrusion is commonly performed in horizontal hydraulic presses. The heated billet is

loaded into a thick-walled container from which it is pushed through the extrusion die by a ram. Between the ram and the billet is an intermediate dummy block. Lubrication is used to reduce friction along the billet length and its container.

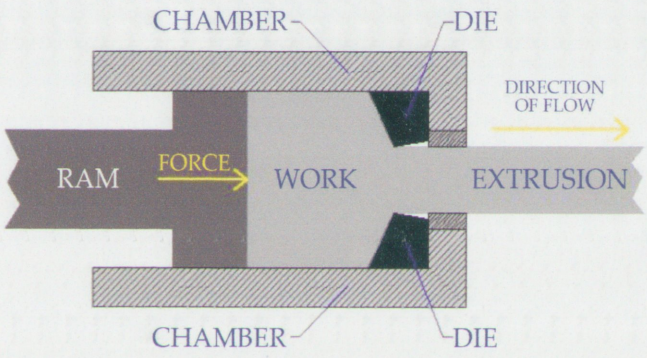


Figure 4.10: Direct extrusion.

In operation, force increases rapidly as the billet is upset to fill the container, then increases further as breakthrough force before extrusion begins. Upon breakthrough, the force declines as billet length decreases until a minimum force is reached. As the billet thins, the force rapidly rises again to continue metal flow radially toward the die opening.

Hot extrusion presses are rated in force capacity which relates to available ram pressure on the billet.

Ram pressure requirements are based upon:

- Billet material and temper
- Cross section dimensions
- Complexity of the extrusion
- Extrusion length and temperature

Another factor in determining ram force requirements is the extrusion ratio. This is determined by dividing the cross sectional area of the container liner by the cross sectional area of the die openings.

Warm and Cold Extrusion Processes

Warm extrusion refers to the extruding of feedstock or billet while it is above room temperature, but well below the recrystallization temperatures used in hot extrusion. Cold extrusion refers to extrusion at room temperatures. Because the feedstock is at lower temperatures, no micro-structural changes occur during processing.

Warm and cold extrusion processes increase the strength and hardness of the finished extrusion. Reduced heat also lowers pollution concerns and eliminates costly high temperature tooling. While virtually all metals may be warm and cold extruded, those having the highest ductility are more suited for processing.

Warm and cold extrusion processes are commonly integrated into continuous and semi-continuous manufacturing operations, with the three primary methods including:

Indirect extrusion

Combination extrusion

Impact extrusion

Indirect extrusion, which is also called backward extrusion, is used to produce hollow shapes with the inside diameter defined by the male punch and the outside diameter controlled by the female die.



Melting point is the temperature at which it changes state from solid to liquid at atmospheric pressure. At the melting point the solid and liquid phase exist in equilibrium.

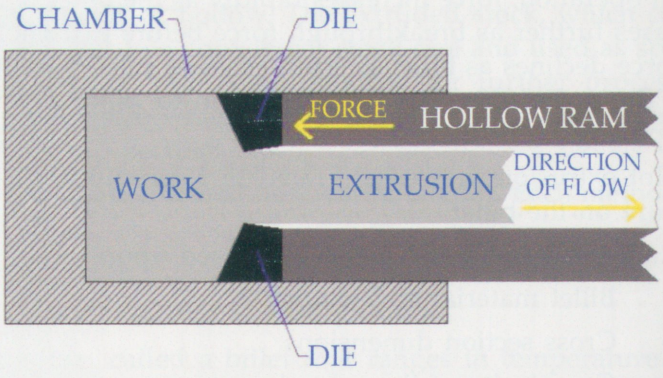


Figure 4.11: Indirect extrusion.

Combination extrusion combines various types of extruding including direct and indirect methods to produce more complex shapes.

Impact extrusion is similar to the other extrusion methods described, but is a much faster process. Using shorter strokes and shallower dies, punch impact moves the feedstock slug either up, down, or in both directions at once, without being completely confined by either the punch or die walls. Ductile

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and low **melting point** metals such as tin, aluminum, zinc, and copper are well suited for impact extruding.

4.2.4. Drawing

Drawing of a round rod or wire is an indirect compression process where the cross-sectional area of the metal is reduced by pulling it though a converging die. A schematic illustration of wire drawing is seen in Figure 4.12. The process is normally done at ambient temperatures. The major factors that need to be controlled include: reduction, die angle, friction at the die-workpiece interface, and drawing speed. Tubes can also be drawn in a similar process. To control the interior diameter of a tube, a mandrel, which can be fixed, moving, or floating, is used. Because the metal is pulled through the die, the final product, which has the reduced cross section, is subjected to tensile stresses. If these tensile stresses become excessive, then the wire would fracture in a mode similar to a tensile test. The limit on the value of the tensile stress that can be supported limits the amount of reduction that can be achieved in one pass. Multiple reduction passes with multiple dies are needed to achieve large reductions in cross-sectional areas. The approach is analogous to a tandem rolling mill with multiple stands. The theoretical maximum reduction for a frictionless, perfectly plastic material is 63%. In production processing, the reduction that is used is often limited to 35% or 40%. The ironing press, which is used to reduce the wall thickness of a sheet metal, is also a drawing-type operation.

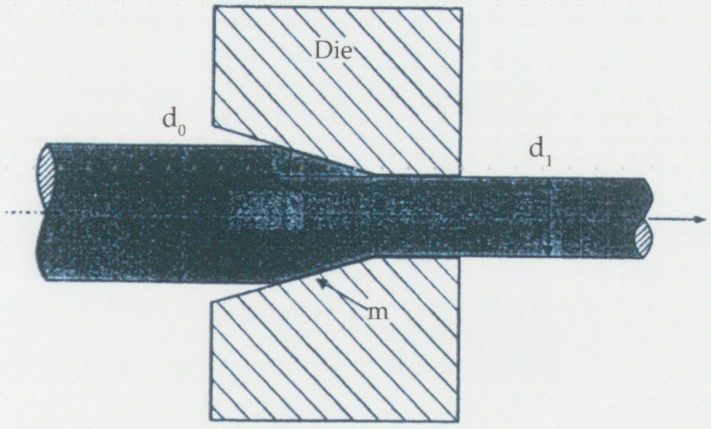


Figure 4.12: Schematic of a wire drawing process.

The configuration of the opening in the final die will control the configuration of the product produced. Although a cylindrical shape is the most common, other shapes can be imparted to the wire in the process.

The metal is cold-worked during the wire drawing process and intermediate anneals may be needed to increase its ductility to sufficient levels in order to reach the final reduction desired. Internal fractures, called central busts, can occur if the die angle is too large, or the reduction is too small. For rods, tubular products, or high-strength wires, post-deformation straightening may be required.

4.3 SHEET-FORMING PROCESSES

In sheet metalworking operations, the cross-section of workpiece does not change—the material is only subjected to shape changes. The ratio cross-section area/volume is very high. Sheet metalworking operations are performed on thin (less than 6 mm) sheets, strips or coils of metal by means of a set of tools called punch and die on machine tools called stamping presses. They are always performed as cold working operations.

4.3.1. Bending Operations

Bending is a metal forming process in which a force is applied to a piece of sheet metal, causing it to bend at an angle and form the desired shape. A bending operation causes deformation along one axis, but a sequence of several different operations can be performed to create a complex part. Bent parts can be quite small, such as a bracket, or up to 20 feet in length, such as a large enclosure or chassis. A bend can be characterized by several different parameters, shown in the figure follows.

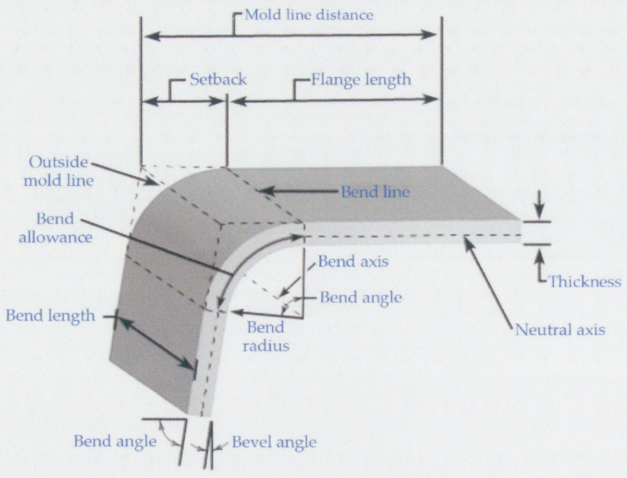


Figure 4.13: Bending diagram.

- Bend line - The straight line on the surface of the sheet, on either side of the bend that defines the end of the level flange and the start of the bend.
- Outside mold line - The straight line where the outside surfaces of the two flanges would meet, were they to continue. This line defines the edge of a mold that would bound the bent sheet metal.
- Flange length - The length of either of the two flanges, extending from the edge of the sheet to the bend line.
- Mold line distance - The distance from either end of the sheet to the outside mold line.
- Setback - The distance from either bend line to the outside mold line. Also equal to the difference between the mold line distance and the flange length.
- Bend axis - The straight line that defines the center around which the sheet metal is bent.
- Bend length - The length of the bend, measured along the bend axis.
- Bend radius - The distance from the bend axis to the inside surface of the material, between the bend lines. Sometimes specified as the inside bend radius. The outside bend radius is equal to the inside bend radius plus the sheet thickness.
- Bend angle - The angle of the bend, measured between the bent flange and its original position, or as the included angle between perpendicular lines drawn from the bend lines.
- Bevel angle - The complimentary angle to the bend angle.

The act of bending results in both tension and compression in the sheet metal. The outside portion of the sheet will undergo tension and stretch to a greater length, while the inside portion experiences compression and shortens. The neutral axis is the boundary line inside the sheet metal, along which no tension or compression forces are present. As a result, the length of this axis remains constant. The changes in length to the outside and inside surfaces can be related to the original flat length by two parameters, the bend allowance and bend deduction, which are defined below.

- Neutral axis - The location in the sheet that is neither stretched nor compressed, and therefore remains at a constant length.
- K-factor - The location of the neutral axis in the material, calculated as the ratio of the distance of the neutral axis (measured from the inside bend surface) to the material thickness. The K-factor is dependent upon several factors (material, bending operation, bend angle, etc.) and is typically greater than 0.25, but cannot exceed 0.50.
- Bend allowance - The length of the neutral axis between the bend lines, or in other words, the arc length of the bend. The bend allowance added to the

flange lengths is equal to the total flat length.

- Bend deduction - Also called the bend compensation, the amount a piece of material has been stretched by bending. The value equals the difference between the mold line lengths and the total flat length.

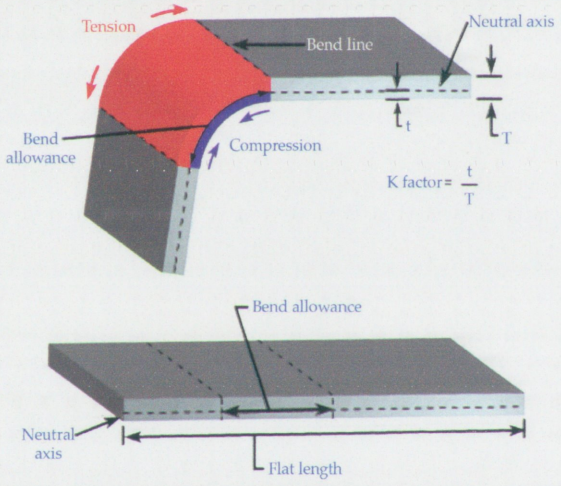


Figure 4.14: Neutral axis.

When bending a piece of sheet metal, the residual stresses in the material will cause the sheet to springback slightly after the bending operation. Due to this elastic recovery, it is necessary to over-bend the sheet a precise amount to achieve the desired bend radius and bend angle.

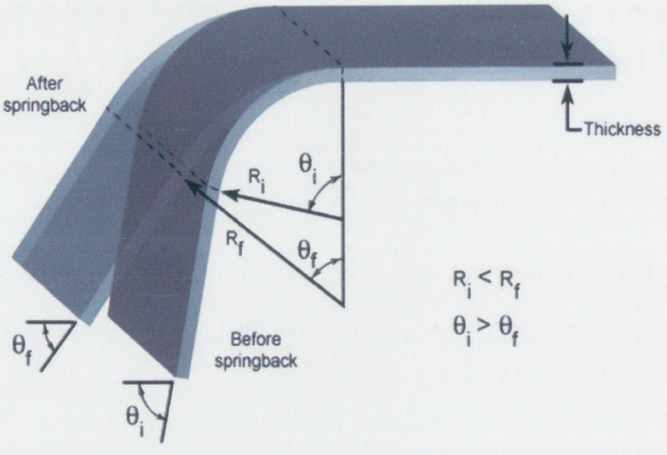


Figure 4.15: Springback.

The final bend radius will be greater than initially formed and the final bend angle will be smaller. The ratio of the final bend angle to the initial bend angle is defined as the springback factor, KS. The amount of springback depends upon several factors, including the material, bending operation, and the initial bend angle and bend radius.

Bending is typically performed on a machine called a press brake, which can be manually or automatically operated. For this reason, the bending process is sometimes referred to as press brake forming. Press brakes are available in a range of sizes (commonly 20-200 tons) in order to best suit the given application. A press brake contains an upper tool called the punch and a lower tool called the die, between which the sheet metal is located. The sheet is carefully positioned over the die and held in place by the back gauge while the punch lowers and forces the sheet to bend. In an automatic machine, the punch is forced into the sheet under the power of a hydraulic ram. The bend angle achieved is determined by the depth to which the punch forces the sheet into the die. This depth is precisely controlled to achieve the desired bend. Standard tooling is often used for the punch and die, allowing a low initial cost and suitability for low volume production. Custom tooling can be used for specialized bending operations but will add to the cost. The tooling material is chosen based upon the production quantity, sheet metal material, and degree of bending. Naturally, a stronger tool is required to endure larger quantities, harder sheet metal, and severe bending operations. In order of increasing strength, some common tooling materials include hardwood, low carbon steel, tool steel, and carbide steel.

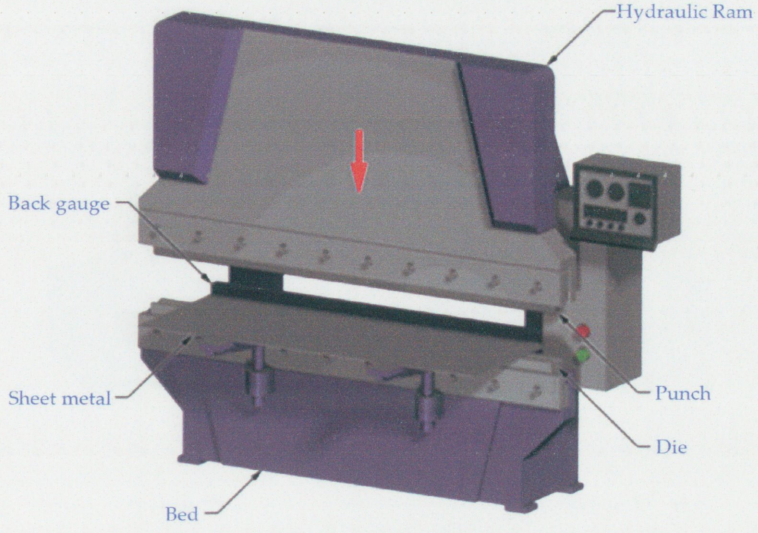


Figure 4.16: Press brake (open).

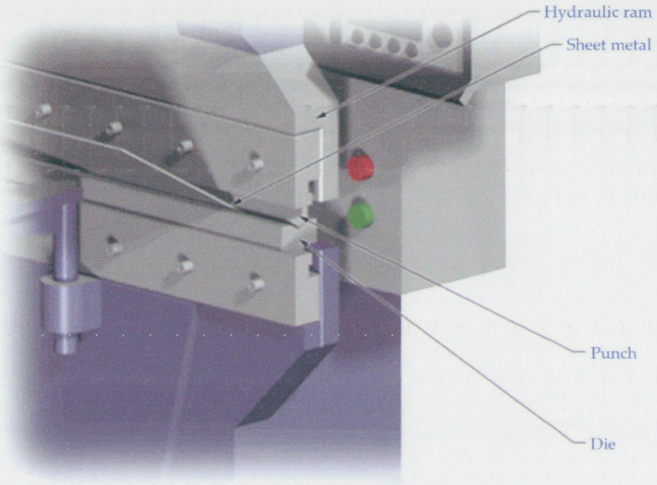


Figure 4.17: Press brake (closed).

While using a press brake and standard die sets, there are still a variety of techniques that can be used to bend the sheet. The most common method is known as V-bending, in which the punch and die are "V" shaped. The punch pushes the sheet into the "V" shaped groove in the V-die, causing it to bend. If the punch does not force the sheet to the bottom of the die cavity, leaving space or air underneath, it is called "air bending".

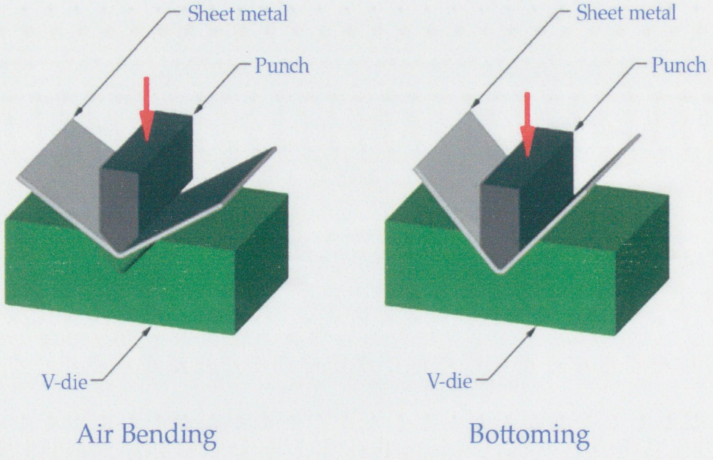


Figure 4.18: V bending.

As a result, the V-groove must have a sharper angle than the angle being formed in the sheet. If the punch forces the sheet to the bottom of the die cavity, it is called "bottoming". This technique allows for more control over the angle because there is less springback. However, a higher tonnage press is required. In both techniques, the width of the "V" shaped groove, or die opening, is typically 6 to 18 times the sheet thickness. This value is referred to as the die ratio and is equal to the die opening divided by the sheet thickness. In addition to V-bending, another common bending method is wipe bending, sometimes called edge bending. Wipe bending requires the sheet to be held against the wipe die by a pressure pad. The punch then presses against the edge of the sheet that extends beyond the die and pad. The sheet will bend against the radius of the edge of the wipe die.

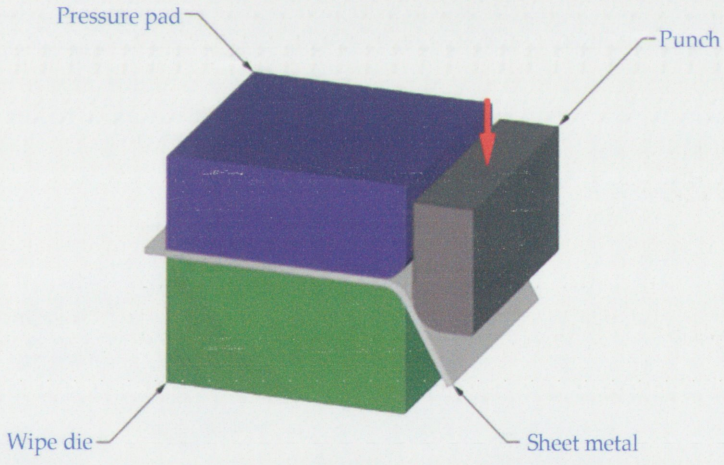


Figure 4.19: Wipe bending

Design Rules

- Bend location - A bend should be located where enough material is present, and preferably with straight edges, for the sheet to be secured without slipping. The width of this flange should be equal to at least 4 times the sheet thickness plus the bend radius.
- Bend radius
  - Use a single bend radius for all bends to eliminate additional tooling or setups
  - Inside bend radius should equal at least the sheet thickness

- Bend direction - Bending hard metals parallel to the rolling direction of the sheet may lead to fracture. Bending perpendicular to the rolling direction is recommended.
- Any features, such as holes or slots, located too close to a bend may be distorted. The distance of such features from the bend should be equal to at least 3 times the sheet thickness plus the bending radius.
- In the case of manual bending, if the design allows, a slot can be cut along the bend line to reduce the manual force required.

4.3.2. Roll forming

Roll forming, sometimes spelled rollforming, is a metal forming process in which sheet metal is progressively shaped through a series of bending operations. The process is performed on a roll forming line in which the sheet metal stock is fed through a series of roll stations. Each station has a roller, referred to as a roller die, positioned on both sides of the sheet.

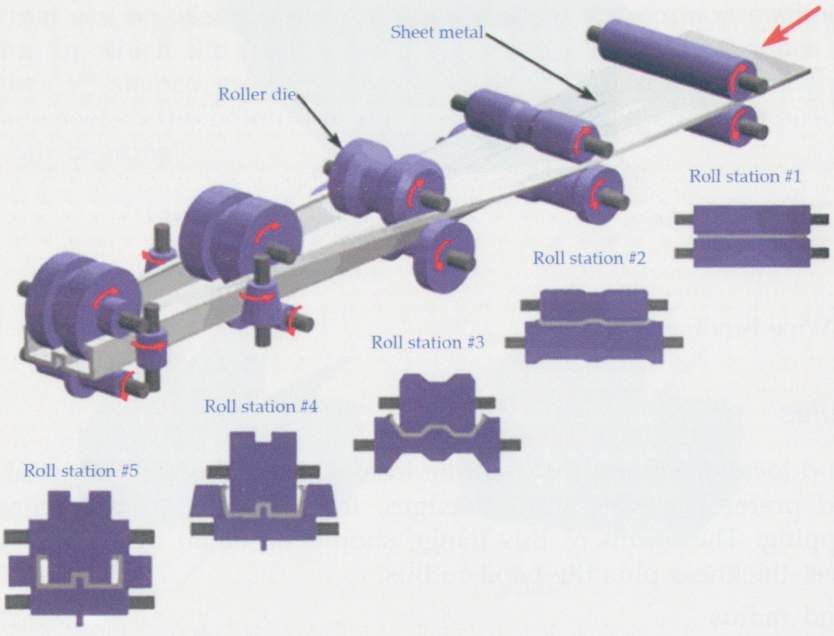


Figure 4.20: Roll forming line.

The shape and size of the roller die may be unique to that station, or several identical roller dies may be used in different positions. The roller dies may be above and below the sheet, along the sides, at an angle, etc. As the sheet is forced through the roller dies in each roll station, it plastically deforms and bends. Each roll station performs one stage in the complete bending of the sheet to form the desired part. The roller dies are lubricated to reduce friction between the die and the sheet, thus reducing the tool wear. Also, lubricant can allow for a higher production rate, which will also depend on the material thickness, number of roll stations, and radius of each bend. The roll forming line can also include other sheet metal fabrication operations before or after the roll forming, such as punching or shearing. The roll forming process can be used to form a sheet into a wide variety of cross-section profiles. An open profile is most common, but a closed tube-like shape can be created as well. Because the final form is achieved through a series of bends, the part does not require a uniform or symmetric cross-section along its length. Roll forming is used to create very long sheet metal parts with typical widths of 1-20 inches and thicknesses of 0.004-0.125 inches. However wider and thicker sheets can be formed, some up to 5 ft. wide and 0.25 inches thick. The roll forming process is capable of producing parts with tolerances as tight as ±0.005 inches. Typical roll formed parts include panels, tracks, shelving, etc. These parts are commonly used in industrial and commercial buildings for roofing, lighting, storage units, and HVAC applications.

4.3.3. Spinning Operations

Spinning, sometimes called spin forming, is a metal forming process used to form cylindrical parts by rotating a piece of sheet metal while forces are applied to one side. A sheet metal disc is rotated at high speeds while rollers press the sheet against a tool, called a mandrel, to form the shape of the desired part. Spun metal parts have a rotationally symmetric, hollow shape, such as a cylinder, cone, or hemisphere. Examples include cookware, hubcaps, satellite dishes, rocket nose cones, and musical instruments.

Spinning is typically performed on a manual or CNC lathe and requires a blank, mandrel, and roller tool. The blank is the disc-shaped piece of sheet metal that is pre-cut from sheet stock and will be formed into the part. The mandrel is a solid form of the internal shape of the part, against which the blank will be pressed. For more complex parts, such as those with reentrant surfaces, multi-piece mandrels can be used. Because the mandrel does not experience much wear in this process, it can be made from wood or plastic. However, high volume production typically utilizes a metal mandrel. The **mandrel** and blank are clamped together and secured between the headstock and tailstock of the lathe to be rotated at high speeds by the spindle. While the blank and mandrel rotate, force is applied to the sheet by a tool, causing the sheet to bend and form around the mandrel. The tool may make several passes to

complete the shaping of the sheet. This tool is usually a roller wheel attached to a lever. Rollers are available in different diameters and thicknesses and are usually made from steel or brass. The rollers are inexpensive and experience little wear allowing for low volume production of parts.



Mandrel is an object used to shape machined work, a tool component that grips or clamps materials to be machined, or a tool component that can be used to grip other moving tool components.

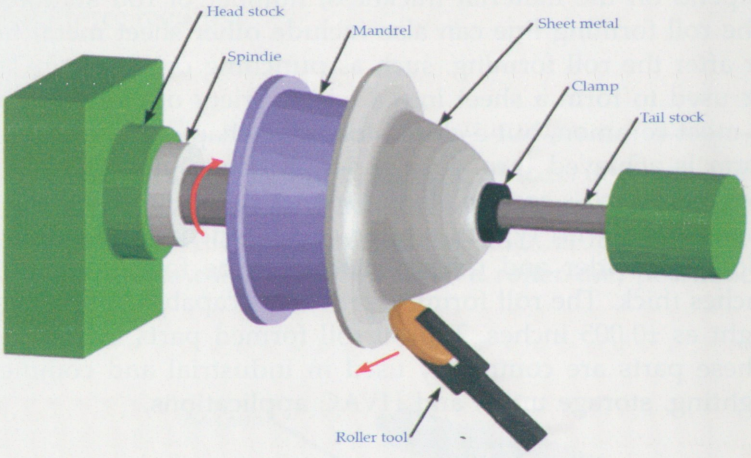


Figure 4.21: Spinning lathe.

There are two distinct spinning methods, referred to as conventional spinning and shear spinning. In conventional spinning, the roller tool pushes against the blank until it conforms to the contour of the mandrel. The resulting spun part will have a diameter smaller than the blank, but will maintain a constant thickness. In shear spinning, the roller not only bends the blank against the mandrel, it also applies a downward force while it moves, stretching the material over the mandrel. By doing so, the outer diameter of the spun part will remain equal to the original blank diameter, but the thickness of the part walls will be thinner.

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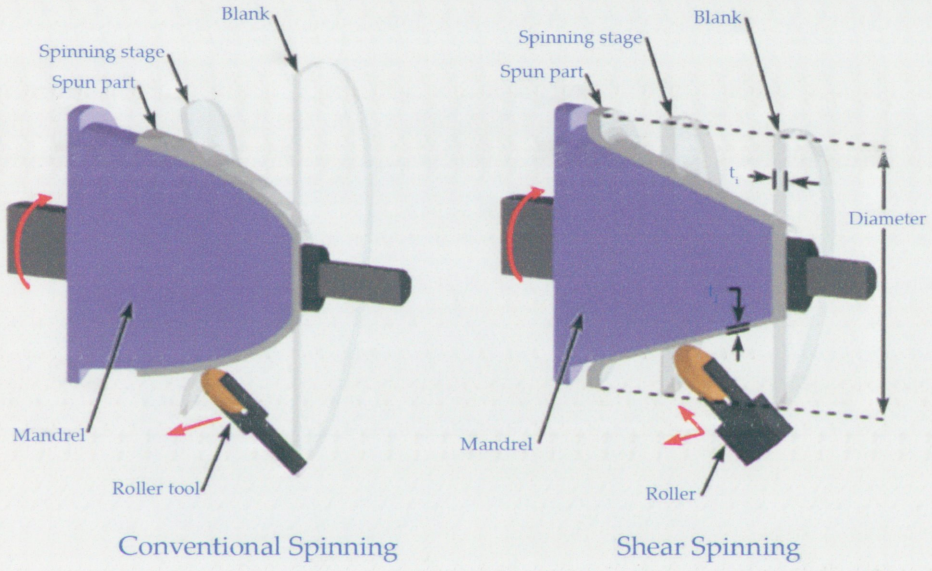


Figure 4.22: Conventional spinning vs. shear spinning.

4.3.4. Deep Drawing

Deep drawing is a metal forming process in which sheet metal is stretched into the desired part shape. A tool pushes downward on the sheet metal, forcing it into a die cavity in the shape of the desired part. The tensile forces applied to the sheet cause it to plastically deform into a cup-shaped part. Deep drawn parts are characterized by a depth equal to more than half of the diameter of the part. These parts can have a variety of cross sections with straight, tapered, or even curved walls, but cylindrical or rectangular parts are most common. Deep drawing is most effective with ductile metals, such as aluminum, brass, copper, and mild steel. Examples of parts formed with deep drawing include automotive bodies and fuel tanks, cans, cups, kitchen sinks, and pots and pans.

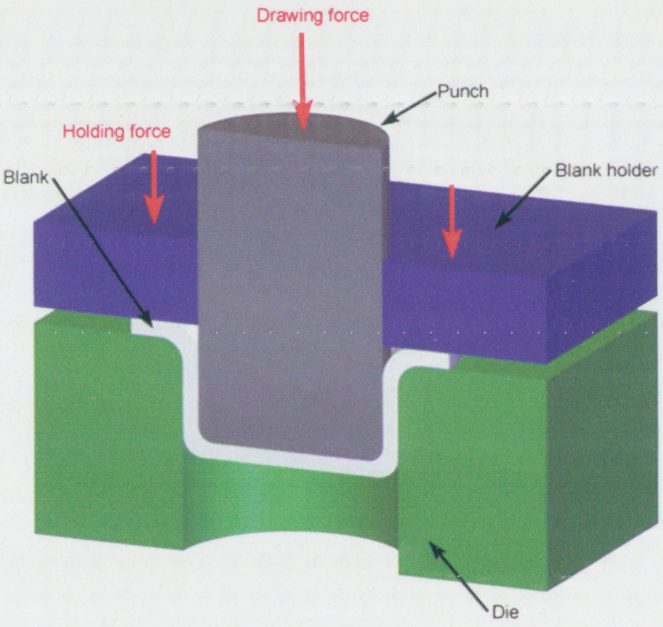


Figure 4.23: Deep drawing.

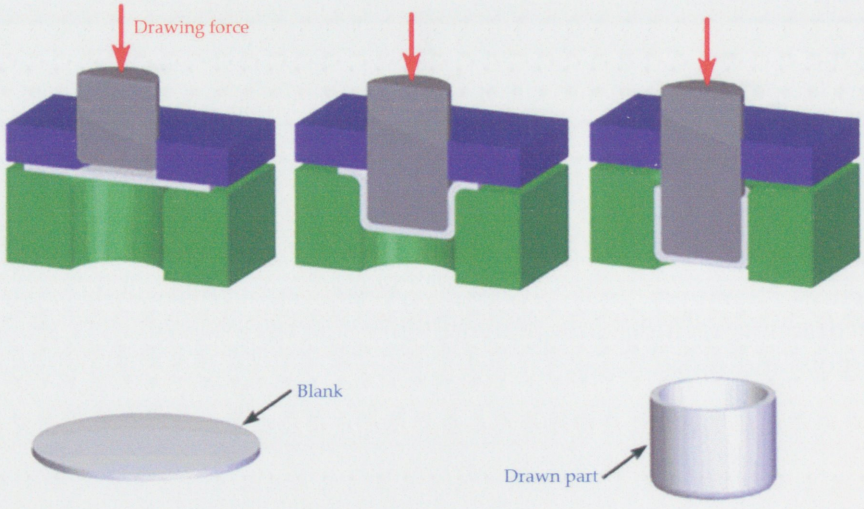


Figure 4.24: Deep drawing sequence.

The deep drawing process requires a blank, blank holder, punch, and die. The blank is a piece of sheet metal, typically a disc or rectangle, which is pre-cut from stock material and will be formed into the part. The blank is clamped down by the blank holder over the die, which has a cavity in the external shape of the part. A tool called a punch moves downward into the blank and draws, or stretches, the material into the die cavity. The movement of the punch is usually hydraulically powered to apply enough force to the blank. Both the die and punch experience wear from the forces applied to the sheet metal and are therefore made from tool steel or carbon steel. The process of drawing the part sometimes occurs in a series of operations, called draw reductions. In each step, a punch forces the part into a different die, stretching the part to a greater depth each time. After a part is completely drawn, the punch and blank holder can be raised and the part removed from the die. The portion of the sheet metal that was clamped under the blank holder may form a flange around the part that can be trimmed off.

4.3.5. Stretch forming

Stretch forming is a metal forming process in which a piece of sheet metal is stretched and bent simultaneously over a die in order to form large contoured parts. Stretch forming is performed on a stretch press, in which a piece of sheet metal is securely gripped along its edges by gripping jaws. The gripping jaws are each attached to a carriage that is pulled by pneumatic or hydraulic force to stretch the sheet. The tooling used in this process is a stretch form block, called a form die, which is a solid contoured piece against which the sheet metal will be pressed. The most common stretch presses are oriented vertically, in which the form die rests on a press table that can be raised into the sheet by a hydraulic ram. As the form die is driven into the sheet, which is gripped tightly at its edges, the tensile forces increase and the sheet plastically deforms into a new shape. Horizontal stretch presses mount the form die sideways on a stationary press table, while the gripping jaws pull the sheet horizontally around the form die.

Stretch formed parts are typically large and possess large radius bends. The shapes that can be produced vary from a simple curved surface to complex non-uniform cross sections. Stretch forming is capable of shaping parts with very high accuracy and smooth surfaces. Ductile materials are preferable, the most commonly used being aluminum, steel, and titanium. Typical stretch formed parts are large curved panels such as door panels in cars or wing panels on aircraft. Other stretch formed parts can be found in window frames and enclosures.

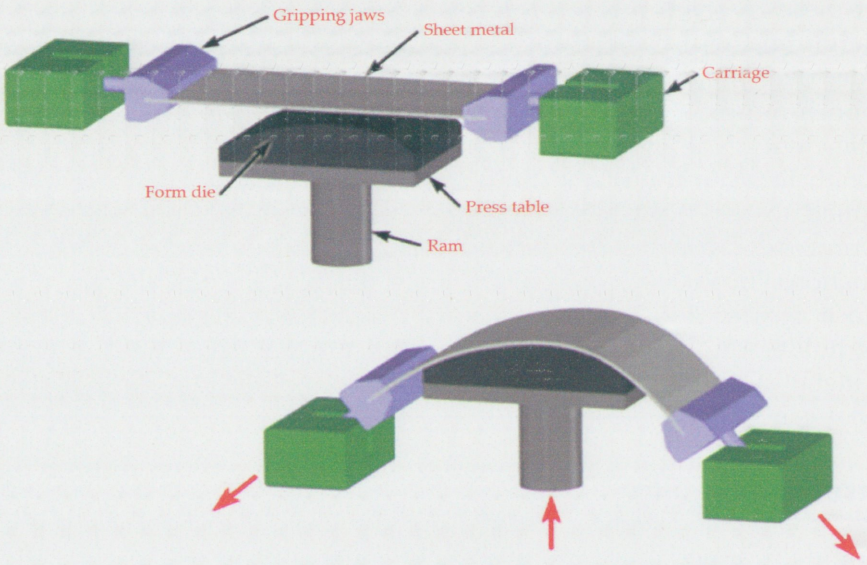


Figure 4.25: Stretch forming.

4.3.6. High-Energy-Rate Forming (HERF)

High energy rate forming is the forming of sheet metal by a high energy surge, delivered over a very short time. Since the forming of the metal occurs so quickly, desirable materials for (HERF) will be ductile at high deformation speeds.

Explosive Forming

Explosives can deliver a huge amount of power. Although most explosive detonations are destructive, the power from an explosive charge can be used to manufacture parts. An explosive forming process commonly used for the production of large parts is called a standoff system. Typically the mold and work piece are submerged in water. The sheet metal is secured over the mold by a ring clamp. Air is drawn out, creating a vacuum in the die cavity. An explosive is placed between the die cavity and the work, a certain distance from the work. This distance is called the standoff distance. Standoff distance depends on the size of the work, for larger parts it is usually about half the diameter of the blank. The explosive itself is also deeply submersed in water. Upon detonation, the shock wave travels through the water and delivers great energy to the work, forming it to the die cavity near instantaneously. This high energy rate forming process can be used to form big thick plates.

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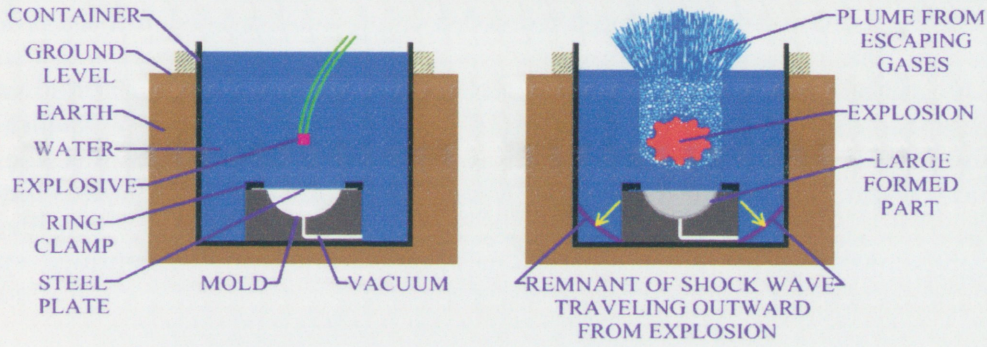


Figure 4.26: Explosive forming.

Explosive forming has a long cycle time and is suitable for low quantity production of large, unique parts. Mechanical properties imparted to the material as a result of the explosive forming process are similar to mechanical properties imparted to work manufactured by other forming processes. Molds can be made out of inexpensive or easy to shape materials, or molds can be made more permanent. Materials for molds include aluminum, wood, concrete, plastic, iron and steel. If a mold is manufactured from a material such as plastic, the low modulus of elasticity will greatly reduce springback in the sheet metal, resulting in higher accuracy.

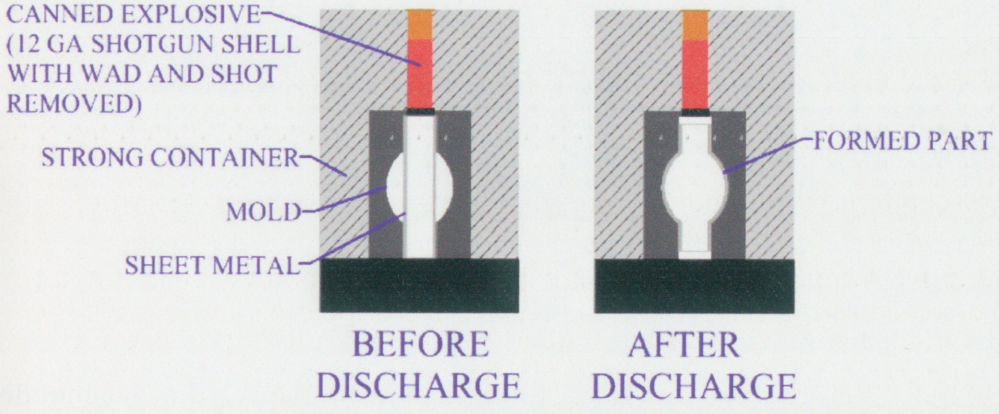


Figure 4.27: Confined explosive forming.

The amount of explosive depends upon the type of system used and the amount of pressure needed to form the part. The shock wave generated by the explosive travels

along an expanding spherical front. Much of the energy from the shock wave is not absorbed by the work piece. A modified setup of the standoff system uses reflectors to focus the energy surge. This provides a more effective use of power and a smaller explosive can be used to form the same part. Another system called a confined system, uses a canned explosive or cartridge. This is usually used for relatively smaller parts than the standoff system. All of the energy is directed into a closed container, the walls of which contain the die cavity. The energy from the canned explosive forces the sheet metal into the walls of the mold, forming the part. Safety is always a consideration when manufacturing by explosive forming, particularly with the confined system, where die failure is a significant concern.

Electrohydraulic Forming

Electrohydraulic forming, also called electric discharge forming, is a unique high energy forming process for sheet metal. This manufacturing process uses the energy from the combustion of a thin metal wire. Two electrodes, with a wire connecting them, are submersed in liquid. The work is set up similar to the standoff system described above, however this process is applicable to relatively smaller parts. A sheet metal blank is secured on top of the mold with a ring clamp and a vacuum is created in the die cavity under the blank. Electrical energy is stored in a capacitor bank. The electricity is discharged through the electrodes and the wire, instantly vaporizing the wire, creating a shock wave that travels through the water. This shock wave forms the sheet metal to the mold cavity.

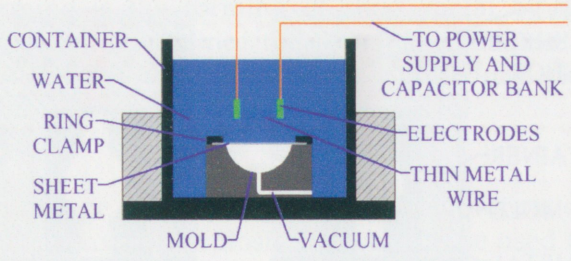


Figure 4.28: Electrohydraulic forming.

Electrohydraulic forming produces a shock wave of relatively low magnitude and is best suited for thinner work. The wire needs to be replaced after every operation. Electrohydraulic forming may be considered to have a low production rate.

Electromagnetic Forming

Electromagnetic forming is a popular high energy rate forming process that uses

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a magnetic surge to form a sheet metal part. In the electromagnetic process, also called magnetic pulse forming, an electric coil is placed near a metal work piece. A capacitor bank is charged up and a large electrical surge is sent through the coil. The current creates a magnetic field. When a conductive material disrupts a magnetic field it produces a current in that material, this is called an eddy current. Due to the close proximity of the conductive sheet metal to the coil, the coil's magnetic field is disrupted and eddy currents are generated in the work piece. These currents in the sheet metal produce their own magnetic field that opposes the original magnetic field of the coil. The opposing forces push these fields apart and form the work. The coil may be placed inside or over the work, depending upon the desired effect.

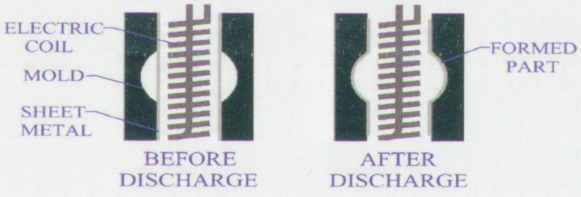


Figure 4.29: Electromagnetic forming.

Many electromagnetic forming operations are used to bulge tubes, or form tubes over other parts such as rods and cables. Electromagnetic forming is used for relatively thinner sheet metal parts.

SUMMARY

- Manufacturing refers to the conversion of raw materials into finished products employing suitable techniques. There are several methods of manufacturing such as metal casting, metal forming, metal machining, metal joining and finishing.
- Forming is the process of obtaining the required shape and size on the raw material by subjecting the material to plastic deformation through the application of tensile force, compressive force, bending or shear force or combinations of these forces.
- Metal forming processes are characteristic of high pressures between two contacting surfaces. In hot forming operations, these high pressures are accompanied by extreme temperatures.
- Bulk deformation refers to the use of raw materials for forming which have low surface area to volume ratio. Rolling, forging, extrusion and drawing are bulk forming processes.
- Bulk deformation is characteristic in that the work formed has a low surface area to volume ratio. These processes involve large amount of plastic deformation.
- Forging is a metalworking process where a workpiece is shaped by compressive forces using various dies and tools. The forging process produces discrete parts. Some finishing operations are usually required.
- In sheet metalworking operations, the cross-section of workpiece does not change—the material is only subjected to shape changes.
- Sheet metalworking operations are performed on thin sheets, strips or coils of metal by means of a set of tools called punch and die on machine tools called stamping presses.

KNOWLEDGE CHECK

1. Good surface finish and better dimensional accuracy can be achieved in

a. cold working process

b. hot working process

c. both (a) and (b)

d. None of the above

2. Mechanical working processes are performed on metals

a. to achieve optimum mechanical properties in the metal

b. to improve the mechanical strength of the metal

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c. to make metal dense

d. All of the above.

3. **Hot working process is the plastic deformation of metal which is carried out**

a. at temperature below the recrystallization temperature

b. at temperature above the recrystallization temperature

c. at temperature equals to boiling point of water

d. None of the above

4. **Worm working or semi-hot working process, which is the plastic deformation of metal or alloy under conditions of temperature and strain rate, is performed to eliminate drawbacks of**

a. cold working process

b. hot working process

c. both cold and hot working processes

d. None of the above

5. **The volume of metal that enters the rolling stand**

a. should increase after rolling process

b. should decrease after rolling process

c. should remain same after rolling process

d. unpredictable

REVIEW QUESTIONS

1. Write the name of four operation which are used in sheet metal stamping?
2. How hot working differs from cold working? Explain.
3. How does the ability of material to withstand unpredictable loads change after forging?
4. Define extrusion and explain any two types.
5. Write short notes on:
   a. Drawing
   b. Shearing

CHECK YOUR RESULT

1. (a) 2. (d) 3. (b) 4. (c) 5. (c)

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CHAPTER

5

PLASTIC, CERAMIC AND GLASS PROCESSING

LEARNING OBJECTIVES

After studying this chapter, you will be able to:

1. Discuss the classification of plastics
2. Explain the plastic part manufacturing processes
3. Define thermoforming
4. Discuss how to shape ceramics
5. Understand by composite materials

INTRODUCTION

The term "plastics" includes materials composed of various elements such as carbon, hydrogen, oxygen, nitrogen, chlorine, and sulfur. Plastics typically have high molecular weight, meaning each molecule can have thousands of atoms bound together. Naturally occurring materials, such as wood, horn and rosin, are also composed of molecules of high molecular weight. The manufactured or synthetic plastics are often designed to mimic the properties of natural materials. Plastics, also called polymers, are produced by the conversion of natural products or by the synthesis from primary chemicals generally coming from oil, natural gas, or coal.

Ceramic processing is used to produce commercial products that are very diverse in size, shape, detail, complexity, and material composition, structure, and cost. The purpose of ceramics processing to an applied science is the natural result of an increasing ability to refine, develop, and characterize ceramic materials. Glass production involves two main methods the float glass process that produces sheet glass, and glassblowing that produces bottles and other containers.



There are several mechanisms that are responsible for plastic deformation in crystalline materials. Nevertheless, dislocation motion is observed in ceramics under specific loading conditions in general, plastic deformation of ceramics requires high temperatures and this is important because:

- We often process ceramics at high temperature.
- Many potential applications for ceramics, such as in fuel cells and engines, require them to be stable at high temperature.
- We know that glass flows and that we can produce complex shape changes in glass.

Selecting ceramics for use at high temperatures or under applied load requires consideration of their long-term stability. Time dependent deformation is known as creep, and creep resistance is a critical design parameter. Even if creep does not lead to failure, a change in shape or size may render a component useless. The mechanism responsible for creep depends on temperature, stress, and the microstructure of the ceramic.

5.1 CLASSIFICATION OF PLASTICS

There are many methods used to classify plastics. The most common method is to classify them according to their polymer backbone. Plastics can, however, also be classified according to the glass transition temperature or thermoplastic versus thermoset. No matter the classification, all plastics are polymers, which is a long chain of atoms that are bonded to one another. These chains are comprised of monomers, which are repeating molecular units. Most plastics are made of carbon polymers or carbon polymers combined with nitrogen, oxygen, sulfur, or chlorine in the backbone, which is the main path linking the units together. Plastic is then customized by "hanging" different molecular groups to the backbone.

Plastic is the general common term for a wide range of synthetic or semi-synthetic materials used in a huge, and growing, range of applications. Everywhere you look you will find plastics. We use plastic products to help make the lives cleaner, easier, safer and more enjoyable. You will find plastics in the clothes we wear, the houses we live in, and the cars we travel in. The toys we play with, the televisions we watch, the computers we use and the CDs we listen to contain plastics. Even the toothbrush you use every day contains plastics.

One of the most outstanding features of plastics is the ease with which they can be processed. In some cases semi-finished articles such as sheets or rods are produced and subsequently fabricated into shape using conventional methods such as welding or machining. In the majority of cases, however, the finished article, which may be quite complex in shape, is produced in a single operation. The processing stages of heating, shaping and cooling may be continuous (e.g. production of pipe by extrusion) or a repeated cycle of events (e.g. production of a telephone housing by injection molding) but in most cases the processes may be automated and so are particularly suitable for mass production. There is a wide range of processing methods which may be used for plastics. In most cases the choice of method is based on the shape of the component and whether it is thermoplastic or thermosetting. It is important therefore that throughout the design process, the designer must have a basic understanding of the range of processing methods for plastics since an ill-



Eckelmann provides controllers and software for modern machines and plants for plastics processing such as plastics shaping, foil production, etc. Typical functions such as temperature control and tool movement are implemented with established modular solutions.

conceived shape or design detail may limit the choice of molding methods. The principal processing methods for plastics is described and where appropriate a Newtonian analysis of the process is developed. Although most polymer melt flows are in fact Non-Newtonian, the simplified analysis is useful at this stage because it illustrates the approach to the problem without concealing it by mathematical complexity. In practice the simplified analysis may provide sufficient accuracy for the engineer to make initial design decisions and at least it provides a quantitative aspect which assists in the understanding of the process.

5.1.1 Advantages and Disadvantages of Plastic

Advantages of Plastic

- Plastic are light in weight.
- They can be easily molded and have excellent finishing.
- They possess very good strength and toughness. They possess good shock absorption capacity.
- Advantages of plastic are corrosion resistant and chemically inert.
- They have low thermal expansion of co-efficient and possess good thermal and electrical insulating property.
- Advantages of plastic is very good water resistant and possess good adhesiveness.
- Plastic is strong, good and cheap to produce.
- Plastic is a recycling process and it does not decompose.
- Plastic bottles can be reused and restored over again and again.
- Plastic is one of the unbreakable.
- Plastic is an odorless.
- Plastic is used for building, construction, electronics, packaging (glad wrap) and transportation industries.
- Used to make - water bottles, pens, plastic bags, cups etc.
- Advantages of plastic are very cheap to make.
- Durability
- Strength
- Chemical resistance
- Advantages of plastic are used to produce another product.
- Used to reduce soil and wind erosion.

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Disadvantages of Plastics

- Plastic is a nonrenewable resources.
- Plastic is softness.
- causes cancer
- Plastics are embrittlement at low temperature.
- Plastics are deformation under load.
- Plastics are low heat resistant and poor ductility.
- Plastics are combustibility.
- Produces toxic fumes when it is burnt
- It is a recycle process, but it is very costly.

5.1.2 Ingredients of Molding Compounds

Molding compounds and resins are industrial plastics and polymers that are suitable for forming. They are used in injection molding, compression molding, reaction injection molding (RIM), resin transfer molding (RTM), and blow molding. Types include thermoset resins, gel elastomers, encapsulates, potting compounds, composites, and optical grade materials. Typically, products are supplied as pellets, liquids, and powders.

Molding compounds the selection of production equipment and processes for thermosetting molding compounds commences with the compound designer's formulation, which designates the type and quantity of various ingredients that make up the compound. Common molding compounds are in the form of pellets or preforms (sheets, ropes, etc.) or loose, semidry batches. Molding compounds are physical mixtures of resin, reinforcement, or filler, catalyst, lubricant, and color. The resin is the key component in any thermosetting molding compound because it is the only component that actually goes through the chemical reaction. The next most important component consideration is the reinforcement or filler, because the type and quantity of either will determine the manufacturing process and equipment. Lubricants, which provide a measure of flow promotion, mold release and barrel life during molding, are generally internally supplied but are occasionally provided as an external addition. Coloring does have an effect on the processing equipment if a wide range of colors is to be used.

5.1.3 Types of Molding Compounds

These type of molding compounds and resins:

- *Elastomers* and rubber materials are characterized by their high degree of flexibility and elasticity. They are based on a variety of different systems,

including silicone, polyurethane, chloroprene, butyl, polybutadiene, neoprene, natural rubber or isoprene, and other synthetic rubber or compounds.

- *Composite* compounds are types of resins made from two or more constituent materials with significantly different physical or chemical properties. One of these constituents is generally a strengthening phase, reinforcement fibers, toughening phase, or other specialty fillers that provide unique properties.
- *Thermoplastics* are polymers that turn to liquid when heated and turn solid when cooled. They can be repeatedly remitted and remolded, allowing parts and scraps to be reprocessed. In most cases they are also very recyclable.
- *Thermosets* or thermosetting plastics are polymer materials that have been irreversibly cured. They are generally stronger than thermoplastics due to polymer cross-linking and are better suited for high-temperature applications. They tend to be more brittle than thermoplastics and many cannot be recycled due to irreversibility.
- *Silicone* molding compounds are used mainly in electrical applications because of their good chemical and electrical properties. They feature high arc resistance, high dielectric strength, and a low dielectric constant. Silicone molding compounds also provide good resistance to corona and electric breakdown, even after exposure to moisture and higher temperatures.



Most molding compounds are composite materials that consist of epoxy resins, phenolic hardeners, silica, catalysts, pigments, and mold release agents. A product's chemistry and filler material help to determine key mechanical, physical, thermal, and electrical properties.

Raw Materials for Molding Compounds

A typical molding compound contains reinforcement, resin, filler, release agent, curing agent, thickener, and sometimes a low profile additive. The discussion on raw materials will be limited to material requirements specific to BMC and SMC. The selection of raw materials for molding compounds is very important. Wide ranges of materials are used and their formulation is also diverse. For making consistent quality molding compounds, all raw materials should be subjected to stringent quality control.

The following categories of raw materials are used for making molding compounds:

- Fiber reinforcement
- Resin
- Curing agent
- Fillers
- Chemical thickener
- Release agent
- Low profile additives
- Miscellaneous additives

The fiber gives mechanical strength to the product. For the BMC the fiber content varies from 10% to 25% and the length of fiber varies between 6 and 12 mm. Reinforcements for BMC include glass, carbon, aramid, sisal, and other natural organic fibers. For the SMC, about 10%-35% fibers of length between 25 and 50 mm are used. SMCs are commonly made with glass fiber roving chopped to 25 mm length, although it is possible to use fiber lengths between 12 and 75 mm. Originally SMC was made from CSM having fibers of length 50 mm. recently, continuous fibers of glass, carbon, and aramid are being used to obtain higher strength.

Increase in fiber length improves the strength and rigidity of the products. Short fibers provide better flow of compound, increased strength along weld lines, and reduced sink marks over ribs and bosses. Fiber length beyond 12 mm cannot be used in BMC because the longer fibers are more prone to entanglement and degradation in the mixer. Moreover, wet-out becomes difficult with long fibers. Mostly chopped fibers are used in molding com-pounds. However, some SMCs are made with CSMs. Molding compounds are generally made using glass fibers as the fiber reinforcement. Other rein-forcing fibers include sisal, carbon, aramid, chopped polyamide rag, and wood fibers. Glass fibers generally give good mechanical properties. Sisal fibers make an easy flowing compound suitable for large and moderately complex parts not requiring high water resistance. A very low cost product with excellent water, stain, and electrical resistance can be made with diced polyamide tricot fabric. The color and weave structure of fabric are difficult to mask, and the mechanical properties of the product made with this fiber are also low. Some molding compounds have been made

with carbon and aramid fibers. Although they increase the mechanical properties, the increase is not proportional to their basic mechanical properties.

5.1.4 General Properties of Plastics

Plastics have numerous properties that make them superior to other materials in many applications. Plastics generally have resistance to corrosion and chemicals, low electrical and thermal conductivity, high strength-to-weight ratio, colors available in a wide variety and transparent, resistance to shock, good durability, low cost, are easy to manufacture, resistant to water and have low toxicity.

It would be difficult to imagine the modem world without plastics. Today they are an integral part of everyone's lifestyle with applications varying from commonplace domestic articles to sophisticated scientific and medical instruments. Nowadays designers and engineers readily turn to plastics because they offer combinations of properties not available in any other materials. Plastics offer advantages such as lightness, resilience, resistance to corrosion, color fastness, transparency, ease of processing, etc., and although they have their limitations, their exploitation is limited only by the ingenuity of the designer.

The term **plastic** refers to a family of materials which includes nylon, polyethylene and PTFE just as zinc, aluminum and steel fall within the family of metals. This is an important point because just as it is accepted that zinc has quite different properties from steel, similarly nylon has quite different properties from PTFE. Few designers would simply specify metal as the material for a particular component so it would be equally unsatisfactory just to recommend plastic. This analogy can be taken still further because in the same way that there are different grades of steel there are also different grades of, say, and polypropylene. In both cases the good designer will recognize this and select the most appropriate material and grade on the basis of process ability, toughness, chemical resistance, etc.

Following are the general properties of plastics:

1. ***Strength:*** The plastics are sufficiently strong and can be used for load bearing structural members. The strength of plastics can further be increased by reinforcing them with various fibrous materials.

   Plastic as structural material has not gained much popularity because of the following resins:

- High cost of construction
- High temperature susceptibility
- Poor stiffness
- Being subjected to creep under constant load

2. ***Weather Resistance***: The plastics, prepared from phenolic resins, are only

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good in resisting weather effects. Certain plastics are seriously affected by ultraviolet light.

3. ***Fire Resistance***: Plastics, being organic in nature, are combustible. But the resistance to fire temperature depends upon the plastic structure.

- Cellulose acetate plastics burn slowly.
- Polyvinyl chloride (PVC) plastics are non-inflammable.
- Phenol formaldehyde and urea formaldehyde plastics are used as fire proofing materials.

4. ***Durability:*** Plastics generally possess sufficient durability, provided they offer sufficient surface hardness. Thermoplastic varieties are found to be attacked by termites and rodents.
5. ***Dimensional Stability:*** Plastics easily maintain its shape and do not go under plastic deformations.
6. ***Chemical Resistance:*** Plastics offer great resistance to moisture, chemicals and solvents. Many plastics are found to possess excellent corrosion resistance. Plastics are used to convey chemicals.
7. ***Thermal Resistance:*** The plastics have low thermal conductivity and therefore foamed or expanded varieties of plastics are used as thermal insulators.
8. ***Working Conditions:*** All operations like drilling, sawing, punching, clamping etc. are carried out easily on plastics, just like wood.
9. ***Moisture Resistance***: This property depends upon variety of plastics used, *for example*, cellulose plastics are considerably affected by the presence of moisture, whereas polyvinyl chloride plastics offer high resistance to moisture.
10. ***Ductility:*** Plastics, generally, have low ductility and hence plastic structural members may fail without prior warning.

5.2 PLASTIC PART MANUFACTURING PROCESSES

Plastic abounds in the business world, you find it as product components, packaging and even in the containers used to ship products. For businesses interested in manufacturing or packaging their own products, an understanding of the major methods used in plastic manufacturing can prove useful in making decisions regarding which process best suits their purposes. The most common methods of processing plastics to manufacture plastic parts are similar to methods we have learnt for metals and glass. These include extrusion, Injection molding, blow molding, casting, etc. Among these, perhaps injection molding is the most significant for local industry almost all manufacturing companies use parts that are injection molded, whether they make toys, home-appliances, electronics or electrical parts, watches, computers, etc.

Manufacturing is a series of interactions between materials, machines, energy and people in the process of making goods and articles. There are manufacturing processes available for the four main groups of materials: metals, ceramics, plastics and composites. Only those processes for metals and polymers will be covered here.

Metals: Alloys composed of two or more elements, at least one of which is metallic, are the predominant type of metals used in manufacturing. Metal are either iron based ferrous metals or nonferrous metals, a group that contains all other metals and their alloys.

Plastics: Plastics are formed from repeating structural units called mars whose atoms share electrons to form large molecules. There are three categories of plastics: thermoplastics, which can be subjected to multiple heating and cooling cycles without a large change in their molecular structure; thermosets, which chemically transform (cure) into stiff structures when they cool from a heated plastic condition and elastomers, which exhibit significant elastic behavior.

Ceramics: Ceramics contain metallic or semi-metallic and nonmetallic elements. For processing purposes ceramics can be divided into crystalline ceramics, which are formed from powders and then sintered, and glass ceramics that can be melted and cast and then formed in processes such as glass blowing.

Composites: Composites are materials that usually consist of two phases, both homogeneous masses of material, that are bonded together to achieve properties superior to those of its constituents. Usually the structure of a composite consists of particles or fibers of one phase mixed into a second phase, which is called the matrix.

5.2.1 Compression Molding

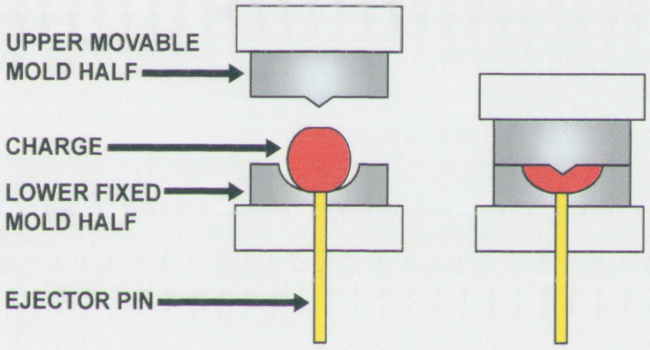
Compression molding is the process of manufacturing by using a mold to produce goods. The mold has two parts that form the complete product shape when they are closed. Materials, which are usually pre-heated, are placed on one of the molds. The two halves are then compressed to spread the material around them. High pressure from the compression distributes the material evenly around the mold cavity.

Compression molding is used primarily for the processing of thermosetting polymers. A premeasured, usually preformed charge of a polymer is enclosed within a closed mold and is subjected to heat and pressure until it takes the shape of the mold cavity and cures. Although the cycle time for compression molding is significantly longer than that for injection molding and intricate parts or very close tolerances are difficult to produce, it does have several advantages including a low capitol cost (the tooling and equipment used are simpler and cheaper), little material waste and the facts that large, bulky parts can be molded and that the process is adaptable to rapid automation.

Heating the material enables it to conform to the mold better. Molds can also be heated to keep the material from cooling too quickly. After the molds are pressed, they

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are left to cure. The curing process ensures that the material will not change its shape when it is removed from the mold. This process can usually take from several hours to days, depending on the materials used.



The materials generally used for compression molding are made from plastic compounds, rubber, and metal alloys. Compression molding plastic is commonly made from vinyl or polyester compounds. Before molding, they are usually in the form of pellet, paste, or sheet to ease handling. Additives and fillers may be added to the compound to reduce cost and prevent shrinkage after the molding process.

Compounds that can withstand high temperatures are sometimes used for rubber compression molding. A relatively smooth surface is one of the benefits of this type of molding. This is ideal for the manufacture of products that need to fit tightly, like rubber stoppers.

The automotive industry extensively uses compression molding to produce car parts. **Metal** alloys are molded to produce fenders and car hoods that have relatively simple shapes. Many other products are making using this process, including plastic cases, electrical equipment, and children's toys.

There are several advantages of using compression molding. The material is commonly in a soft solid state when it is placed on the mold, so the manufacturer can more accurately determine the amount of material inside the compression molding machine. Expensive compounds are used more efficiently through this process. Excess materials called flash are the result of material overflowing the mold. They can



Metal is a material that is typically hard, opaque, shiny, and has good electrical and thermal conductivity.

be recycled by reheating them and adding them back to the process; this saves the manufacturer resource costs.

Another advantage of compression molding is the ability to produce more intricate products. High pressure from the compression forces the material to follow the mold to its exact design. This is best for small and precise instruments, like electronic gadgets.

5.2.2 Transfer Molding

Transfer molding is defined as a process during which a specific weight of polymer is placed into a special chamber called a transfer pot. The transfer pot is preheated before the polymer is placed inside. A sprue is then used and the polymer is put through a preheated cavity or opening, so it may take the shape of this opening or mold. Finally, the polymer is cured when pressure and heat are applied to it, so it permanently takes the shape of the mold. The transfer molding process makes creating integrated packaging for circuits, and various other molded pins for electronic components that require a high level of precision and care, much simpler. The transfer molding process can also be used for the creation of thermoplastics. The most common use for transfer molding processes is for the creation of thermosets.



REMEMBER

The earliest ceramics made by humans were pottery objects, including 27,000-year-old figurines, made from clay, either by itself or mixed with other materials like silica, hardened, sintered, in fire.



The process of transfer molding is quite simple. It is very much like the process of compression molding, however, there is one major difference. Instead of the polymer substance being loaded into a mold that is open, the polymer is forced

into a closed mold after being melted down. The steps for the transfer molding process begin when the pre-heated and uncured molding material is placed into a transfer pot, which is located at the top of the closed mold. A plunger is then inserted with force to push the melted material down into the mold through a tiny opening at the bottom of the transfer pot called a sprue.

Once the **polymer** is pushed down past the sprue and into the cavity for the mold, the material is left to cure. After the curing process, the enclosed mold is then opened with the help of an ejector pin located at the bottom of the mold. Once the pin is removed, the mold can be opened. The finished piece is then removed from the mold and used for whatever it has been created for. Transfer molds are used for a number of different purposes. Transfer molding is essential for the creation of products that contain various items including semiconductor chips and ceramics. Some of the materials used in the creation of these thermosets for the types of products mentioned above include epoxy, unsaturated polyester, and Phenol-formaldehyde plastic and silicone rubber.

Transfer molding is generally used only for forming thermosetting plastics. It is similar to compression molding because the plastic is cured into an infusible state through pressure and heat. Unlike compression molding, however, transfer molding involves heating the plastic to a point of plasticity prior to being placed into the mold. The mold is then forced closed with a hydraulically operated plunger.

Transfer molding was initially developed as a method for molding intricate products, such as those with many metal inserts or with small, deep holes. This is because compression molding sometimes disturbed the position of the metal inserts and the holes of these types of products. With transfer molding, on the other hand, the liquefied plastic easily flows around the metal parts without causing them to change position.

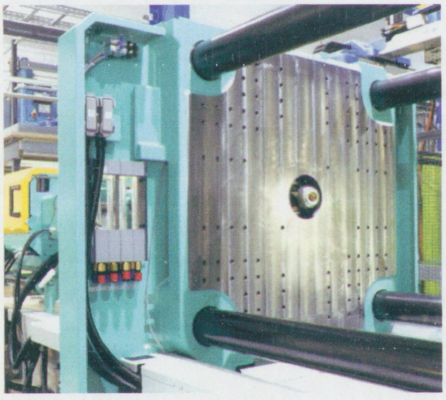


Polymer is a large molecule, or macromolecule, composed of many repeated subunits.

5.2.3 Injection Molding

One of the most common plastic manufacturing methods, injection molding lends itself to mass production of products ranging from cell phone stands to toys. The injection molding process melts resin pellets inside the injection machine with a

heated barrel. An auger moves the plastic forward and ensures an even mix of melted plastic. The machine then drives the melted plastic into a metal mold. The plastic fills the mold and results in a solid plastic part or product. Most injection molding processes employ thermoplastics that you can melt and cool multiple times, which limits material waste. Injection molding is the most commonly used method for mass production of plastic products due to its high production rates and good control over the products' dimensions.



In this method, the polymer is fed from a hopper in pellet or powdered form into a cylinder where it is heated to plasticity. It is then forced into a split-mold cavity and hardens under pressure, after which the mold is opened and the part is ejected. The advantages of injection molding are high production rates, low labor costs, high reproducibility of complex details and an excellent surface finish. Its limitations are high initial tool and die costs and the fact that it is not economically practical for small runs.

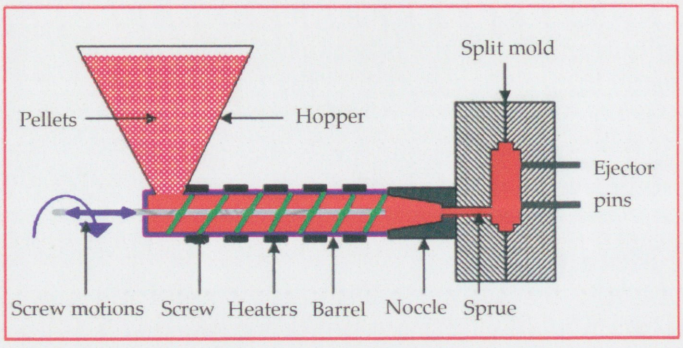
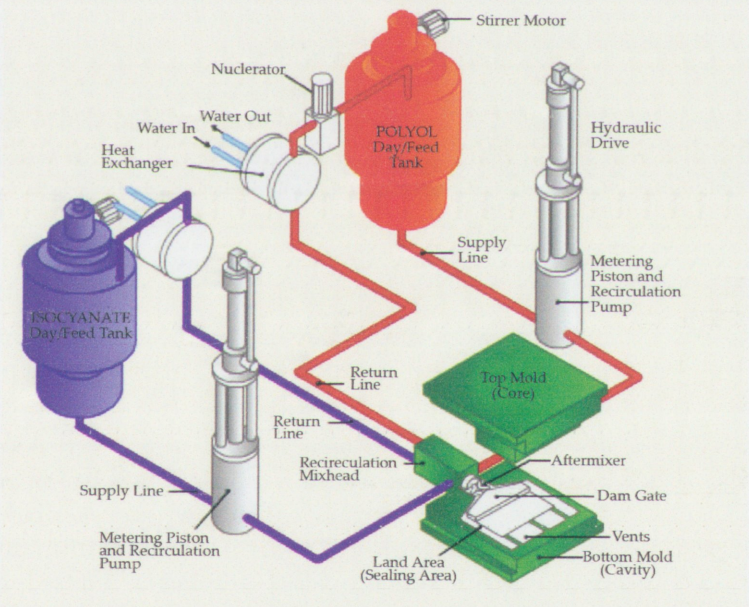


Figure 5.1: Schematic set-up of injection molding.

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Reaction Injection Molding (RIM)

The concept of RIM is two reactant liquids are heated and brought together under high pressure one example process is polyurethane RIM, at the heart of the polyurethane RIM process is a chemical reaction between the two liquid components, which are held in separate, temperature-controlled feed tanks equipped with agitators. From these tanks, the isocyanatc and polyol feed through supply lines to metering units that precisely meter both components.



Making the Mold for Injection Molding

The mold used in the injection molding process is made from a mold maker, or toolmaker. The mold itself is made of metal, which is usually either aluminum or steel. It is then precision-machined in order to create all of the features needed to form the part in the way it is needed. This process is used to create very tiny components for items such as cell phones to large items, such as the entire body panel used for a car. Other common items made with injection molding include outdoor furniture and bottle caps.

A great deal of time and thought must be put into the creation of a mold for injection molding. Besides achieving the desired shape, the mold needs to be made in a manner that will prevent the product being created from being trapped in the mold. In addition, care must be made to ensure the mold will be able to be completely filled with the molten resin before it solidifies. Care must also be made to compensate for

material shrinkage and to reduce the chances of imperfections being created in the final product.

5.2.4 Extrusion Molding

DID YOU KNOW?

In 1907 Leo Baekeland invented Bakelite, the first fully synthetic plastic, meaning it contained no molecules found in nature.

Extrusion molding, or extrusion molding, is the molding of plastic or metals into a pre-defined shape. During the process, metal or plastic is melted and pushed through a die to create a linear form. The final shape, commonly called a rod, although it is not necessarily cylindrical, is then cooled and can then be cut to various lengths, depending upon the application. If you slice a rod of material, the shape you see is called the cross-section. The shape that emerges from an extrusion molding machine is identical to this cross-section piece. It is uniform throughout the item until the material or the die is changed.

An extrusion molding machine varies in size, but is typically at least the size of an automobile. It is equipped with some method of inserting the material into the machine and melting it to a liquid state. Then it can be pushed through a die to create its shape.

The assemblies for plastic and metal extrusion molding are similar in effect, but different in operation. For plastic extrusion molding, a large funnel, called a hopper, is placed on top of the machine. Into it are poured small pellets of material, *for example* high density polyethylene, or plastic. Those pellets are easily melted into a liquid state and pushed through a die to create a plastic tube or rod of some shape. For metal extrusion molding, pre-heated heavy metal rods called billets are inserted into the machine and then pressed to force it through a die to create a metal tube or rod.

As with injection molding, there are many variables to consider when extruding materials. The temperature of the material, the pressure at which the material is forced through the die, and the time of extrusion are all factors that can be adjusted to create ideal material conditions. Extrusion molding is similar to injection molding in that it melts and forms plastic or metal into pre-defined shapes. However, with injection molding, the plastic or metal is not continuously extruded. The mold or die fills with material, the material cools, and then it opens to drop pre-formed shapes into a container.

When designing a die for an extrusion molding machine, one must take into consideration factors that affect the finished material after it cools.



Plastics and metals have a shrink rate, which is a percentage of the size that is lost after material cools. The shrink rate of various materials must be considered when designing a die.

Extrusion is used for the continuous manufacturing of film, sheet, tubing, channels, piping, bars, angles and fibers as well as other profiles and in conjunction with blow molding. A powdered or granular thermoplastic or thermoset polymer is fed from a hopper into a heated barrel where it melts and is then forwarded, usually by a rotating screw, through a nozzle possessing the desired cross section. It is cooled with a spray of water and is then cut to the desired lengths. The extrusion process is favored because of its low tool costs, the ability to process complex profile shapes, the possibility of rapid production rates and the ability of applying coatings or jacketing to core materials (such as wire).

5.2.5 Blow Molding

Blow molding is a simple process where compressed air is introduced underneath a warmed sheet of thermoplastic material forcing the material into a mold cavity, or allowing it to expand freely into the shape of a hemisphere. It is a good way of forming large domes, which when made out of clear acrylic sheet is often used in shop displays.

Blow molding is a manufacturing method used in the plastic industry to create strong, hollow containers; some examples of products commonly created through this process are plastic beverage bottles, plastic drums, and fuel tanks. A typical blow molding process involves melting plastic into a hollow tube, known as a parison, placing the tube between two halves of a mold, and pumping pressurized air into the parison until it expands to fit the form of the mold; the two halves of the mold then separate and the finished container is released.

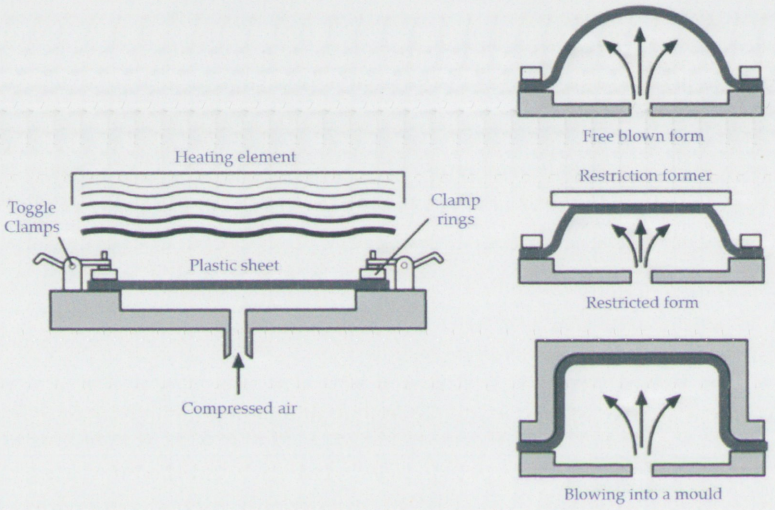


Figure 5.2: Blow molding.

Strength of Plastic

Plastics are actually chains of polymers held together by a strong, but fluid, bond. The reason a thin soda bottle is strong enough to withstand the pressure of carbonated liquids is a result of the polymer chains in a plastic bottle forming in two directions; this generally creates a very strong webbing effect. The plastic can then be stretched thin without sacrificing strength, and blow molding experts takes advantage of this property to make thin, but strong, containers.

The Process

Blow molding any type of container requires a preformed piece of plastic called a parison; this parison is usually extruded from a plastic injection mold placed very close to the blow molding machinery. The warm parison looks like an upside down plastic test tube, with a preformed collar and threads for the cap at the bottom. The parison is mechanically loaded onto a stand and two sides of a bottle-shaped metal mold come together around it. The difference between the three processes lies at this point of the process.

At this point in the process, a hollow ramrod is injected into the parison's center and pushed to the top of the mold, stretching out the warm plastic preform as it goes. Compressed air is then forced out in controlled, low-pressure stages through the hollow ramrod, which forces the plastic form to form to the sides of the mold;

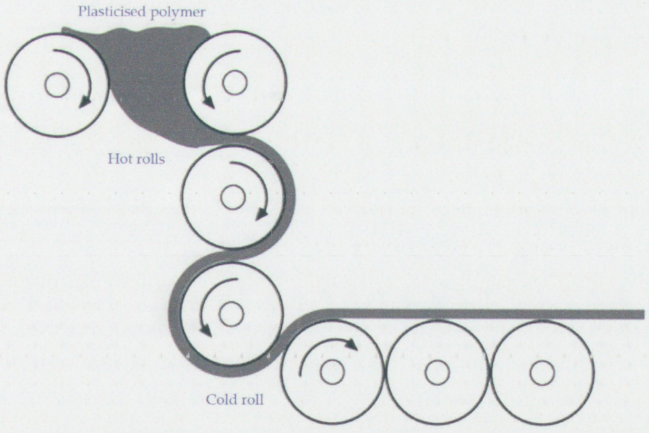
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because the stretching is performed evenly, the plastic remains uniformly thin and strong. This process is expensive to do, but is very efficient when used for producing mass quantities, making it ideal for such things as water bottles.

The plastic acts much like a latex rubber balloon as long as the pressure from the compressed air is controlled, the material will expand uniformly and form the shape of the mold. Blow molding engineers who design new pieces of equipment for the molding process often need first-hand experience with the machinery in order to understand how to improve the equipment and molding process.

5.2.6 Calendaring

Calendaring is used to manufacture thermoplastic sheets and films and to apply plastic coverings to the backs of other materials. Thermoplastics of dough-like consistency are passed through and over a series of heated or cooled rolls. Its advantages include low cost and that the sheet materials produced are virtually free of molded in stresses. It is limited to sheet materials and very thin films are not possible.



Calendaring is used to produce plastic sheeting and products such as floor tiles, coated fabrics and coverings for car interiors. Fused thermoplastic is extruded on to heated rotating rollers that squeeze the material into a continuous sheet or film. The film is cooled by jets of air or water, before being cut to suitable lengths or loaded onto rolls.

Casting

Casting is used to produce sheets, rods, tubes, trial jigs and fixtures as well as to insulate electrical components. It is a simple process, requiring no external force or pressure. A mold is filled with liquid plastic (acrylics, epoxies, polyesters, polypropylene, nylon

or PVC can be used) and is then heated to cure, after which the material becomes isotropic (has uniform properties in all directions). Its benefits include: low mold costs, the capability to form large parts with thick cross sections, a good surface finish and its convenience for low-volume production. Unfortunately, it is limited to relatively simple shapes and it can be uneconomical at high production rates.

Rotational Molding

Rotational molding is a process by which hollow objects can be manufactured from thermoplastics and occasionally thermosets. A charge of solid or liquid polymer is placed in a mold, which is heated while being simultaneously rotated around two perpendicular axes. Thus, the centrifugal force pushes the polymer against the walls of the mold, forming a layer of uniform thickness conforming to the shape of the cavity and which is then cooled and ejected from the mold. The overall process has a relatively long time cycle but it does have the advantages of offering almost unlimited product design freedom and allowing complex parts to be molded using low-cost machinery and tooling.

5.3 THERMOFORMING

Thermoforming involves a variety of processes employed to manufacture cup-shaped products such as containers, panels, housings and machine guards from thermoplastic sheets. A heat-softened thermoplastic sheet is positioned over the mold and the air is evacuated from between the two, forcing the sheet to conform to the contour of the mold. The polymer is then cooled so it will retain its shape, removed from the mold and the web surrounding it is trimmed. The advantages of thermoforming include: low tooling costs, the possibility of large part production with thin sections and that it is often economical for limited part production. It is however limited in that the parts must be of a simple configuration, there is a high scrap output, there are only a few materials that can be used with this process, and the shape of the product cannot contain holes. In thermoforming, a sheet of plastic is used to cover a shape (e.g. a die) by heating the sheet till it is semifluid, and then pulling it over the die using vacuum suction (this method is called vacuum forming). In an alternate form, called pressure forming, the pressure is applied using high pressure air from above the plastic sheet. This process is most commonly seen in packaging of food, toys etc.; it is also used to make appliance housings, etc. The following schematic shows different types of thermoforming. The advantage of thermoforming is that the tooling (usually made by machining aluminum) is cheap to produce. The vacuum forming process leaves tiny marks where the mold has holes for vacuuming out the air; these holes are made small, e.g. 0.5mm. The main quality control issues include non-uniform thickness of parts, warping of parts when they cool, and tearing of the sheet.

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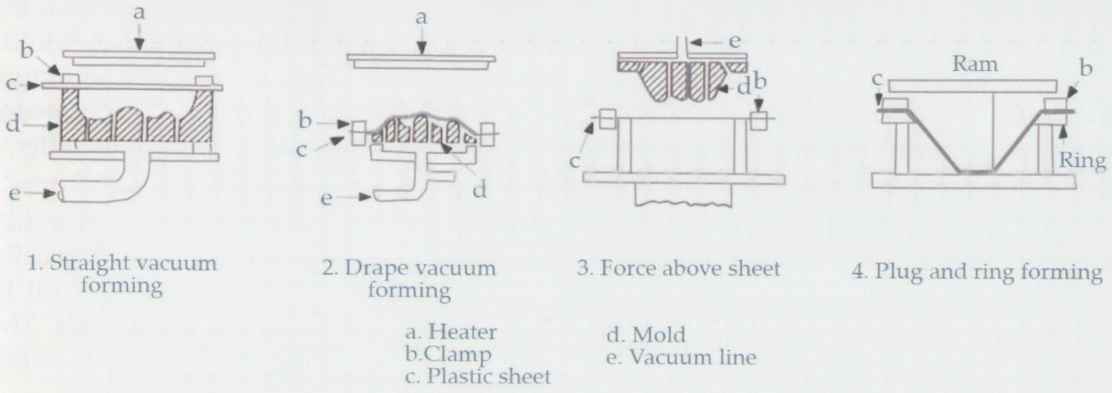
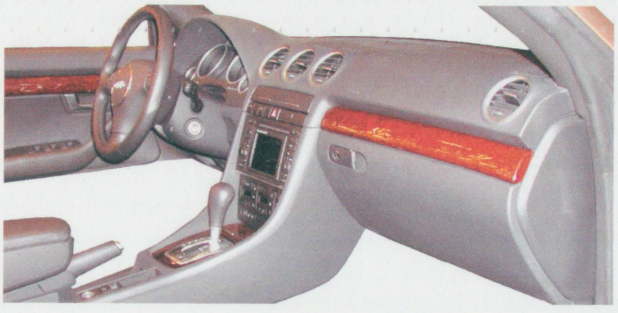


Figure 5.3: Schematic of thermoforming processes.

5.3.1 Slush Molding

Slush molding is an excellent method of producing open, hollow objects, including rain boots, shoes, toys, dolls and automotive products, such as protective skin coatings on arm rests, head rests and crash pads. The basic process of slush molding involves exposing a hollow mold to heat, filling a hollow mold with vinyl plastisol or vinyl powder compound, gelling an inner layer or wall of plastisol or partially fused powder compound in the mold, inverting the mold to pour out the excess liquid plastisol or unfazed powder compound and then heating the mold again to fuse the vinyl compound which remains in the mold. The mold is then cooled and the finished part is removed.



Slush molding can be a simple hand operation for limited production, or an elaborate conveyor zed system for long runs. This process can be a one pour method, where finished or semi-finished products can be made by one slushing step, or a multiple-pour method where two or more slushing steps are used. The wall thickness of the slush molded part, made from powder compound at a given oven temperature, is determined

by several factors: the thickness of the metal wall of the mold, the length of time the mold is preheated, and the amount and type of plasticizer in the compound. Molds used in slush molding are produced from spun, machined or electroformed aluminum. Vinyl powder compound will reproduce the surface finish of the mold, whether matte or glossy. Mold porosity, depending upon severity, may cause such detrimental effects as surface gloss reduction, pinholing, and voids in the molded part.

This is a method for making hollow articles using liquid plastics, particularly PVC plastisol. A shell-like mold is heated to a pre-determined temperature (typically 130°C for plastisol) and the liquid is then poured into the mold to completely fill it. A period of time is allowed to elapse until the required thickness of plastic gels. The excess liquid is then poured out and the plastic skin remaining in the mold is cured in an oven. The molding is then taken from the mold.

It should be noted that when the plastisol liquid gels it has sufficient strength to remain in position on the inside surface of the mold. However, it has insufficient tear strength to be useful and so it has to go through the higher temperature curing stage to provide the necessary toughness and strength in the end-product. The mold is not rotated during slush molding.

Laminating

Lamination is the technique of manufacturing a material in multiple layers, so that the composite material achieves improved strength, stability, sound insulation, appearance or other properties from the use of differing materials. A laminate is a permanently assembled object by heat, pressure, welding, or adhesives.

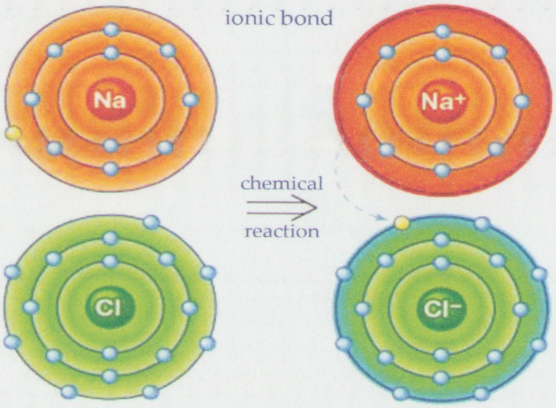
5.3.2 Ceramic Structure and Properties

The properties of ceramic materials, like all materials, are dictated by the types of atoms present, the types of bonding between the atoms, and the way the atoms are packed together. The type of bonding and structure helps determine what type of properties a material will have.

Ceramics usually have a combination of stronger bonds called ionic (occurs between a metal and nonmetal and involves the attraction of opposite charges when electrons are transferred from the metal to the nonmetal); and covalent (occurs between two nonmetals and involves sharing of atoms). The strength of an ionic bond depends on the size of the charge on each ion and on the radius of each ion.

The greater the number of electrons being shared, is the greater the force of attraction, or the stronger the covalent bond.

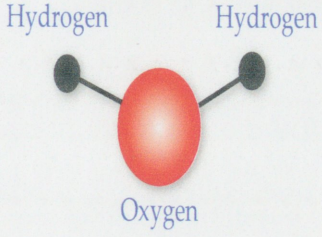
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These types of bonds result in high elastic modulus and hardness, high melting points, low thermal expansion, and good chemical resistance. On the other hand, ceramics are also hard and often brittle (unless the material is toughened by reinforcements or other means), which leads to fracture.

In general, metals have weaker bonds than ceramics, which allows the electrons to move freely between atoms. Think of a box containing marbles surrounded by water. The marbles can be pushed anywhere within the box and the water will follow them, always surrounding the marbles. This type of bond results in the property called ductility, where the metal can be easily bent without breaking, allowing it to be drawn into wire. The free movement of electrons also explains why metals tend to be conductors of electricity and heat.

Covalent Bond



Plastics or polymers of the organic type consist of long chains of molecules which are either tangled or ordered at room temperature. Because the forces (known as van der Waals) between the molecules are very weak, polymers are very elastic (like a rubber band), can be easily melted, and have low strength. Like ceramics, polymers

have good chemical resistance, electrical and thermal insulation properties. They are also brittle at low temperatures. Table 5.1 provides a general comparison of the properties between the three types of materials.

Table 5.1: General comparison of materials

Property	Ceramic	Metal	Polymer
Hardness	Very High	Low	Very Low
Elastic modulus	Very High	High	Low
High temperature strength			
Thermal expansion	High	Low	Very Low
Ductility	Low	High	High
Corrosion resistance	High	Low	Low
Wear resistance	High	Low	Low
Electrical conductivity	Depends on material	High	Low
Density	Low	High	Very Low
Thermal conductivity	Depends on material	High	Low
Magnetic	Depends on material	High	Very Low

These three material types can also be combined in various ways to form composites to take advantage of each material's properties. For instance, ceramic particles or fibers can be added to a ceramic or metal matrix to improve the mechanical properties and/or produce a special property the matrix by itself generally would not have. Polymers are also reinforced with glass fibers for a wide range of construction and structural applications.

5.4 SHAPING CERAMICS

For the production of advanced ceramics, many shaping technologies are used, e.g. cold and hot isostatic pressing, injection molding, slip casting etc. Uniaxial hydraulic pressing is regarded traditionally as a possible shaping technology only for few special applications, mainly limited to smaller product sizes with additional restrictions regarding the complexity of the specimen and their aspect ratio. However, during the last decade hydraulic pressing technology was improved in many aspects, like

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sophisticated hydraulic and electric control systems, vacuum technology and others. These improvements open up new fields for application of uniaxial hydraulic pressing, also for the production of advanced oxide and non-oxide ceramics and composites. Also slip pressure casting technology, originally mainly used for tableware and sanitary ware **ceramics**, has been improved to become a suitable production technology for technical ceramics, even for larger dimensions and especially for complex shapes.

5.4.1 Shaping Plastics using Heat

Shaping plastics using heat is termed thermoforming. Acrylic sheet and styrene sheet are the two most commonly used plastics materials. Heat can be applied to acrylic sheet using an oven or a strip heater, and to both acrylic and styrene sheet using a vacuum forming machine.

When thermoforming plastics, there are certain points to remember:

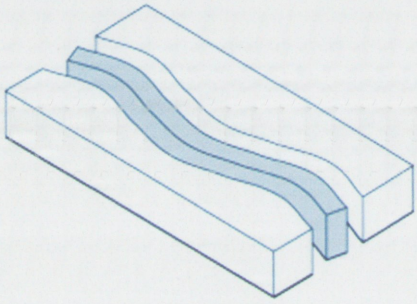
- Acrylic needs to be warmed to 180°c to make it soft enough to bend and mold easily. At this temperature the material will burn the fingers so always were asbestos-substitute gloves when handling hot sheet.
- Sheet plastics need to be heated throughout their thickness before they can be molded allow the core of the material time to warm up as well. If the core is not soft the material may tear or break when you try to form it.
- Thermoplastic sheet is supplied wrapped in a protective layer of polythene or paper. Remove this protective layer before you do any thermoforming.



Ceramic is an inorganic, nonmetallic solid material comprising metal, nonmetal or metalloid atoms primarily held in ionic and covalent bonds.

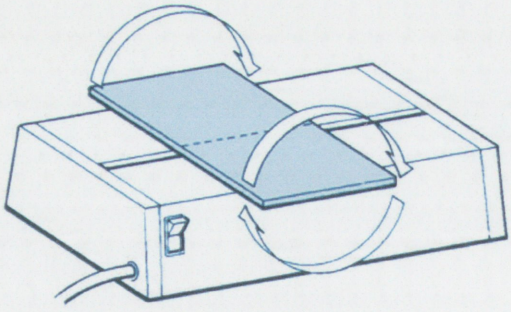
Using an Oven

Acrylic sheet in an oven set at a temperature of 180°c will soften so that it becomes 'plastic', or easy to form. Acrylic at this temperature can easily be shaped freely by hand. A more controlled process is press forming using a former made from wood.



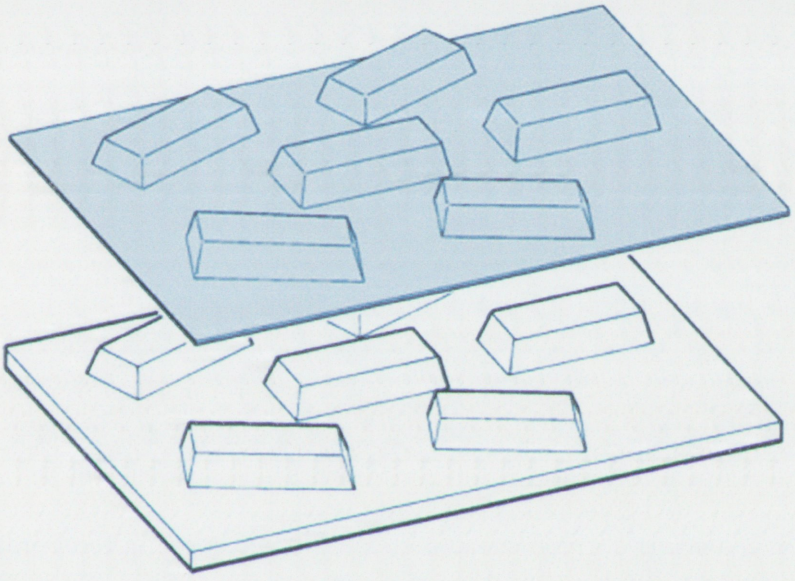
Using a Strip Heater

A strip heater, containing an element like a one bar electric fire, is used to heat up a localized area of sheet plastics so that it can be bent in a straight line. In fact sometimes these devices are called line benders. Unlike an oven that heats the whole sheet, the strip heater only warms a given strip. Bending the sheet, *for example* at a right angle then becomes a very controllable process. Before using the strip heater mark where you want the bend line on the plastic. Turn the plastic over regularly on the strip heater so that both sides are heated and the core of the material also becomes softened.



The Vacuum Forming Machine

Vacuum forming machines are available in a variety of types and designs although they all achieve the same end. They work by creating a vacuum under a piece of heated thermoplastic sheet allowing atmospheric pressure to push the sheet down over a prepared mold. Therefore before you use the vacuum forming machine you will have to make the mold. This is usually constructed from wood, and is made in the shape that you want the plastic to assume. When designing a mold remember that after vacuum forming the mold has to be withdrawn from the formed plastic sheet and to enable this to happen the mold has to be slightly tapered with angled sides. This angle is called a draft angle – 5° is usually sufficient.

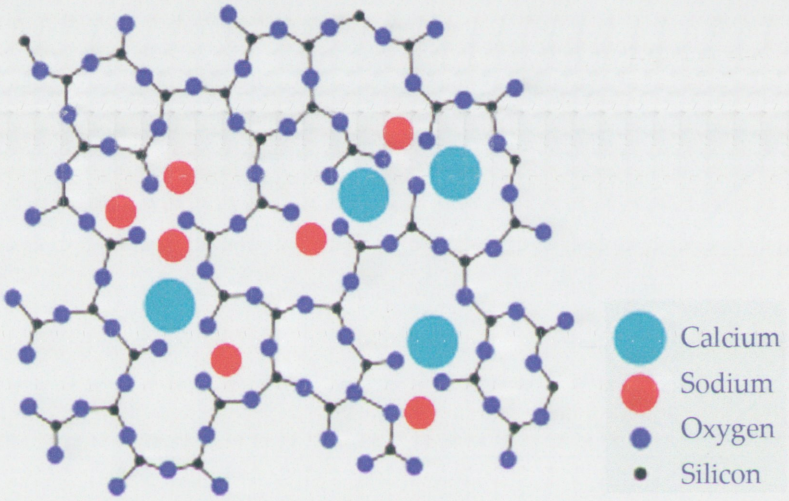


The mold must also have a high degree of finish, as any marks on it will be picked up by the hot sheet. You can polish the mold using wax polish. This helps give a good finish and also assists mold release from the formed plastic sheet.

A complete mold is placed inside the machine on a platform that can be raised and lowered. Thermoplastic sheet is then clamped to a frame and heated using electric elements. When the plastic has been heated until it has thoroughly softened the mold is raised up into it and a vacuum pump switched on. This evacuates the air from underneath the softened sheet, and atmospheric pressure forces the sheet down over the mold.

5.4.2 Glasses Structure, Properties, and Applications

Glass is an amorphous material that lacks a long range periodic crystalline structure. Glasses can be formed through several methods but the most common method involves heating raw materials into a molten liquid and then rapidly cooling the liquid in such a way that the atoms remain in a randomly arranged atomic state. When using the melting/cooling method to form glass, the process often begins as a mixture of several critical raw material powders. These powder mixtures are composed of many different components, with each playing an important role. In most glasses, the compositions are engineered to include network formers, fluxing agents, property modifiers, fining agents, and colorants. The chemical formulation dictates the physical properties and characteristics of the formed glass.



These raw materials are then heated to a sufficient melting temperature so that a homogeneous viscous liquid is formed. At this point, depending on the manufacturing technique, the molten glass can be manipulated and shaped into the desired glass form. The chemical formulation can be altered to meet different performance specifications or to improve manufacturability.

Glass and Other Ceramics

One of the characteristic properties of a substance is its viscosity, which is a measure of its resistance to flow. Motor oils are more viscous than gasoline, *for example*, and the maple syrup used on pancakes is more viscous than the vegetable oils used in salad dressings. Viscosity depends on any factor that can influence the ease with which molecules slip past each other. Liquids tend to become more viscous as the molecules become larger, or as the intermolecular forces become stronger. They also become more viscous when cooled.

Imagine what would happen if you cooled a liquid until it became so viscous that it was rigid and yet it lacked any of the long-range order that characterizes the solids discussed. You would have something known as a glass. Glasses have three characteristics that make them more closely resemble "frozen liquids" than crystalline solids. First, and foremost, there is no long-range order. Second, there are numerous empty sites or vacancies. Finally, glasses do not contain planes of atoms.

The simplest way to understand the difference between a glass and a crystalline solid is to look at the structure of glassy metals at the atomic scale. By rapidly condensing metal atoms from the gas phase, or by rapidly quenching a molten metal, it is possible to produce glassy metals that have the structure following in the Figure 5.4.

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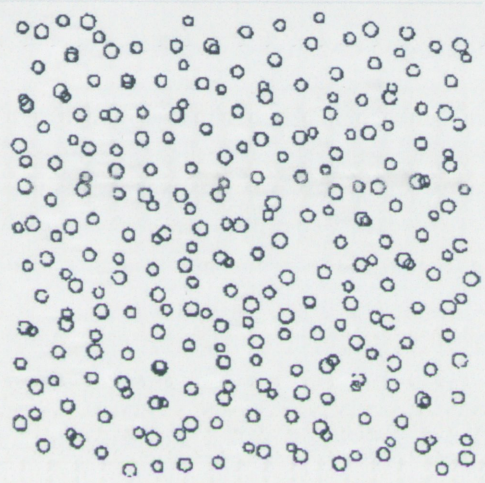


Figure 5.4: The structure of a glassy metal on the atomic scale.

The amorphous structure of glass makes it brittle. Because glass does not contain planes of atoms that can slip past each other, there is no way to relieve stress. Excessive stress therefore forms a crack that starts at a point where there is a surface flaw. Particles on the surface of the crack become separated. The stress that formed the crack is now borne by particles that have fewer neighbors over which the stress can be distributed. As the crack grows the intensity of the stress at its tip increases. This allows more bonds to break, and the crack widens until the glass breaks. Thus, if you want to cut a piece of glass, start by scoring the glass with a file to produce a scratch along which it will break when stressed.

Glass has been made for at least 6000 years, since the Egyptians coated figurines made from sand (SiO_2) with sediment from the Nile River heated these objects until the coating was molten, and then let them cool. Calcium oxide or "lime" (CaO) and sodium oxide or "soda" (Na_2O) from the sediment flowed into the sand to form a glass on the surface of the figurines. Trace amounts of copper oxide (CuO) in the sediment gave rise to a random distribution of Cu^{2+} ions in the glass that produced a characteristic blue color.

Sand is still the most common ingredient from which glass is made. (More than 90% of the sand consumed each year is used by the glass industry.) Sand consists of an irregular network of silicon atoms held together by Si-O-Si bonds. If the network was perfectly regular, each silicon atom would be surrounded by four oxygen atoms arranged toward the corner of a tetrahedron. Because each oxygen atom in this network is shared by two silicon atoms, the empirical formula of this solid would be SiO_2 and the material would have the structure of quartz. In sand, however, some of the Si-O-Si bridges are broken, in a random fashion.

Modifiers (or fluxes) such as Na2O and CaO are added to the sand to alter the network structure by replacing Si-O-Si bonds with Si-O- Na+ or Si-O- Ca2+ bonds. This separates the SiO2 tetrahedral from each other, which makes the mixture more fluid and therefore more likely to form a glass after it has been melted and then cooled. These so-called "soda-lime" glasses accounts for 90% of the glass produced.

Al_2O_3 is added to some glasses to increase their durability; MgO is added to slow down the rate at which the glass crystallizes. Replacing Na_2O with B_2O_3 produces a borosilicate glass that expands less on heating. Adding PbO produces lead glasses that are ideally suited for high-quality optical glass.

The most common way of preparing a glass is to heat the mixture of sand and modifiers until it melts, and then cool it quickly so that it solidifies to produce a glass. If the cooling is rapid enough, the particles in the liquid state cannot return to the original crystalline arrangement of the starting materials. Instead, they occupy randomly arranged lattice sites in which no planes of atoms can be identified. The result is an amorphous (literally: «without shape») material.

Most Common Commercial Glass Types and Their Applications

Glass compositions are engineered to exhibit different physical, chemical, and optical properties. Different applications demand specific types of glass and manufacturing processes. In commercial glass manufacturing, several glass compositions are commonly used. You will briefly highlight three of the most common commercial glass compositions, their properties, and typical applications.

Glass Type	Primary Components	Linear Thermal Expansion	Thermal Shock Resistance	Chemical Resistance	Applications
Borosilicate	SiO_2, B_2O_3	-30-60 x 10^{-7}/°C	Average - High	High	• Industrial equipment • Exterior lighting • Laboratory and kitchen glassware
Soda-lime silicate	SiO_2, Na_2O, CaO	-80-100 x 10^{-7}/°C	Low	Average	• Food and beverage containers • Windows • Lamp envelopes
Phosphates	P_2O_5	-90-110 x 10^{-7}/°C	Low	Low, except high resistance to hydrofluoric acid	• Bone scaffolds • Optical fibers • Heat absorbers

5.4.3 Forming and Shaping of Glass

Glass is processed by melting and then shaping it, either in molds, with tools, or by blowing. Glass shapes produced include flat sheets and plates, rods, tubing, glass fibers, and discrete products such as bunks, light bulbs, and headlights. Glass products may be thick as those for large telescope mirrors and as thin as those for holiday tree ornaments. The strength of glass can be improved by thermal and chemical treatments

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(which induce compressive surface residual stresses) or by laminating it with a thin sheet of tough plastic.

Class products generally can be categorized as follows:

- Flat sheets or plates ranging in thickness from about 0.8 to 10 mm, such as window glass, glass doors, and tabletops.
- Rods and tubing used for chemicals, neon lights, and decorative artifacts.
- Discrete products such as bottles, vases, headlights, and television tubes.
- Glass fibers to reinforce composite materials and for use in fiber optics.

All glass forming and shaping processes begin with molten glass, typically in the range from 1000° to 1200°C. The glass has the appearance of a red-hot, viscous syrup and is supplied from a melting furnace or tank.

5.5 COMPOSITE MATERIALS

A composite material can be defined as a combination of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components. The reinforcement fibers can be cut aligned placed in different ways to affect the properties of the resulting composite. The matrix, normally a form of resin, keeps the reinforcement in the desired orientation. It protects the reinforcement from chemical and environmental attack, and it bonds the reinforcement so that applied loads can be effectively transferred.

Composites are made by combining two or more natural or artificial materials to maximize their useful properties and minimize their weaknesses. One of the oldest and best-known composites, glass-fiber reinforced plastic (GRP), combines glass fibers (which are strong but brittle) with plastic (which is flexible) to make a composite material that is tough but not brittle. Composites are typically used in place of metals because they are equally strong but much lighter.

Most composites consist of fibers of one material tightly bound into another material called a matrix. The matrix binds the fibers together somewhat like an adhesive and makes them more resistant to external damage, whereas the fibers make the matrix stronger and stiffer and help it resist cracks and fractures. Fibers and matrix are usually (but not always) made from different types of materials. The fibers are typically glass, carbon, silicon carbide, or asbestos, while the matrix is usually plastic, metal, or a ceramic material.

These three types of matrix produce three common types of composites:

- *Polymer matrix composites (PMCs),* of which GRP is the best-known example, use ceramic fibers in a plastic matrix.
- *Metal-matrix composites (MMCs)* typically use silicon carbide fibers embedded



Material is a broad term for the (chemical) substance, or a mixture of substances that constitute a thing.

in a matrix made from an alloy of aluminum and magnesium, but other matrix materials such as titanium, copper, and iron are increasingly being used. Typical applications of MMCs include bicycles, golf clubs, and missile guidance systems; an MMC made from silicon-carbide fibers in a titanium matrix is currently being developed for use as the skin (fuselage material) of the US National Aerospace Plane.

- *Ceramic-matrix composites (CMCs)* are the third major type and examples include silicon carbide fibers fixed in a matrix made from a borosilicate glass.

The ceramic matrix makes them particularly suitable for use in lightweight, high-temperature components, such as parts for airplane jet engines.

5.5.1 Type of Composites

The term 'composite' can be used for a multitude of materials. Composites use the term composite or reinforced polymers to encompass:

- Carbon fiber-reinforced polymers (CFRP)
- Glass fiber-reinforced polymers (GFRP)
- Aramid products (e.g. Kevlar)
- Bio-derived polymers (or bio-composites as they are sometimes referred)

Making Composites

Objects made from glass-reinforced plastic, such as row boats, are frequently made by hand by cutting layers of composite from a continuous reel and sticking them into a mold with resin. The reel of composite used for this process is typically manufactured by drawing continuous lengths of the fiber material through a tank containing the resin that will act as the matrix. The coated fibers are then pressed onto a backing tape and formed into long sheets or continuous rolls called laminates. The tape is a composite whose fibers all run in the same direction. This makes it anisotropic, which means its physical properties vary in different directions. *For example,* it is stronger and stiffer in one direction than in others.

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That may be a good thing if the **material** needs to be particularly strong along one axis but, for something like a boat hull or the fuselage or an airplane, the composite needs to be equally strong in every direction. The problem can be solved in one of two ways. First, when the hull or fuselage is being manufactured, the laminates can be pasted in so that each successive layer has its fibers pointing in a different direction. Alternatively, another kind of laminate can be used in which the fibers have been chopped up before they are stuck to the backing tape. Although this type of laminate is weaker in any one direction, it has the advantage of being equally strong in all directions

Why use composites?

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be molded into complex shapes. The downside is often the cost. Although the resulting product is more efficient, the raw materials are often expensive. The primary reason composite materials are chosen for components is because of weight saving for its relative stiffness and strength.

Carbon-fiber reinforced composite can be five times stronger than 1020 grade steel while having only one fifth of the weight. Aluminum is much nearer in weight to carbon-fiber composite, though still somewhat heavier, but the composite can have twice the modulus and up to seven times the strength.



5.5.2 Processing of Metal Matrix

Metal matrix composite materials can be produced by many different techniques. The focus of the selection of suitable process engineering is the desired kind, quantity and distribution of the reinforcement components, the matrix alloy and the application. By altering the manufacturing method, the processing and the finishing, as well as by the form of the reinforcement components it is possible to obtain different characteristic profiles, although the same composition and

amounts of the components are involved. The production of a suitable precursor material, the processing to a construction unit or a semi-finished material and the finishing treatment must be separated. For cost effective reasons prototypes, with dimensions close to the final product, and reforming procedures are used, which can minimize the mechanical finishing of the construction units.

In general the following product engineering types are possible:

- Melting metallurgical processes
  - infiltration of short fiber-, particle- or hybrid preforms by squeeze casting, vacuum infiltration or pressure infiltration
  - reaction infiltration of fiber- or particle preforms
  - processing of precursor material by stirring the particles in metallic melts, followed by sand casting, permanent mold casting or high pressure die casting
- Powder metallurgical processes
  - pressing and sintering and/or forging of powder mixtures and composite powders
  - extrusion or forging of metal-powder particle mixtures
  - extrusion or forging of spraying compatible precursor materials
- Hot isostatic pressing of powder mixtures and fiber clutches
- Further processing of precursor material from the melting metallurgy by thixocasting or -forming, extrusion, forging, cold massive forming or super plastic forming
- Joining and welding of semi-manufactured products
- Finishing by machining techniques
- Combined deformation of metal wires (group superconductors).

Melting metallurgy for the production of MMCs is at present of greater technical importance than powder metallurgy. It is more economical and has the advantage of being able to use well proven casting processes for the production of MMCs.

Metal matrix composites (MMCs) offer high strength to weight ratio, high stiffness and good damage resistance over a wide range of operating conditions, making them an attractive selection in replacing conventional materials for several engineering applications. Normally the metal matrix materials of MMCs are aluminum alloys, titanium alloys, copper alloys and magnesium alloys, while the reinforcement materials are silicon carbide, aluminum oxide, boron carbide, graphite etc. in the form of fibers, whiskers and particles. Perhaps the single most important difference between fiber reinforced and particulate composites or conventional metallic materials is the directionality of properties. Particulate composites and conventional metallic materials

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are isotropic, while the fiber reinforced composites are generally anisotropic. Particulate reinforced composites offer higher ductility and their isotropic nature as compared to fiber reinforced composites makes the m an attractive alternative.

Machining of particulate reinforced MMC has been extensively studied experimentally in the past, while studies on the machining of fiber-reinforced MMCs are limited. MMCs are shown to cause excessive tool wear, which in turn induces such damage phenomena as fiber pullout, particle fracture, delamination and deboning at the fiber or particle and matrix interface.

The parameters that are the major contributors to the machinability of these composites are the reinforcement type and orientation, tool type and geometry and the machining parameters. Although MMCs are generally processed near-net shape, subsequent machining operations are inevitable.

Classification of MMC

Metal matrix composites can be classified in various ways. Classification is the consideration of type and contribution of reinforcement components in particle, layer, fiber and penetration composite materials. Fiber composite materials can be further classified into continuous fiber composite materials (multi and monofilament) and short fibers or, rather, whisker composite materials.

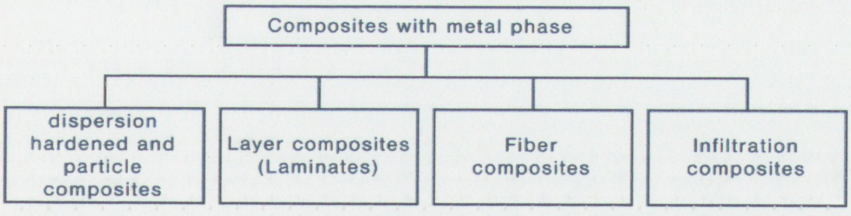


Figure 5.5: Classification of composite materials with metal matrixes.

Reinforcements

Reinforcements for metal matrix composites have a manifold demand profile, which is determined by production and processing and by the matrix system of the composite material.

The following demands are generally applicable:

- low density,
- mechanical compatibility (a thermal expansion coefficient which is low but adapted to the matrix),

- chemical compatibility,
- thermal stability,
- high Young's modulus,
- high compression and tensile strength,
- good process ability,
- Economic efficiency.

These demands can be achieved only by using non-metal inorganic reinforcement components. For metal reinforcement ceramic particles or, rather, fibers or carbon fibers are often used. Due to the high density and the affinity to reaction with the matrix alloy the use of metallic fiber usual fails. Which components are finally used, depends on the selected matrix and on the demand profile of the intended application.

5.5.3 Ceramic Matrix Composites

Ceramic matrix composites (CMC) are produced from ceramic fibers embedded in a ceramic matrix. Various ceramic materials, oxide or non-oxide, are used for the fibers and the matrix. Also a large variety of fiber structures is available. So properties of CMC can be adapted to special construction tasks. They are especially valuable for components with demanding thermal and mechanical requirements. Ceramic matrix composites (CMCs) provide high temperature oxidation stability relative to metals and enhanced toughness relative to monolithic ceramics.

Characteristic of this material ceramic matrix composite is the matrix made of a ceramic material embedded between the fibers. Typical fibrous materials include carbon, silicon carbide, aluminum oxide and mullite. Aluminum oxide, zirconium oxide and silicon carbide are chiefly used as matrix components. CMC terminology is based on the principle "Fiber type/Matrix type" (e.g. "C/SiC" for carbon fiber reinforced silicon carbide). This designation frequently precedes the production methods which are usually realized in three steps.

5.5.4 Processing Semiconductors

Semiconductor device fabrication is the process used to create chips, the integrated circuits that are present in everyday electrical and electronic devices. It is a multiple-step sequence of photographic and chemical processing steps during which electronic circuits are gradually created on a wafer made of pure semiconducting material. Silicon is the most commonly used semiconductor material today, along with various compound semiconductors. The entire manufacturing process from start to packaged chips ready for shipment takes six to eight weeks and is performed in highly specialized facilities referred to as fabs.

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Each issue will aim to provide a snapshot of current insights, new achievements, breakthroughs and future trends in such diverse fields as microelectronics, energy conversion and storage, communications, biotechnology, (photo)catalysis, nano- and thin-film technology, hybrid and composite materials, chemical processing, vapor-phase deposition, device fabrication, and modelling, which are the backbone of advanced semiconductor processing and applications.

Coverage will Include: advanced lithography for submicron devices; etching and related topics; ion implantation; damage evolution and related issues; plasma and thermal CVD; rapid thermal processing; advanced metallization and interconnect schemes; thin dielectric layers, oxidation; sol-gel processing; chemical bath and (electro) chemical deposition; compound semiconductor processing; new non-oxide materials and their applications; (macro)molecular and hybrid materials; molecular dynamics, ab-initio methods, Monte Carlo, etc.; new materials and processes for discrete and integrated circuits; magnetic materials and spintronics; heterostructures and quantum devices; engineering of the electrical and optical properties of semiconductors; crystal growth mechanisms; reliability, defect density, intrinsic impurities and defects.

Processing

In semiconductor device fabrication, the various processing steps fall into four general categories: deposition, removal, patterning, and modification of electrical properties.

Deposition is any process that grows, coats, or otherwise transfers a material onto the wafer. Available technologies consist of physical vapor deposition (PVD), chemical vapor deposition (CVD), electrochemical deposition (ECD), molecular beam epistaxis (MBE) and more recently, atomic layer deposition (ALD) among others.

Removal processes are any that remove material from the wafer either in bulk or selective form and consist primarily of etch processes; both wet etching and dry etching such as reactive ion etch (RIE). Chemical-mechanical planarization (CMP) is also a removal process used between levels. Patterning covers the series of processes that shape or alter the existing shape of the deposited materials and is generally referred to as lithography. *For example*, in conventional lithography, the wafer is coated with a chemical called a photoresist. The photoresist is exposed by a stepper, a machine that focuses, aligns, and moves the mask, exposing select portions of the wafer to short wavelength light. The unexposed regions are washed away by a developer solution. After etching or other processing, the remaining photoresist is removed by plasma ashing. Modification of electrical properties has historically consisted of doping transistor sources and drains originally by diffusion furnaces and later by ion implantation. These doping processes are followed by furnace anneal or in advanced devices, by rapid thermal anneal (RTA) which serve to activate the implanted dopants. Modification of electrical properties now also extends to reduction of dielectric constant in low-k insulating materials via exposure to ultraviolet light in UV processing (UVP).



ROLE MODEL

LEO BAEKELAND

Leo Henricus Arthur Baekeland was an American chemist well-known for his discovery of photographic paper Velox and polymeric plastic Bakelite. His creation of low-cost, incombustible and flexible plastic Bakelite that paved the way for the modernized plastic industry earned him the epithet "The Father of the Plastics Industry". Originally a Belgian, he studied in the 'University of Ghent' after receiving a scholarship from the port city of Glent in northwest Belgium. Post Ph.D he served at the 'University of Ghent' as an associate professor of chemistry. While visiting New York on a fellowship he was convinced to settle there. He joined a photographic company where he served for a few years and discovered the photographic paper Velox that consists of a gelatine silver chloride coating and can be created by artificial light. After a few years he sold the rights of the photographic paper, which by that time became a commercial success, to the 'Eastman Kodak Company'. He ventured into many other chemical technological projects of which his discovery of Bakelite formed using phenol and formaldehyde was revolutionary. It marked the beginning of an era of plastics. After acquiring a patent of his invention he established the 'General Bakelite Company'. During his later stage of life he sold his business to 'Union Carbide'.

Childhood & Early Life

- He was born on November 14, 1863, in Sint-Martens-Latem, Belgium, to Charles Baekeland and Rosalie (Merchie) Baekeland. His father was a cobbler and his mother was a housemaid.
- He joined elementary school at five years of age and later joined the government high school, 'Atheneum'. He attended evening classes at the 'Ghent Municipal Technical School' and studied economics, mechanics, physics and chemistry. He earned medal in all the subjects.
- In 1880 after receiving a scholarship from the port city of Glent in northwest Belgium he joined the University of Ghent. In 1882 he completed his 'Bachelor in Science' degree. At 21 years of age he earned his PhD maxima cum laude.

Career

In 1887 he was appointed by the 'Government Higher Normal School of Science' in Bruges. He served there as professor of chemistry and physics till sometime in 1889. Meanwhile, he discovered a procedure of using water as an alternative to chemicals in developing photographic plates and patented the invention in 1887 in Belgium.

In 1889 he accepted an offer from the 'University of Ghent' for the post of Associate Professor of chemistry. The same year he received a travel scholarship and visited many universities in the United States and England along with his wife.

While visiting NewYork he was persuaded by Professor Charles F. Chandler of Columbia University to settle there. After deciding to stay back he sent his resignation from the post of Associate Professor of the 'University of Ghent'. While his resignation was accepted by the Minister of Education of Belgium, he was authorised to hold an honorary title as Associate Professor of the university.

In New York he met Richard Anthony, of the 'E. and H.T. Anthony' photographic company who offered him a job. He joined the photographic company where he served for a couple of years.

In 1891 he settled as a consulting and research chemist. After around two years of exhaustive endeavour he discovered the photographic paper Velox that consists of a gelatine silver chloride coating and can be created by artificial light.

As recession posed a problem in finding suitable buyers and investors for the product, he joined Leonard Jacobi and set up the 'Nepera Chemical Company' in Yonkers, New York. After a few years in 1899, he sold the rights of the photographic paper, which by that time became a commercial success, to the 'Eastman Kodak Company'. The deal contained a 'non-compete clause' that disallowed him to conduct research in photography at least for the next two decades.

With some of the sale proceeds he bought a family house 'Snug Rock' in North Yonkers and set up a laboratory in the house to continue with his experiments.

Since he could not research in photography he looked into new areas of research. He found that electrochemistry which was earlier restricted to the electro-deposition of some metals from aqueous solution had evolved into a prominent section of chemical industry.

His interest in electrochemistry made him visit Germany in 1900. After spending a winter at the 'Technological Institute of Charlottenburg' in its electrochemical laboratory, he returned to Yonkers and equipped his laboratory with electrochemical devices.

For a short while he aided Elon Huntington Hooker and Clinton Paul Townsend in developing a production-quality electrolytic cell. For the chloralkali process he used iron hydroxide, asbestos fibre and woven cloth of asbestos filled up with a mix of iron oxide in developing an improved diaphragm cell.

His developments were prominent in setting up of the 'Hooker Chemical Company' in 1903 and erection of electrochemical plants at the 'Niagara Falls', one of the biggest such plants around the world.

In 1905 he started researching for a synthetic alternative for shellac, a natural resin created from the excretion of female lac bug. He analysed that precise control of temperature and pressure in combining phenol and formaldehyde can produce a polymer which when mixed with fillers like asbestos or wood develop into a hard mouldable plastic. Thus Bakelite was discovered, the chemical name of which is polyoxybenzylmethylenglycolanhydride.

On December 7, 1909 he obtained a patent of his invention, the Bakelite and in 1910 he established the 'General Bakelite Company'.

The 'Columbia University' through a special appointment inducted him as a professor in 1917. The same year he became the Chairman of the 'National Research Council's' 'Committee on Patents'.

The documents of the County of West Chester Court House in White Plains, New York, that are present in the Smithsonian indicate that on December 16, 1919 he was granted the U.S. Citizenship.

Following a patent litigation that came in favour of Leo Baekeland, two companies namely the 'Redmanol Chemical Products Co.' and the 'Condensite Co.' were merged with his 'General Bakelite Company' to form the 'Bakelite Corporation' in 1922.

In 1924 he became the President of 'American Chemical Society'. His other memberships include that of the 'U.S. Nitrate Supply Commission' and the 'U.S. Naval Consulting Board'. For several years he remained the Trustee of the 'Institute of International Education'.

From 1925 for a few years he remained a member of the 'Advisory Board' of the 'Chemistry Division' at the 'U.S. Department of Commerce'.

He received several honorary doctorates including that of 'University of Pittsburgh' (1916), 'Columbia University' (1929) and 'University of Edinburgh' (1937).

He held several honorary positions and received many awards such as 'Willard Gibbs Medal' (1913), 'Parkin Medal' (1916), 'Messel Medal' (1938) and 'Franklin Medal' (1940).

In 1939 following his disputes with his son over several issues, he sold his business to 'Union Carbide' and retired. He spent the rest of his life attempting to build a tropical garden in 'Coconut Grove', his winter estate in Florida, which became his obsession.

Major Works

His revolutionary invention of Bakelite marked the beginning of an era of plastics. The application of Bakelite proved to be immense and varied. Some earlier products

that used Bakelite include electrical devices, radios, electron tubes, car parts, billiard balls and jewellery. Later it covered many other sections of the industry.

Personal Life & Legacy

He married his professor Theodore Swarts' daughter Céline Swarts on August 8, 1889. The couple had three children - Nina, Jenny and George.

On February 23, 1944, he succumbed to cerebral haemorrhage at a sanatorium in Beacon, NY. He was interred in the 'Sleepy Hollow Cemetery' in Sleepy Hollow, a village in Mount Pleasant, Westchester County, New York.

Trivia

- He was bestowed with the 'Officer of the Legion of Honor' by France and with 'Officer of the Order of the Crown' and 'Commander of the Order of Leopold' by Belgium.
- In Arkon, Ohio, he was included in the 'National Inventors Hall of Fame', posthumously in 1978.

SUMMARY

- Ceramic processing is used to produce commercial products that are very diverse in size, shape, detail, complexity, and material composition, structure, and cost.
- Plastic is the general common term for a wide range of synthetic or semi-synthetic materials used in a huge, and growing, range of applications.
- Molding compounds and resins are industrial plastics and polymers that are suitable for forming.
- Compression molding is the process of manufacturing by using a mold to produce goods.
- Transfer molding is defined as a process during which a specific weight of polymer is placed into a special chamber called a transfer pot.
- Injection molding is the most commonly used method for mass production of plastic products due to its high production rates and good control over the products' dimensions.
- Extrusion molding, or extrusion molding, is the molding of plastic or metals into a pre-defined shape. During the process, metal or plastic is melted and pushed through a die to create a linear form.
- Blow molding is a simple process where compressed air is introduced underneath a warmed sheet of thermoplastic material forcing the material into a mold cavity, or allowing it to expand freely into the shape of a hemisphere.
- Calendaring is used to manufacture thermoplastic sheets and films and to apply plastic coverings to the backs of other materials.
- Rotational molding is a process by which hollow objects can be manufactured from thermoplastics and occasionally thermosets.
- Slush molding is an excellent method of producing open, hollow objects, including rain boots, shoes, toys, dolls and automotive products, such as protective skin coatings on arm rests, head rests and crash pads.

KNOWLEDGE CHECK

1. Which process is used to deposit metals on glass, ceramic and plastic?

a. Silk plating technique

b. Gas plating technique

c. Electro-less plating technique

d. Electroplating technique

2. **How is the process of film deposition carried out in cathode sputtering?**
   a. Slower than evaporation method
   b. Faster than evaporation method
   c. Similar to same as evaporation method
   d. d)All of the mentioned

3. **The following ceramic product is mostly used as pigment in paints**
   a. TiO_2
   b. SiO_2
   c. UO_2
   d. ZrO_2

4. **Most commercial glasses consist of.....**
   a. lime
   b. soda
   c. silica
   d. All of the above

5. **Hot isostatic pressing is not a viable option if the chief criterion is.....**
   a. strength without grain growth
   b. lost cost
   c. zero porosity
   d. processing refractory ceramics

REVIEW QUESTIONS

1. What is plastic? And also discuss its advantages and disadvantages.
2. What do you understand by ingredients of molding compounds?
3. Discuss the different types of molding compounds.
4. Define the ceramic structure and properties.
5. How to process metal matrix and semiconductors?

CHECK THE RESULT

1. (c) 2. (a) 3. (a) 4. (d) 5. (b)

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CHAPTER

6

MATERIAL REMOVAL PROCESSES AND MACHINE TOOLS

LEARNING OBJECTIVES

After studying this chapter, you will be able to:

1. Discuss the mechanics of metal cutting
2. Describe cutting-tool materials
3. Understand gear manufacturing
4. Discuss the machining and grinding of plastics
5. Explain other material removal processes

INTRODUCTION

Machining is a term used to describe a variety of material removal processes in which a cutting tool removes unwanted material from a workpiece to produce the desired shape. The workpiece is typically cut from a larger piece of stock, which is available in a variety of standard shapes, such as flat sheets, solid bars, hollow tubes, and shaped beams. Machining can also be performed on an existing part, such as a casting or forging.

Parts that are machined from a pre-shaped workpiece are typically cubic or cylindrical in their overall shape, but their individual features may be quite complex. Machining can be used to create a variety of features including holes, slots, pockets, flat surfaces, and even complex surface contours. Also, while machined parts are typically

metal, almost all materials can be machined, including metals, plastics, composites, and wood. For these reasons, machining is often considered the most common and versatile of all manufacturing processes.

As a material removal process, machining is inherently not the most economical choice for a primary manufacturing process. Material, which has been paid for, is cut away and discarded to achieve the final part. Also, despite the low setup and tooling costs, long machining times may be required and therefore be cost prohibitive for large quantities. As a result, machining is most often used for limited quantities as in the fabrication of prototypes or custom tooling for other manufacturing processes. Machining is also very commonly used as a secondary process, where minimal material is removed and the cycle time is short. Due to the high tolerance and surface finishes that machining offers, it is often used to add or refine precision features to an existing part or smooth a surface to a fine finish.

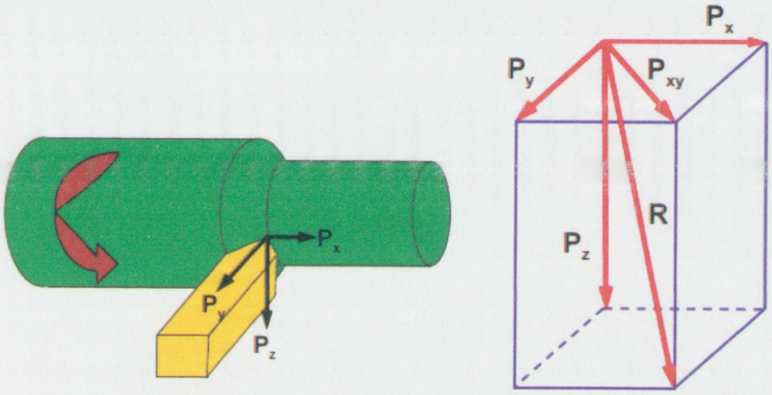
Machining includes a variety of processes that each removes material from an initial workpiece or part. The most common material removal processes, sometimes referred to as conventional or traditional machining, are those that mechanically cut away small chips of material using a sharp tool. Non-conventional machining processes may use chemical or thermal means of removing material. Conventional machining processes are often placed in three categories - single point cutting, multi-point cutting, and abrasive machining. Each process in these categories is uniquely defined by the type of cutting tool used and the general motion of that tool and the workpiece. However, within a given process a variety of operations can be performed, each utilizing a specific type of tool and cutting motion.

6.1 BASIC MECHANICS OF METAL CUTTING

The force acting on a cutting tool during the process of metal cutting are the fundamental importance in the design of cutting tools. The determination of cutting forces necessary for deformation the work material at the shear zone is essential for several important requirements:

- To estimate the power requirements of a machine tool
- To estimate the straining actions that must be resisted by the machine tool components, bearings, jigs and fixtures
- To evaluate the role of various parameters in cutting forces
- To evaluate the performance of any new work material, tool material, environment, techniques etc. with respect to machinability(cutting forces)
- The force system in the general case of conventional turning process is shown in the following figure

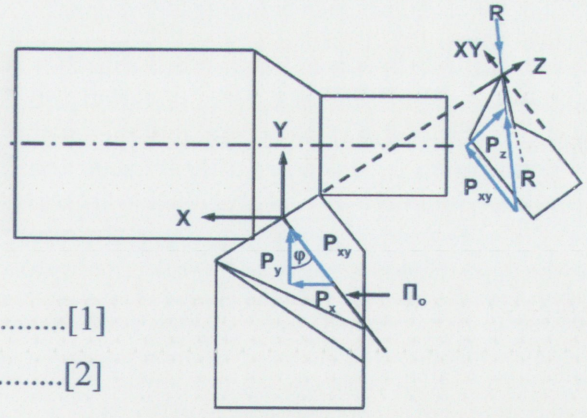
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P_x=Feed force in the direction of the tool travel

P_y=Thrust force in the direction perpendicular to the produced surface

P_z=Cutting force and main force acting in the direction of the cutting velocity.



$$P_x = P_{xy}\sin\varphi \text{.....[1]}$$

$$P_y = P_{xy}\cos\varphi \text{.....[2]}$$

The basic mechanics of chip-type machining processes (Figure 6.1) are shown, in simplest two-dimensional form, in Figure 6.2. A tool with a certain rake angle a (positive as shown) and relief angle moves along the surface of the workpiece at a depth t_1. The material ahead of the tool is sheared continuously along the shear plane, which makes an angle of ϕ with the surface of the workpiece.

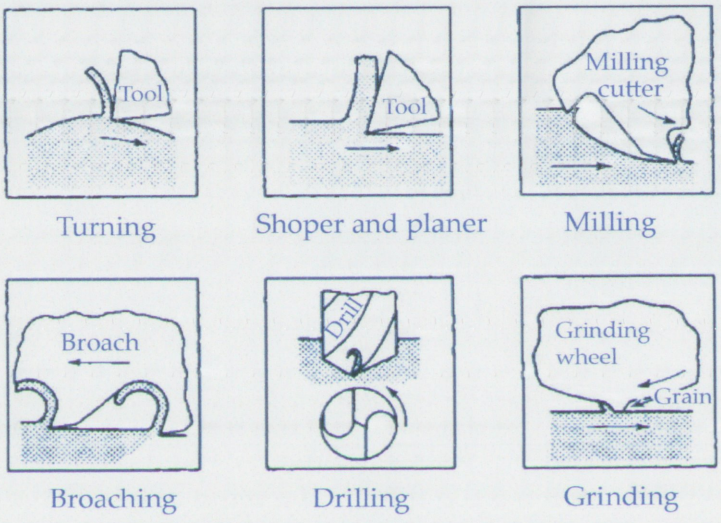


Figure 6.1: Examples of chip-type machining operations.

This angle is called the shear angle and, together with the rake angle, determines the chip thickness t_2. The ratio of t_1 to t_2 is called the cutting ratio r. The relationship between the shear angle, the rake angle, and the cutting ratio is given by the equation tan ϕ 5 r cos α/(1 2 r sin α). It can readily be seen that the shear angle is important in that it controls the thickness of the chip. This, in turn, has great influence on cutting performance. The shear strain that the material undergoes is given by the equation γ 5 cot ϕ 1 tan (ϕ 2 α). Shear strains in metal cutting are usually less than 5.

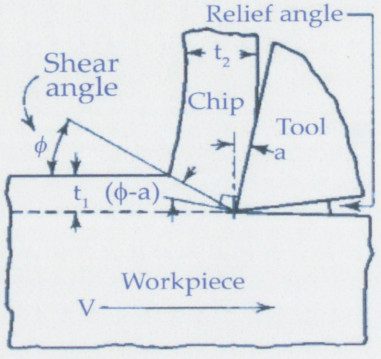


Figure 6.2: Basic mechanics of metal cutting process.

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Investigations have shown that the shear plane may be neither a plane nor a narrow zone, as assumed in simple analysis. Various formulas have been developed which define the shear angle in terms of such factors as the rake angle and the friction angle β. (See Figure 6.3.) Because of the large shear strains that the chip undergoes, it becomes hard and brittle. In most cases, the chip curls away from the tool. Among possible factors contributing to chip curl are non-uniform normal stress distribution on the shear plane, strain hardening, and thermal effects. Regardless of the type of machining operation, some basic types of chips or combinations of these are found in practice (Figure 6.4):

Continuous chips are formed by continuous deformation of the work piece material ahead of the tool, followed by smooth flow of the chip along the tool face. These chips ordinarily are obtained in cutting ductile materials at high speeds. Discontinuous chips consist of segments which are produced by fracture of the metal ahead of the tool. The segments may be either loosely connected to each other or unconnected. Such chips are most often found in the machining of brittle materials or in cutting ductile materials at very low speeds or low or negative rake angles.

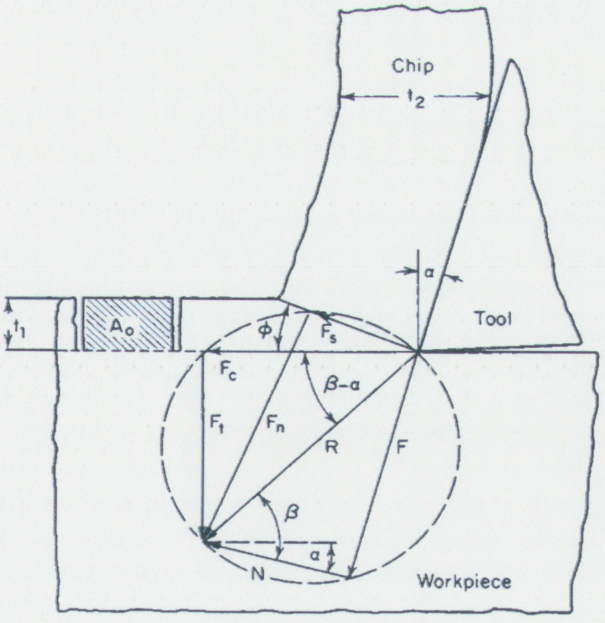


Figure 6.3: Force system in metal cutting process.

Inhomogeneous (serrated) chips consist of regions of large and small strain. Such chips are characteristic of metals with low thermal conductivity or metals whose yield strength decreases sharply with temperature. Chips from titanium alloys frequently

are of this type. ***Built-up edge chips*** consist of a mass of metal which adheres to the tool face while the chip itself flows continuously along the face. This type of chip is often encountered in machining operations at low speeds and is associated with high adhesion between chip and tool and causes poor surface finish.

The forces acting on the cutting tool are shown in Figure 6.3. The resultant force R has two components, F_c and F_t. The cutting force Fc in the direction of tool travel determines the amount of work done in cutting. The thrust force Ft does no work but, together with F_c , produces deflections of the tool. The resultant force also has two components on the shear plane: F_s is the force required to shear the metal along the shear plane, and F_n is the normal force on this plane. Two other force components also exist on the face of the tool: the friction force F and the normal force N. whereas the cutting force F_c is always in the direction shown in Figure 6.3, the thrust force Ft may be in the opposite direction to that shown in the figure. This occurs when both the rake angle and the depth of cut are large, and friction is low from the geometry of Figure 6.3, the following relationships can be derived:

The coefficient of friction at the tool-chip interface is given by:

$\mu = (F_t + F_c \tan \alpha)/(F_c - F_t \tan \alpha)$.

The friction force along the tool is

$F = F_t \cos \alpha + Fc \sin \alpha$.

The shear stress in the shear plane is:

$\tau = (F_c \sin \phi \cos \phi - F_t \sin 2 \phi) / A_0$,

where A_0 is the cross-sectional area that is being cut from the workpiece.

The coefficient of friction on the tool face is a complex but important factor in cutting performance; it can be reduced by such means as the use of an effective cutting fluid, higher cutting speed, improved tool material and condition, or chemical additives in the workpiece material.

The net power consumed at the tool is $P = F_c V$. Since F_c is a function of tool geometry, workpiece material, and process variables, it is difficult reliably to calculate its value in a particular machining operation. Depending on workpiece material and the condition of the tool, unit power requirements in machining range between 0.2 hp?min/in^3 (0.55 W?s/mm^3) of metal removal for aluminum and magnesium alloys, to 3.5 for high-strength alloys. The power consumed is the product of unit power and rate of metal removal: P = (unit power)(vol/min). The power consumed in cutting is transformed mostly to heat. Most of the heat is carried away by the chip, and the remainder is divided between the tool and the workpiece. An increase in cutting speed or feed will increase the proportion of the heat transferred to the chip. It has been observed that, in turning, the average interface temperature between the tool and the chip increases with cutting speed and feed, while the influence of the depth of cut on temperature has been found to be limited. Interface temperatures to the range of 1,500

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to 2,000°F (800 to 1,100°C) have been measured in metal cutting. Generally, the use of a cutting fluid removes heat and thus avoids temperature buildup on the cutting edge. In cutting metal at high speeds, the chips may become very hot and cause safety hazards because of long spirals which whirl around and become entangled with the tooling. In such cases, chip breakers are introduced on the tool geometry, which curl the chips and cause them to break into short sections. Chip breakers can be produced on the face of the cutting tool or insert, or are separate pieces clamped on top of the tool or insert.

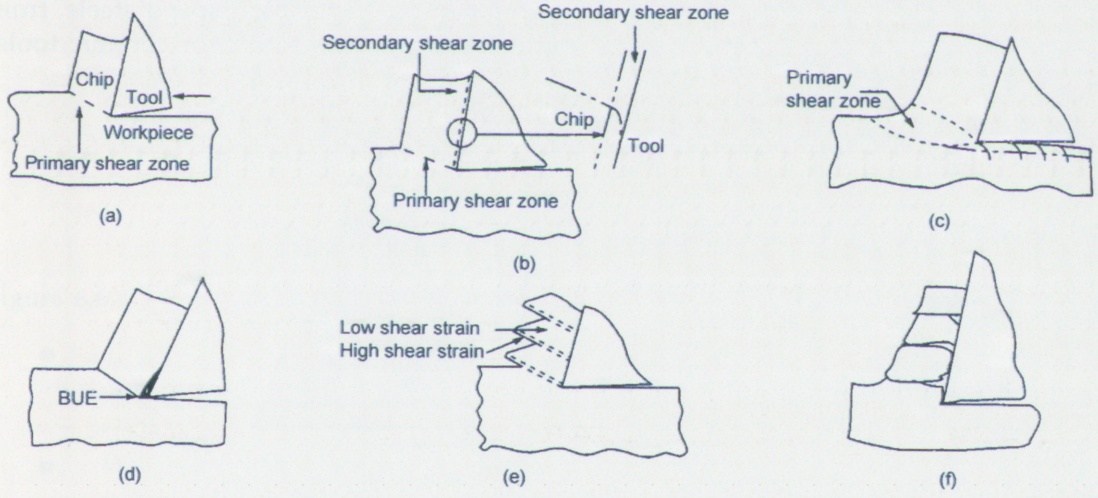


Figure 6.4: Basic types of chips produced in metal cutting: (a) continuous chip with narrow, straight primary shear zone; (b) secondary shear zone at the tool-chip interface; (c) continuous chip with large primary shear zone; (d) continuous chip with built-up edge; (e) segmented or nonhomogeneous chip, (f) discontinuous chip.

A factor of great significance in metal cutting is tool wear. Many factors determine the type and rate at which wear occurs on the tool. The major critical variables that affect wear are tool temperature, type and hardness of tool material, grade and condition of workpiece, abrasiveness of the microconstituents in the workpiece material, tool geometry, feed speed, and cutting fluid. The type of wear pattern that develops depends on the relative role of these variables. Tool wear can be classified as (1) flank wear (Figure 6.5); (2) crater wear on the tool face; (3) localized wear, such as the rounding of the cutting edge; (4) chipping or thermal softening and plastic flow of the cutting edge; (5) concentrated wear resulting in a deep groove at the edge of a turning tool, known as wear notch. In general, the wear on the flank or relief side of the tool is the most dependable guide for tool life. A wear land of 0.060 in (1.5 mm) on high-speed steel tools and 0.015 or 0.030 in (0.4 or 0.8 mm) for carbide tools is usually used as the endpoint. The cutting speed is the variable which has the greatest influence on tool life. The relationship between tool life and cutting speed is given by the Taylor

equation $VT^n = C$, where V is the cutting speed; T is the actual cutting time to develop a certain wear land, min; C is a constant whose value depends on workpiece material and process variables, numerically equal to the cutting speed that gives a tool life of 1 min; and n is the exponent whose value depends on workpiece material and other process variables. The recommended cutting speed for a high-speed steel tool is generally the one which produces a 60 to 120-min tool life. With carbide tools, a 30 to 60-min tool life may be satisfactory. Values of n range from 0.08 to 0.2 for high-speed steels, from 0.2 to 0.5 for carbides, and from 0.5 to 0.7 for ceramic tools.

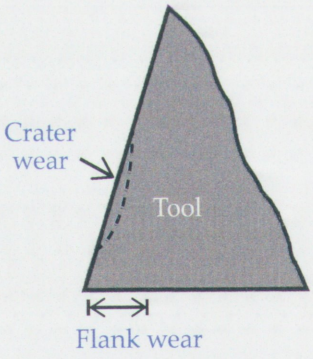


Figure 6.5: Types of tool wear in cutting.



REMEMBER

Cutting tools must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal-cutting process.

6.2 CUTTING-TOOL MATERIALS

The cutting tool materials must possess a number of important properties to avoid excessive wear, fracture failure and high temperatures in cutting. The following characteristics are essential for cutting materials to withstand the heavy conditions of the cutting process and to produce high quality and economical parts:

- *Hardness:* At elevated temperatures (so-called hot hardness) so that hardness and strength of the tool edge are maintained in high cutting temperatures:

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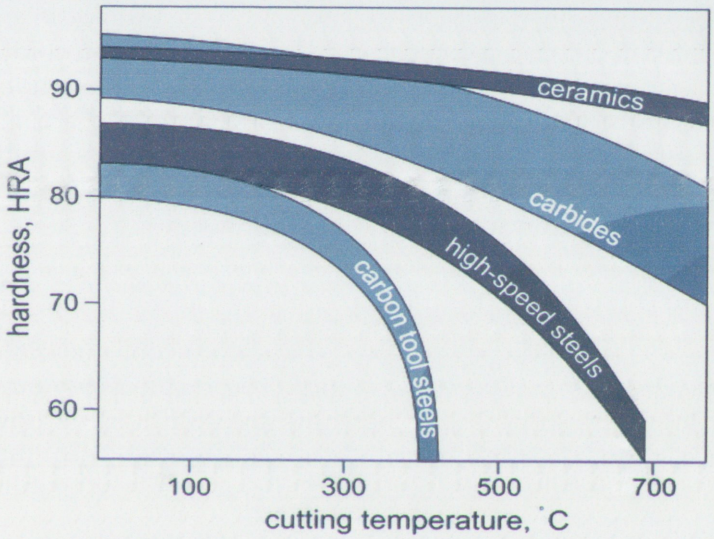


Figure 6.6: Hot hardness for different tool materials

- *Toughness*: Ability of the material to absorb energy without failing. Cutting if often accompanied by impact forces especially if cutting is interrupted, and cutting tool may fail very soon if it is not strong enough.
- *Wear resistance*: Although there is a strong correlation between hot hardness and wear resistance, later depends on more than just hot hardness. Other important characteristics include surface finish on the tool, chemical inertness of the tool material with respect to the work material, and thermal conductivity of the tool material, which affects the maximum value of the cutting temperature at tool-chip interface.

6.2.1 Uses of Common Cutting Tool Material

Carbon Steels

It is the oldest of tool material. The carbon content is 0.6~1.5% with small quantities of silicon, chromium, manganese, and vanadium to refine grain size. Maximum hardness is about HRC 62. This material has low wear resistance and low hot hardness. The use of these materials now is very limited.

High-Speed Steel (HSS)

First produced in 1900s. They are highly alloyed with vanadium, cobalt, molybdenum,

tungsten and chromium added to increase hot hardness and wear resistance. Can be hardened to various depths by appropriate heat treating up to cold hardness in the range of HRC 63-65. The cobalt component give the material a hot hardness value much greater than carbon steels. The high toughness and good wear resistance make HSS suitable for all type of cutting tools with complex shapes for relatively low to medium cutting speeds. The most widely used tool material today for taps, drills, reamers, gear tools, end cutters, slitting, broaches, etc.

Cemented Carbides

Introduced in the 1930s. These are the most important tool materials today because of their high hot hardness and wear resistance. The main disadvantage of cemented carbides is their low toughness. These materials are produced by powder metallurgy methods, sintering grains of tungsten carbide (WC) in a cobalt (Co) matrix (it provides toughness). There may be other carbides in the mixture, such as titanium carbide (TiC) and/or tantalum carbide (TaC) in addition to WC.

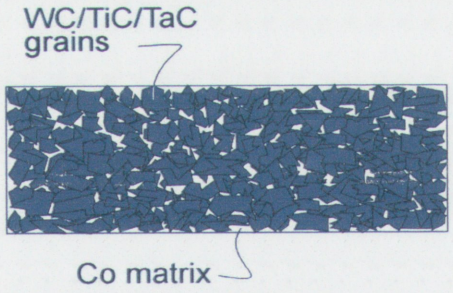


Figure 6.7: Microstructure of cemented carbides



In spite of more traditional tool materials, cemented carbides are available as inserts produced by powder metalurgy process. Inserts are available in various shapes, and are usually mechanically attached by means of clamps to the tool holder, or brazed to the tool holder (see the figure in the next page). The clamping is preferred because after a cutting edge gets worn, the insert is indexed (rotated in the holder) for another cutting edge. When all cutting edges are worn, the insert is thrown away. The indexable carbide inserts are never reground. If the carbide insert is brazed to the tool holder, indexing is not available, and after reaching the wear criterion, the carbide insert is reground on a tool grinder.

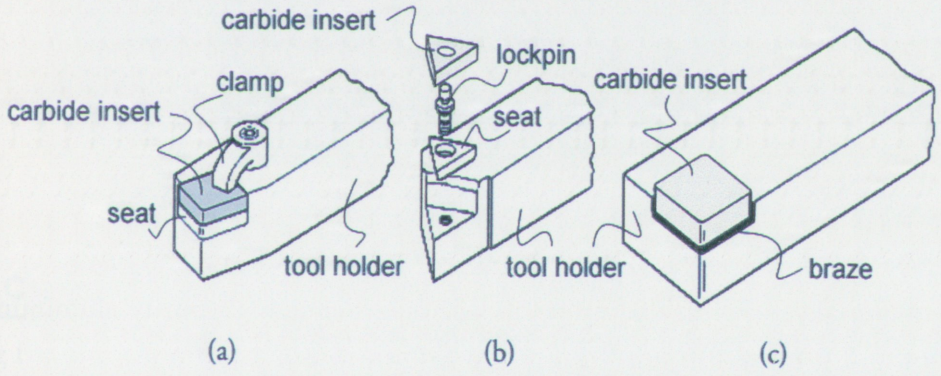


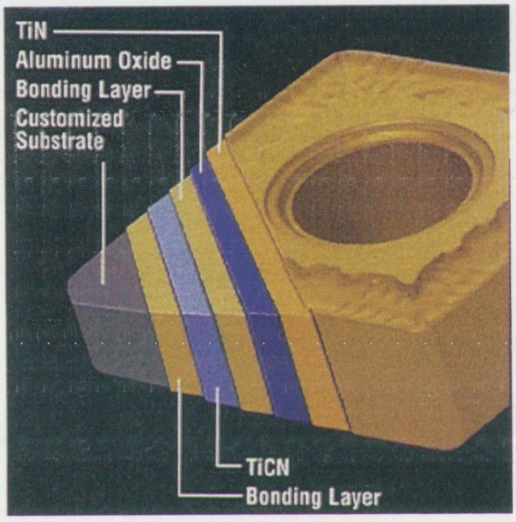
Figure 6.8: Methods of attaching carbide inserts to tool holder: (a) clamping; (b) wing lockpins; and (c) brazing.

The ISO specifies three basic grades for cemented carbides according to use:

SYMBOL	COMPOSITION	WORK MATERIAL	COLOUR†	DESIGNATION
P	WC + TiC	Low-carbon, stainless and other steels	Blue	P01, P10, ... P50
M	WC + TiC + TaC	For all types of materials, especially difficult-to-cut materials	Yellow	M10, M20, ... M40
K	WC	Cast iron, non-ferrous metals, non-metallic materials	Red	K01, K10, ... K40

† Colour of the tool holder for brazed cutting tools

One advance in cutting tool materials involves the application of a very thin coating (~ 10 μm) to a K-grade substrate, which is the toughest of all carbide grades. Coating may consists of one or more thin layers of wear-resistant material, such as titanium carbide (TiC), titanium nitride (TiN), aluminum oxide (Al_2O_3), and/or other, more advanced materials. Coating allows to increase significantly the cutting speed for the same tool life.



Ceramics

Ceramic materials are composed primarily of fine-grained, high-purity aluminum oxide ($Al_2 O_3$), pressed and sintered with no binder.

Two types are available:

- White, or cold-pressed ceramics, which consists of only $Al_2 O_3$ cold pressed into inserts and sintered at high temperature.
- Black, or hot-pressed ceramics, commonly known as cermet (from ceramics and metal). This material consists of 70% $Al_2 O_3$ and 30% TiC.

Both materials have very high wear resistance but low toughness, therefore they are suitable only for continuous operations such as finishing turning of cast iron and steel at very high speeds. There is no occurrence of built-up edge, and coolants are not required.

Cubic Boron Nitride (CBN) and Synthetic Diamonds

Diamond is the hardest substance ever known of all materials. It is used as a coating material in its polycrystalline form, or as a single-crystal diamond tool for special applications, such as mirror finishing of non-ferrous materials. Next to diamond, CBN is the hardest tool material. CBN is used mainly as coating material because it is very brittle. In spite of diamond, CBN is suitable for cutting ferrous materials.



6.2.2 Cutting Fluids

Cutting fluids, frequently referred to as lubricants or coolants, comprise those liquids and gases which are applied to the cutting zone in order to facilitate the cutting operation.

A cutting fluid is used:

- To keep the tool cool and prevent it from being heated to a temperature at which the hardness and resistance to abrasion are reduced;
- To keep the workpiece cool, thus preventing it from being machined in a warped shape to inaccurate final dimensions;
- Through lubrication to reduce the power consumption, wear on the tool, and generation of heat;
- To provide a good finish on the workpiece;
- To aid in providing a satisfactory chip formation;
- To wash away the chips (this is particularly desirable in deep-hole drilling, hacksawing, milling, and grinding); and
- To prevent corrosion of the workpiece and machine tool

Classification of Cutting Fluids

Cutting fluids may be classified as follows:

(1) Air blast,

(2) Emulsions,

(3) Oils, and

(4) Solutions.

Cutting fluids are also classified as light-, medium-, and heavy-duty; light-duty fluids are for general-purpose machining.

Air Blast: Induced air blast may be used with internal and surface grinding and polishing operations. Its main purpose is to remove the small chips or dust, although some cooling is also obtained, especially in machining of plastics.

Emulsions: It consist of a soluble oil emulsified with water in the ratio of 1 part oil to 10 to 100 parts water, depending upon the type of product and the operation. Emulsions have surface-active or extreme-pressure additives to reduce friction and provide an effective lubricant film under high pressure at the tool-chip interface during machining. Emulsions are low-cost cutting fluids and are used for practically all types of cutting and grinding when machining all types of metals. The more concentrated mixtures of oil and water, such as 1:10, are used for broaching, threading, and gear cutting. For most operations, a solution of 1 part soluble oil to 20 parts water is satisfactory.

Oils: A variety of oils are used for metal cutting. They are used where lubrication rather than cooling is essential or on high-grade finishing cuts, although sometimes superior finishes are obtained with emulsions.

Oils generally used in machining are mineral oils with the following compositions:

(1) Straight mineral oil,

(2) With fat,

(3) With fat and sulfur,

(4) With fat and chlorine, and

(5) With fat, sulfur, and chlorine.

The more severe the machining operation, the higher the composition of the oil. Broaching and tapping of refractory alloys and high-temperature alloys, for instance, require highly compounded oils. In order to avoid staining of the metal, aluminum and copper, for example, inhibited sulfur and chlorine are used.

Solutions: Solutions are a family of cutting fluids that blend water and various chemical agents such as amines, nitrites, nitrates, phosphates, chlorine, and sulfur compounds. These agents are added for purposes of rust prevention, water softening, lubrication, and reduction of surface tension. Most of these chemical fluids are coolants but some are lubricants. The selection of a cutting fluid for a particular operation requires consideration of several factors: the workpiece material, the difficulty of the machining operation, the compatibility of the fluid with the workpiece material and the machine tool components, surface preparation, method of application and removal of

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the fluid, contamination of the cutting fluid with machine lubricants, and the treatment of the fluid after use. Also important are the biological and ecological aspects of the cutting fluid used. There may be potential health hazards to operating personnel from contact with or inhalation of mist or fumes from some fluids. Recycling and waste disposal are also important problems to be considered.

Methods of Application

The most common method is flood cooling in quantities such as 3 to 5 gal/min (about 10 to 20 L/min) for single point tools and up to 60 gal/min (230 L/min) per cutter for multiple tooth cutters. Whenever possible, multiple nozzles should be used. In mist cooling a small jet equipment is used to disperse water-base fluids as very fine droplets in a carrier that is generally air at pressures 10 to 80 lb/in^2 (70 to 550 kPa). Mist cooling has a number of advantages, such as providing high-velocity fluids to the working areas, better visibility, and improving tool life in certain instances. The disadvantages are that venting is required and also the cooling capability is rather limited.

6.2.3 Machine Tools

The general types of machine tools are lathes; turret lathes; screw, boring, drilling, reaming, threading, milling, and gear-cutting machines; planers and shapers; broaching, cutting-off, grinding, and polishing machines. Each of these is subdivided into many types and sizes. General items common to all machine tools are discussed first, and individual machining processes and equipment are treated later in this section. Automation is the application of special equipment to control and perform manufacturing processes with little or no manual effort. It is applied to the manufacturing of all types of goods and processes, from the raw material to the finished product. Automation involves many activities, such as handling, processing, assembly, inspecting, and packaging. Its primary objective is to lower manufacturing cost through controlled production and quality, lower labor cost, reduced damage to work by handling, higher degree of safety for personnel, and economy of floor space. Automation may be partial, such as gaging in cylindrical grinding, or it may be complete. The conditions which play a role in decisions concerning automation are rising production costs, high percentage of rejects, lagging output, scarcity of skilled labor, hazardous working conditions, and work requiring repetitive operation. Factors which must be carefully studied before deciding on automation are high initial cost of equipment, maintenance problems, and type of product.

Mass production with modern machine tools has been achieved through the development of self-contained power-head production units and the development of transfer mechanisms. Power-head units, consisting of a frame, electric driving motor, gearbox, tool spindles, etc., are available for many types of machining operations. Transfer mechanisms move the workpieces from station to station by various methods.

Transfer-type machines can be arranged in several configurations, such as a straight line or a U pattern. Various types of machine tools for mass production can be built from components; this is known as the building block principle. Such a system combines flexibility and adaptability with high productivity. Numerical control (NC), which is a method of controlling the motions of machine components by numbers, was first applied to machine tools in the 1950s. Numerically controlled machine tools are classified according to the type of cutting operation. For instance, in drilling and boring machines, the positioning and the cutting take place sequentially (point to point), whereas in die-sinking machines, positioning and cutting take place simultaneously. The latter are often described as continuous-path machines, and since they require more exacting specifications, they give rise to more complex problems. Machines now perform over a very wide range of cutting conditions without requiring adjustment to eliminate chatter, and to improve accuracy. Complex contours can be machined which would be almost impossible by any other method. A large variety of programming systems has been developed. The control system in NC machines has been converted to computer control with various software. In computer numerical control (CNC), a microcomputer is a part of the control panel of the machine tool. The advantages of computer numerical control are ease of operation, simpler programming, greater accuracy, versatility, and lower maintenance costs. Although, numerical control of machine tools has many advantages such as high productivity and flexibility, it has certain limitations. Among these are high initial cost of equipment and the need for trained personnel and special maintenance. Further developments in machine tools are machining centers. This is a machine equipped with as many as 200 tools and with an automatic tool changer (Figure 6.9). It is designed to perform various operations on different surfaces of the workpiece, which is placed on a pallet capable of as much as five-axis movement (three linear and two rotational). Machining centers, which may be vertical or horizontal spindle, have flexibility and versatility that other machine tools do not have, and thus they have become the first choice in machine selection in modern manufacturing plants and shops. They have the capability of tool and part checking, tool-condition monitoring, in-process and post process gaging, and inspection of machined surfaces. Universal machining centers are the latest development, and they have both vertical and horizontal spindles. Turning centers are a further development of computer controlled lathes and have great flexibility. Many centers are now constructed on a modular basis, so that various accessories and peripheral equipment can be installed and modified depending on the type of product to be machined.

An approach to optimize machining operations is adaptive control. While the material is being machined, the system senses operating conditions such as forces, tool-tip temperature, rate of tool wear, and surface finish, and converts these data into feed and speed control that enables the machine to cut under optimum conditions for maximum productivity. Combined with numerical controls and computers, adaptive controls are expected to result in increased efficiency of **metalworking** operations.

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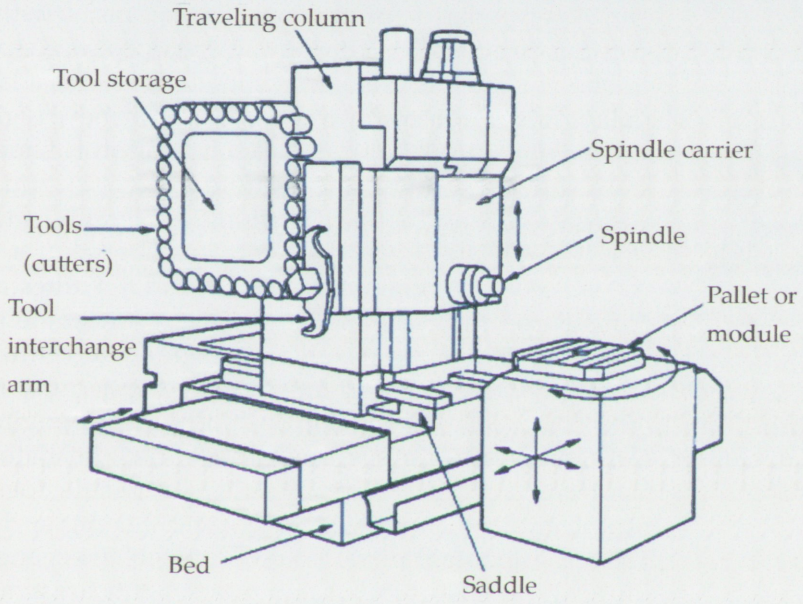


Figure 6.9: Schematic of a horizontal spindle machining center, equipped with an automatic tool changer.

With the advent of sophisticated computers and various software, modern manufacturing has evolved into computer-integrated manufacturing (CIM). This system involves the coordinated participation of computers in all phases of manufacturing. Computer-aided design combined with computer-aided manufacturing (CAD/CAM), results in a much higher productivity, better accuracy and efficiency, and reduction in design effort and prototype development. CIM also involves the management of the factory, inventory, and labor, and it integrates all these activities, eventually leading to untended factories.

The highest level of sophistication is reached with a flexible manufacturing system (FMS). Such a system is made of manufacturing cells and an automatic materials-handling system interfaced with a central computer. The manufacturing cell is a system in which CNC machines are used to make a specific part or parts with similar shape. The workstations, i.e., several machine tools, are placed around an industrial robot which automatically loads, unloads, and transfers the parts. FMS has the capability to optimize each step of the total manufacturing operation, resulting in the highest possible level of efficiency and productivity.

6.2.4 Turning

Turning is a machining operation for all types of metallic and nonmetallic materials



Metalworking is the process of working with metals to create individual parts, assemblies, or large-scale structures.

and is capable of producing circular parts with straight or various profiles. The cutting tools may be single-point or form tools. The most common machine tool used is a lathe; modern lathes are computer-controlled and can achieve high production rates with little labor. The basic operation is shown in Figure 6.10, where the workpiece is held in a chuck and rotates at N r/min; a cutting tool moves along the length of the piece at a feed f (in/r or mm/r) and removes material at a radial depth d, reducing the diameter from D_0 to D_f. Lathes are generally considered to be the oldest member of machine tools, having been first developed in the late eighteenth century. The most common lathe is called an engine lathe because it was one of the first machines driven by Watt's steam engine. The basic lathe has the following main parts: bed, headstock, tailstock, and carriage. The types of lathes available for a variety of applications may be listed as follows: engine lathes, bench lathes, horizontal turret lathes, vertical lathes, and automatics. A great variety of lathes and attachments are available within each category, also depending on the production rate required. It is common practice to specify the size of an engine lathe by giving the swing (diameter) and the distance between centers when the tailstock is flush with the end of the bed. The maximum swing over the ways is usually greater than the nominal swing. The length of the bed is given frequently to specify the overall length of the bed. A lathe size is indicated thus: 14 in (356 mm) (swing) by 30 in (762 mm) (between centers) by 6 ft (1,830 mm) (length of bed). Lathes are made for light-, medium-, or heavy-duty work. Geometric progression is used extensively in designing machine-tool feeds and speeds. Feeds in geometric progression are used on cylindrical grinders, boring mills, milling machines, drilling machines, etc.; but for screw-cutting lathes, the power feeds for thread cutting and turning must be in proportion to the pitch of threads to be cut. All geared-head lathes, which are single-pulley (belt-driven or arranged for direct-motor drive through short, flat, or V belts, gears, or silent chain), increase the power of the drive and provide a means for obtaining 8, 12, 16, or 24 spindle speeds. The teeth may be of the spur, helical, or herringbone type and may be ground or lapped after hardening

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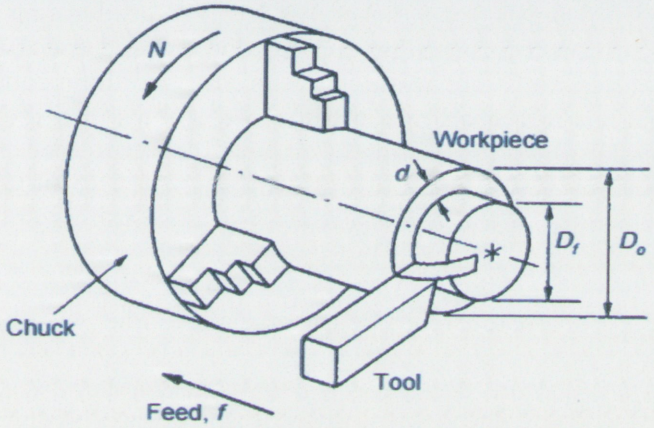


Figure 6.10: A turning operation on a round workpiece held in a three-jaw chuck.

Variable speeds are obtained by driving with adjustable-speed dc shunt-wound motors with stepped field-resistance control or by electronics or motor-generator system to give speed variation in infinite steps. AC motors driving through infinitely variable speed transmissions of the mechanical or hydraulic type are also in general use. Modern lathes, many of which are now computer-controlled (turning centers), are built with the speed capacity, stiffness, and strength capable of taking full advantage of new and stronger tool materials. The main drive-motor capacity of lathes ranges from fractional to more than 200 hp (150 kW). Speed preselectors, which give speed as a function of work diameter, are introduced, and variable-speed drives using dc motors with panel control are standard on many lathes.

Tool Shapes for Turning

The standard nomenclature for single-point tools, such as those used on lathes, planers, and shapers, is shown in Figure 6.11. Each tool consists of a shank and point. The point of a single-point tool may be formed by grinding on the end of the shank; it may be forged on the end of the shank and subsequently ground; a tip or insert may be clamped or brazed to the end of the shank. The best tool shape for each material and each operation depends on many factors.

Positive rake angles improve the cutting operation with regard to forces and deflection; however, a high positive rake angle may result in early failure of the cutting edge. Positive rake angles are generally used in lower-strength materials. For higher-strength materials, negative rake angles may be used. Back rake usually controls the direction of chip flow and is of less importance than the side rake. The purpose of relief angles is to avoid interference and rubbing between the workpiece and tool flank surfaces. In general, they should be small for high-strength materials

and larger for softer materials. Excessive relief angles may weaken the tool. The side cutting-edge angle influences the length of chip contact and the true feed. This angle is often limited by the workpiece geometry, e.g., the shoulder contour. Large angles are apt to cause tool chatter. Small end cutting-edge angles may create excessive force normal to the workpiece, and large angles may weaken the tool point. The purpose of the nose radius is to give a smooth surface finish and to obtain longer tool life by increasing the strength of the cutting edge. The nose radius should be tangent to the cutting-edge angles. A large nose radius gives a stronger tool and may be used for roughing cuts; however, large radii may lead to tool chatter. A small nose radius reduces forces and is therefore preferred on thin or slender workpieces.

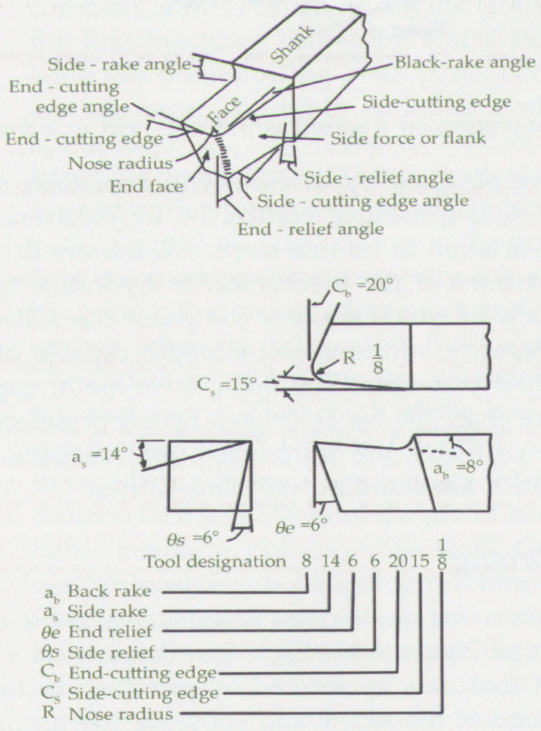


Figure 6.11: Standard nomenclature for single-point cutting tools

6.2.5 Turret Lathes

Turret lathes are used for the production of parts in moderate quantities and produce interchangeable parts at low production cost. Turret lathes may be chucking, screw machine, or universal. The universal machine may be set up to machine bar stock as

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a screw machine or have the work held in a chuck. These machines may be semiautomatic, i.e., so arranged that after a piece is chucked and the machine started, it will complete the machining cycle automatically and come to a stop. They may be horizontal or vertical and single- or multiple-spindle; many of these lathes are now computer-controlled and have a variety of features.

The basic principle of the turret lathe is that, with standard tools, setups can be made quickly so that combined, multiple, and successive cuts can be made on a part. By combined cuts, tools on the cross slide operate simultaneously with those on the turret, e.g., facing from the cross slide and boring from the turret. Multiple cuts permit two or more tools to operate from either or both the cross slide or turret. By successive cuts, one tool may follow another to rough or finish a surface; e.g., a hole may be drilled, bored, and reamed at one chucking. In the tool-slide machine only roughing cuts, such as turn and face, can be made in one machine. A second machine similarly tooled must be available to make the finishing cuts.



Turret Lathe is a form of metalworking lathe that is used for repetitive production of duplicate parts, which by the nature of their cutting process are usually interchangeable.

Ram-type turret lathes have the turret mounted on a ram which slides in a separate base. The base is clamped at a position along the bed to suit a long or short workpiece. A cross slide can be used so that combined cuts can be taken from the turret and the cross slide at the same time. Turret and cross slide can be equipped with manual or power feed. The short stroke of the turret slide limits this machine to comparatively short light work, in both small and quantity-lot production.

Saddle-type turret lathes have the turret mounted on a saddle which slides directly on the bed. Hence, the length of stroke is limited only by the length of bed. A separate square-turret carriage with longitudinal and transverse movement can be mounted between the head and the hex-turret saddle so that combined cuts from both stations at one time are possible. The saddle type of **turret lathe** generally has a large hollow vertically faced turret for accurate alignment of the tools.

6.2.6 Boring

Boring is a machining process for producing internal straight cylindrical surfaces or profiles, with process characteristics

and tooling similar to those for turning operations.

- ***Boring Machines***: These are of two general types, horizontal and vertical, and are frequently referred to as horizontal boring machines and vertical boring and turning mills. A classification of boring machines comprises horizontal boring, drilling, and milling machines; vertical boring and turning mills; vertical multispindle cylinder boring mills; vertical cylinder boring mills; vertical turret boring mills (vertical turret lathes); carwheel boring mills; diamond or precision boring machines (vertical and horizontal); and jig borers.
- *The horizontal type* is made for both precision work and general manufacturing. It is particularly adapted for work not conveniently revolved, for milling, slotting, drilling, tapping, boring, and reaming long holes, and for making interchangeable parts that must be produced without jigs and fixtures. The machine is universal and has a wide range of speeds and feeds, for a face-mill operation may be followed by one with a small-diameter drill or end mill.
- *Vertical boring mills* are adapted to a wide range of faceplate work that can be revolved. The advantage lies in the ease of fastening a workpiece to the horizontal table, which resembles a four-jaw independent chuck with extra radial T slots, and in the lessened effect of centrifugal forces arising from unsymmetrically balanced workpieces.
- ***Jig-Boring Machine***: It has a single-spindle sliding head mounted over a table adjustable longitudinally and transversely by lead screws which roughly locate the work under the spindle. Precision setting of the table may be obtained with end measuring rods, or it may depend only on the accuracy of the lead screw. These machines, made in various sizes, are used for accurately finishing holes and surfaces in definite relation to one another. They may use drills, rose or fluted reamers, or single-point boring tools. The latter are held in an adjustable boring head by which the tool can be moved eccentrically to change the diameter of the hole.
- ***Precision-boring Machines***: It may have one or more spindles operating at high speeds for the purpose of boring to accurate dimensions such surfaces as wrist-pin holes in pistons and connecting-rod bushings.

6.2.7 Threading

Threads may be formed on the outside or inside of a cylinder or cone:

(1) With single-point threading tools,

(2) With threading chasers,

(3) With taps,

(4) With dies,

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(5) By thread milling,

(6) By thread rolling, and

(7) By grinding.

There are numerous types of taps, such as hand, machine screw, pipe, and combined pipe tap and drill. Small taps usually have no radial relief. They may be made in two, three, or four flutes. Large taps may have still more flutes. The feed of a tap depends upon the lead of the screw thread. The cutting speed depends upon numerous factors: Hard tough materials, great length of hole, taper taps, and full-depth thread reduce the speed; long chamfer, fine pitches, and a cutting fluid applied in quantity increase the speed. Taps are cut or formed by grinding. The ground-thread taps may operate at much higher speeds than the cut taps. Speeds may range from 3 ft/min (1 m/min) for high-strength steels to 150 ft/min (45 m/min) for aluminum and magnesium alloys. Common high-speed steel tool materials for taps are M1, M7, and M10. Threading dies, used to produce external threads, may be solid, adjustable, spring-adjustable, or self-opening die heads. Replacement chasers are used in die heads and may be of the fixed or self-opening type. These chasers may be of the radial type, hobbed or milled; of the tangenital type; or of the circular type. Emulsions and oils are satisfactory for most threading operations.

6.2.8 Milling

Milling is one of the most versatile machining processes and is capable of producing a variety of shapes involving flat surfaces, slots, and contours (Figure 6.12).

Milling machines use cutters with multiple teeth in contrast with the single-point tools of the lathe and planer. The workpiece is generally fed past the cutter perpendicular to the cutter axis. Milling usually is face or peripheral cutting.

Standard Spindle Noses and Arbors for Milling Machines: It provide interchangeability of arbors and face-milling cutters, regardless of make or size of machine. The taper of the spindle end and arbor is $3^{1/2}$ in/ft, to make them self-releasing. The retention of the shank is dependent upon a positive locking device, such as screws or draw-in bolt. When unlocked, these tapers release themselves.

Milling-machine classification is based on design, operation, or purpose.

- *Knee-and-column* type milling machines have the table and saddle supported on the vertically adjustable knee gibbed to the face of the column. The table is fed longitudinally on the saddle, and the latter transversely on the knee to give three feeding motions. Knee-type machines are made with horizontal or vertical spindles. The horizontal universal machines have a swiveling table for cutting helices. The plain machines are used for jobbing or production work, the universal for tool room work. Vertical milling machines with fixed or sliding heads are otherwise similar to the horizontal type. They are used

for face or end milling and are frequently provided with a rotary table for making cylindrical surfaces. The fixed-bed machines have a spindle mounted in a head dovetailed to and sliding on the face of the column. The table rests directly on the bed. They are simple and rigidly built and are used primarily for high production work. These machines are usually provided with work-holding fixtures and may be constructed as plain or multiple-spindle machines, simple or duplex.

- *Rotary-type* millers usually have a rotating table on which fixtures carrying the workpiece are mounted. The cutter spindles are mounted over the edge of the table past which the workpiece is fed.
- *Drum-type* millers consist of a drum carrying the work and rotating on a horizontal axis. Both rotary and drum types are mass-production machines, there being no idle time, for the drums rotate continuously while the parts, loaded on one side of the machine, pass first the roughing and then the finishing cutters and are replaced when they return to the loading position.
- *Planer-type* millers are used only on the heaviest work. They are used to machine a number of surfaces on a particular part or group of parts arranged in series in fixtures on the table.

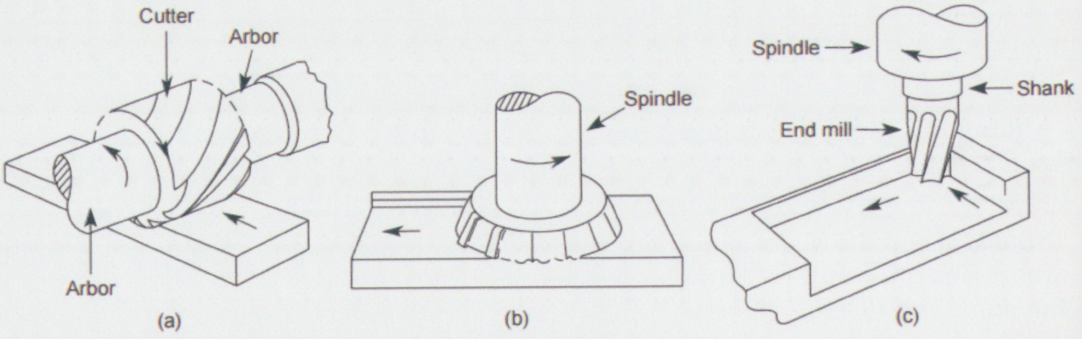


Figure 6.12: Basic types of milling cutters and operations. (a) Slab (peripheral) milling; (b) face milling; (c) end milling.

Milling Cutters

Milling cutters are made in a wide variety of shapes and sizes. The nomenclature of tooth parts and angles is standardized as in Figure 6.13. Milling cutters may be classified in various ways, such as purpose or use of the cutters (Woodruff keyseat cutters, T-slot cutters, gear cutters, etc.); construction characteristics (solid cutters,

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carbidetipped cutters, etc.); method of mounting (arbor type, shank type, etc.); and relief of teeth. The latter has two categories: profile cutters which produce flat, curved, or irregular surfaces, with the cutter teeth sharpened on the land; and formed cutters which are sharpened on the face to retain true cross-sectional form of the cutter. Two kinds of milling are generally considered to represent all forms of milling processes: peripheral (slab) and face milling. In the peripheral milling process the axis of the cutter is parallel to the surface milled, whereas in face milling, the cutter axis is generally at a right angle to the surface. The peripheral-milling process is also divided into two types: conventional (up) milling and climb (down) milling. Each has its advantages, and the choice depends on a number of factors such as the type and condition of the equipment, tool life, surface finish, and machining parameters.

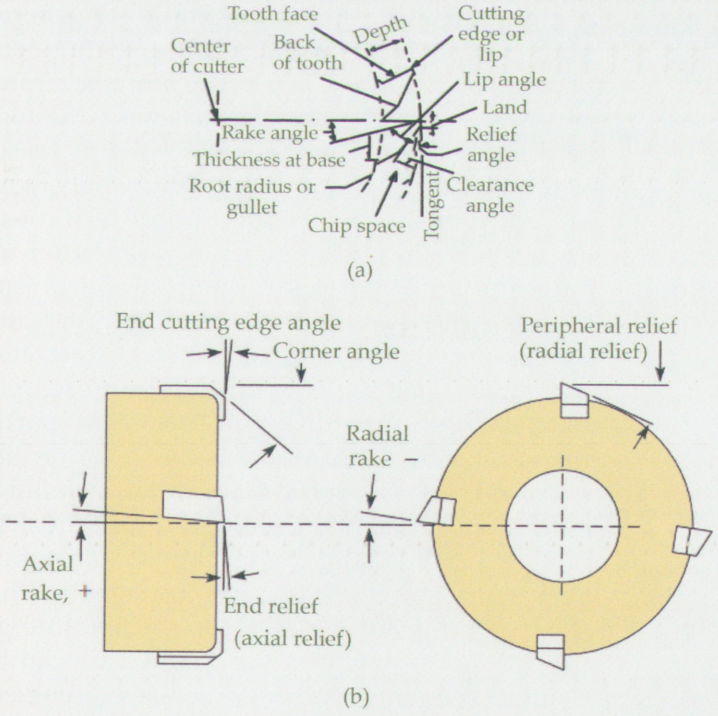


Figure 6.13: (a) Plain milling cutter teeth; (b) face milling cutter.

6.3 GEAR MANUFACTURING

Gear manufacturing is the process of making gears out of different types of material, including steels, alloys, plastics, and other metals. Many different products and industries

make use of gears. Small gears can be used in small electronics, medical devices, tool kits, and exercise equipment. Large gears are often used in heavy, industrial machinery, cars, airplanes, and more. As these components are needed all across the world, gear manufacturing is a large industry.

Gear cutting processes can be classified as either forming or generating. In a forming process, the shape of the tool is reproduced on the workpiece; in a generating process, the shape produced on the workpiece depends on both the shape of the tool and the relative motion between the tool and the workpiece during the cutting operation. A soft live center on a lathe can be formed by means of a broad, flat-form tool fed at right angles to the lathe spindle, or generated by a single-point tool fed at the point angle in the compound rest. In general, a generating process is more accurate than a forming process. In the form cutting of gears, the tool has the shape of the space between the teeth. For this reason, form cutting will produce precise tooth profiles only when the cutter is accurately made and the tooth space is of constant width, such as on spur and helical gears. A form cutter may cut or finish one of or all the spaces in one pass. Single-space cutters may be disk-type or end-mill-type milling cutters. In all single-space operations, the gear blank must be retracted and indexed, i.e., rotated one tooth space, between each pass. Single-space form milling with disk-type cutters is particularly suitable for gears with large teeth, because, as far as metal removal is concerned, the cutting action of a milling cutter is more efficient than that of the tools used for generating. Form milling of spur gears is done on machines that retract and index the gear blank automatically. For the same tooth size (pitch), the shape (profile) of the teeth on an involute gear depends on the number of teeth on the gear. Gears can be manufactured by most of manufacturing processes discussed so far (casting, forging, extrusion, powder metallurgy, blanking). But as a rule, machining is applied to achieve the final dimensions, shape and surface finish in the gear. The initial operations that produce a semi-finishing part ready for gear machining as referred to as blanking operations; the starting product in gear machining is called a gear blank.



Tool material should be tough and ductile. Low carbon steels and stainless steels give good performance.

Two principal methods of gear manufacturing include:

- Gear forming, and

- Gear generation.

Gear Forming

In gear form cutting, the cutting edge of the cutting tool has a shape identical with the shape of the space between the gear teeth.

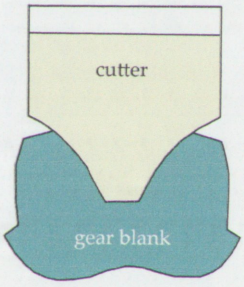


Figure 6.14: The principle of gear forming.

Two machining operations, milling and broaching can be employed to form cut gear teeth.

Form Milling

In form milling, the cutter called a form cutter travels axially along the length of the gear tooth at the appropriate depth to produce the gear tooth. After each tooth is cut, the cutter is withdrawn, the gear blank is rotated (indexed), and the cutter proceeds to cut another tooth. The process continues until all teeth are cut.

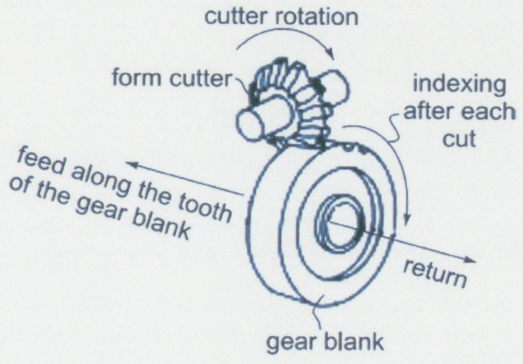
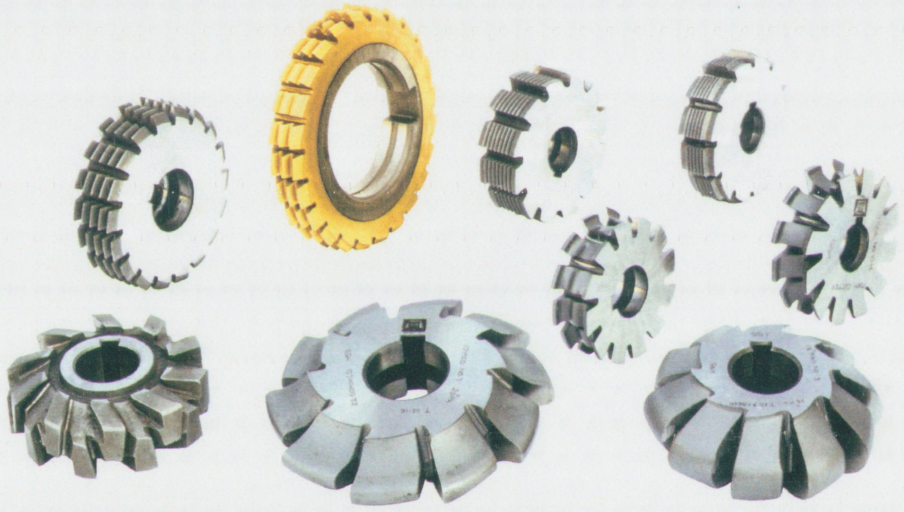


Figure 6.15: Setup of form milling.

Each cutter is designed to cut a range of tooth numbers. The precision of the form-cut tooth profile depends on the accuracy of the cutter and the machine and its stiffness.



In form milling, indexing of the gear blank is required to cut all the teeth. Indexing is the process of evenly dividing the circumference of a gear blank into equally spaced divisions. The index head of the indexing fixture is used for this purpose. The index fixture consists of an index head (also dividing head, gear cutting attachment) and footstock, which is similar to the tailstock of a lathe. The index head and footstock attach to the worktable of the milling machine. An index plate containing graduations is used to control the rotation of the index head spindle. Gear blanks are held between centers by the index head spindle and footstock. Workpieces may also be held in a chuck mounted to the index head spindle or may be fitted directly into the taper spindle recess of some indexing fixtures.

Broaching

Broaching can also be used to produce gear teeth and is particularly applicable to internal teeth. The process is rapid and produces fine surface finish with high dimensional accuracy. However, because broaches are expensive-and a separate broach is required for each size of gear-this method is suitable mainly for high-quantity production.

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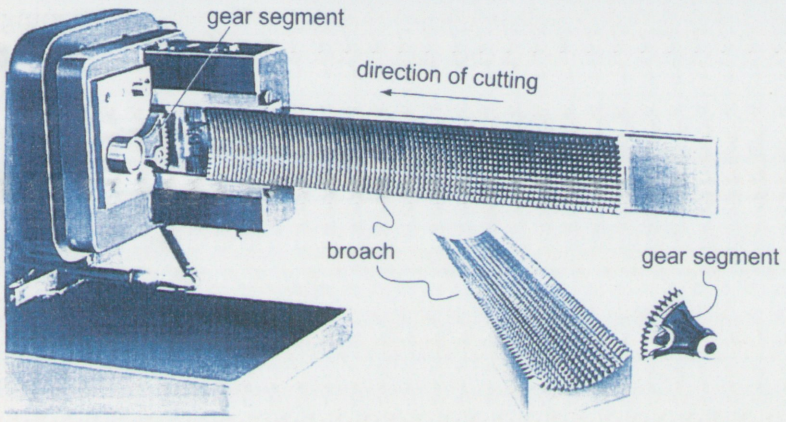


Figure 6.16: Broaching the teeth of a gear segment by horizontal external broaching in one pass.

Gear Generation

In gear generating, the tooth flanks are obtained (generated) as an outline of the subsequent positions of the cutter, which resembles in shape the mating gear in the gear pair:

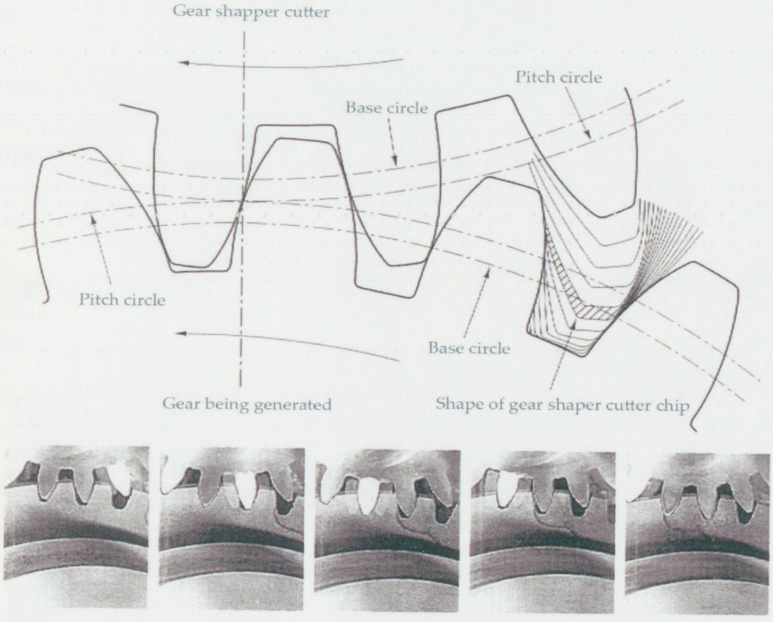


Figure 6.17: Generating action of a gear-shaper cutter.

In gear generating, two machining processes are employed, shaping and milling. There are several modifications of these processes for different cutting tool used:

- Milling with a hob (gear hobbing),
- Gear shaping with a pinion-shaped cutter, or
- Gear shaping with a rack-shaped cutter.

Gear Hobbing

Gear hobbing is a machining process in which gear teeth are progressively generated by a series of cuts with a helical cutting tool (hob). All motions in hobbing are rotary, and the hob and gear blank rotate continuously as in two gears meshing until all teeth are cut.

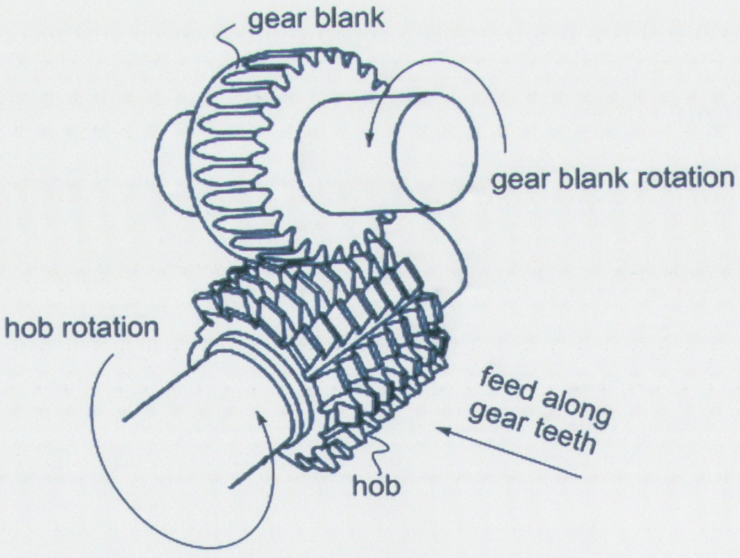


Figure 6.18: Setup of gear hobbing operation.

When bobbing a spur gear, the angle between the hob and gear blank axes is 90° minus the lead angle at the hob threads. For helical gears, the hob is set so that the helix angle of the hob is parallel with the tooth direction of the gear being cut. Additional movement along the tooth length is necessary in order to cut the whole tooth length:

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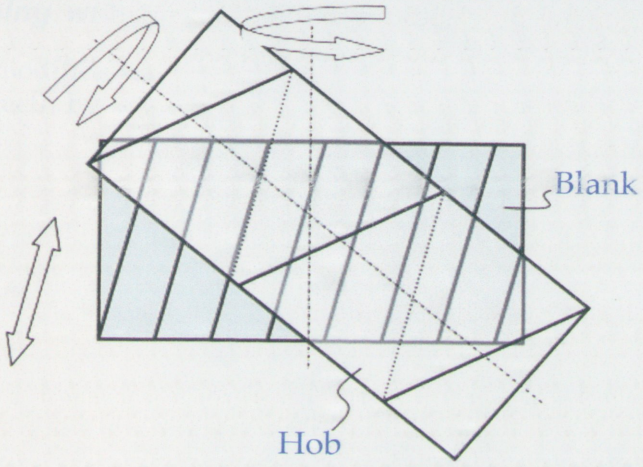
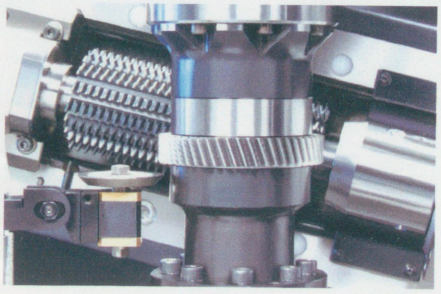
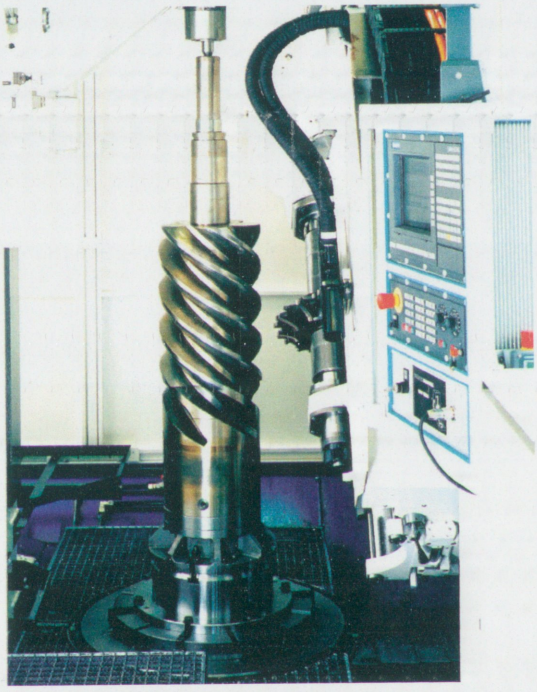


Figure 6.19: Kinematics of the gear hobbing operation for cutting of a helical gear.

The action of the **hobbing** machine (also gear hobber) is shown in the figures. The cutting of a gear by means of a hob is a continuous operation. The hob and the gear blank are connected by a proper gearing so that they rotate in mesh. To start cutting a gear, the rotating hob is fed inward until the proper setting for tooth depth is achieved, then cutting continues until the entire gear is finished. Machines for cutting precise gears are generally CNC-type and often are housed in temperature controlled rooms to avoid dimensional deformations.

The work is rotating and the tool is moved into its path such that it forms an obstruction and shearing takes place. Of course the amount of movement is of paramount importance - too much at once could for instance result in breakage of the tool.





The gear hob is a formed tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges.



Shaping with a pinion-shaped cutter

This modification of the gear shaping process is defined as a process for generating gear teeth by a rotating and reciprocating pinion-shaped cutter:

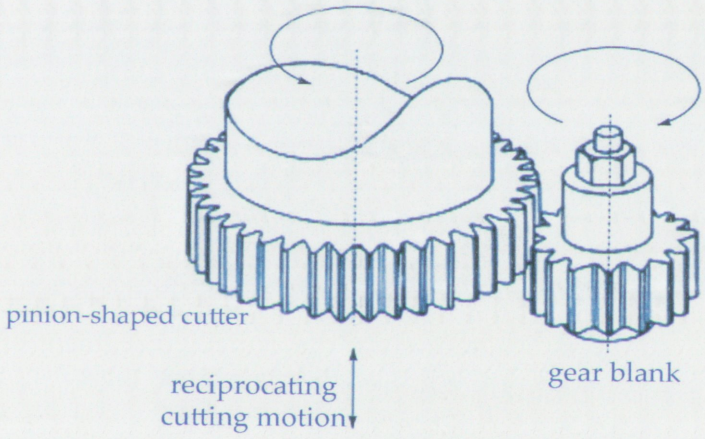


Figure 6.20: Setup of gear shaping operation with a pinion-shaped cutter.

The cutter axis is parallel to the gear axis. The cutter rotates slowly in timed relationship with the gear blank at the same pitch-cycle velocity, with an axial primary reciprocating motion, to produce the gear teeth. A train of gears provides the required relative motion between the cutter shaft and the gear-blank shaft. Cutting may take place either at the down stroke or upstroke of the machine. Because the clearance required for cutter travel is small, gear shaping is suitable for gears that are located close to obstructing surfaces such as flanges. The tool is called gear cutter and resembles in shape the mating gear from the conjugate gear pair, the other gear being the blank. Gear shaping is one of the most versatile of all gear cutting operations used to produce internal gears, external gears, and integral gear-pinion arrangements. Advantages of gear shaping with pinion-shaped cutter are the high dimensional accuracy achieved and the not too expensive tool. The process is applied for finishing operation in all types of production rates.

Shaping with a rack-shaped cutter

In the gear shaping with a rack-shaped cutter, gear teeth are generated by a cutting tool called a rack shaper. The rack shaper reciprocates parallel to the axis of the gear axis. It moves slowly linearly with the gear blank rotation at the same pitch-cycle velocity.

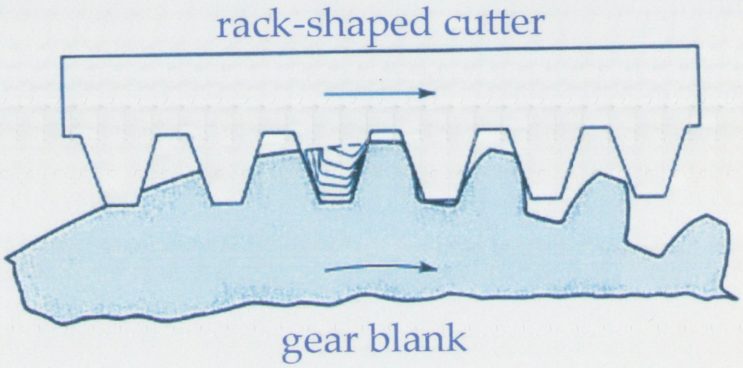


Figure 6.21: Shaping with a rack-shaped cutter.

The rack shaper is actually a segment of a rack. Because it is not practical to have more than 6-12 teeth on a rack cutter, the cutter must be disengaged at suitable intervals and returned to the starting point, the gear blank meanwhile remaining fixed. Advantages of this method involve a very high dimensional accuracy and cheap cutting tool (the rack shaper's teeth blanks are straight, which makes sharpening of the tool easy). The process can be used for low-quantity as well as high-quantity production of spur and helix external gears.

KEYWORD

Hobbing is a machining process for gear cutting, cutting splines, and cutting sprockets on a hobbing machine, which is a special type of milling machine.

Finishing Operations

As produced by any of the process described, the surface finish and dimensional accuracy may not be accurate enough for certain applications. Several finishing operations are available, including the conventional process of shaving, and a number of abrasive operations, including grinding, honing, and lapping.

6.4 MACHINING AND GRINDING OF PLASTICS

The low strength of thermoplastics permits high cutting speeds and feeds, but the low heat conductivity and greater resilience require increased reliefs and less rake in order to avoid undersize cutting. Hard and sharp tools should be used. Plastics are usually abrasive and cause the tools to wear or become dull rapidly. Dull tools generate heat and cause the

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tools to cut to shallow depths. The depth of cut should be small. When high production justifies the cost, diamond turning and boring tools are used. Diamond tools maintain sharp cutting edges and produce an excellent machined surface. They are particularly advantageous when a more abrasive plastic such as reinforced plastic is machined. A cutting fluid, such as a small blast of air, a stream of water, or a cutting fluid, improves the turning and cutting of plastics as it prevents the heating of the tool and causes the chips to remain brittle and to break rather than become sticky and gummy. A zero or slightly negative back rake and a relief angle of 8 to 12° should be used. For thermoplastics cutting speeds generally range from 250 to 400 ft/min (75 to 120 m/min) and for thermosetting plastics from 400 to 1,000 ft/min (120 to 300 m/min). Recommended tool materials are M2 and T5 high-speed steels and C-2 carbide.

In milling plastics, speeds of 400 to 1,000 ft/min (120 to 300 m/min) should be used, with angles similar to those on a single-point tool. From 0 to 10° negative rake may be used. Good results have been obtained by hobbing plastic gears with carbide-tipped hobs. Recommended tool materials are M2 and M7 high-speed steels and C-2 carbide.

In sawing plastics, either precision or buttress tooth forms may be used, with a pitch ranging from 3 to 14 teeth/in (1.2 to 5.5 teeth/cm), the thicker the material the lower the number of teeth per unit length of saw. Cutting speeds for thermoplastics range from 1,000 to 4,000 ft/min (300 to 1,200 m/min) and for thermosetting plastics from about 3,000 to 5,500 ft/min (900 to 1,700 m/min), with the higher speeds for thinner stock. High-carbon-steel blades are recommended. An air blast is helpful in preventing the chips from sticking to the saw. Abrasive saws operating at 3,500 to 6,000 ft/min (1,000 to 1,800 m/min) are also used for cutting off bars and forms.

Plastics are tapped and threaded with standard tools. Ground M1, M7, or M10 high-speed steel taps with large polished flutes are recommended. Tapping speeds are usually from 25 to 50 ft/min (8 to 15 m/min); water serves as a good cutting fluid as it keeps the material brittle and prevents sticking in the flutes. Thread cutting is generally accomplished with tools similar to those used on brass.

Reaming is best accomplished in production by using tools of the expansion or adjustable type with relatively low

DID YOU KNOW?

Hobbing machines, also known as hobbers, are fully automated machines that come in many sizes, because they need to be able to produce anything from tiny instrument gears up to 10 ft (3.0 m) diameter marine gears.

speeds but high feeds. Less material should be removed in reaming plastics than in reaming other materials.

Polishing and buffing are done on many types of plastics. Polishing is done with special compounds containing wax or a fine abrasive. Buffing wheels for plastics should have loose stitching. Vinyl plastics can be buffed and polished with fabric wheels of standard types, using light pressures. Thermoplastics and thermosets can be ground with relative ease, usually by using silicon carbide wheels. As in machining, temperature rise should be minimized.



Grinding is an abrasive machining process that uses a grinding wheel as the cutting tool.

6.4.1 Machining and Grinding of Ceramics

The technology of machining and **grinding** of ceramics, as well as composite materials, has advanced rapidly, resulting in good surface characteristics and product integrity. Ceramics can be machined with carbide, high-speed steel, or diamond tools, although care should be exercised because of the brittle nature of ceramics and the resulting possible surface damage. Machinable ceramics have been developed which minimize machining problems. Grinding of ceramics is usually done with diamond wheels.

6.5 OTHER MATERIAL REMOVAL PROCESSES

In addition to the mechanical methods of material removal, there are a number of other important processes which may be preferred over conventional methods. Among the important factors to be considered are the hardness of the workpiece material, the shape of the part, its sensitivity to thermal damage, residual stresses, tolerances, and economics. Some of these processes produce a heat-affected layer on the surface; improvements in surface integrity may be obtained by post processing techniques such as polishing or peening. Almost all machines are now computer-controlled.

Electric-Discharge Machining (EDM)

It is based on the principle of erosion of metals by spark discharges. Figure 6.22 gives a schematic diagram of this

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process. The spark is a transient electric discharge through the space between two charged electrodes, which are the tool and the workpiece. The discharge occurs when the potential difference between the tool and the workpiece is large enough to cause a breakdown in the medium (which is called the dielectric fluid and is usually a hydrocarbon) and to procure an electrically conductive spark channel. The breakdown potential is usually established by connecting the two electrodes to the terminals of a capacitor charged from a power source. The spacing between the tool and workpiece is critical; therefore, the feed is controlled by servomechanisms. The dielectric fluid has the additional functions of providing a cooling medium and carrying away particles produced by the electric discharge. The discharge is repeated rapidly, and each time a minute amount of workpiece material is removed.

The rate of metal removal depends mostly on the average current in the discharge circuit; it is also a function of the electrode characteristics, the electrical parameters, and the nature of the dielectric fluid. In practice, this rate is normally varied by changing the number of discharges per second or the energy per discharge. Rates of metal removal may range from 0.01 to 25 in^3/h (0.17 to 410 cm^3/h), depending on surface finish and tolerance requirements. In general, higher rates produce rougher surfaces. Surface finishes may range from 1,000 min R_q (25 mm) in roughing cuts to less than 25 min (0.6 mm) in finishing cuts. The response of materials to this process depends mostly on their thermal properties. Thermal capacity and conductivity, latent heats of melting and vaporization are important. Hardness and strength do not necessarily have significant effect on metal removal rates. The process is applicable to all materials which are sufficiently good conductors of electricity. The tool has great influence on permissible removal rates. It is usually made of graphite, copper-tungsten, or copper alloys. Tools have been made by casting, extruding, machining, powder metallurgy, and other techniques and are made in any desired shape. Tool wear is an important consideration, and in order to control tolerances and minimize cost, the ratio of tool material removed to workpiece material removed should be low. This ratio varies with different tool and workpiece material combinations and with operating conditions. Therefore, a particular tool material may not be best for all workpieces. Tolerances as low as 0.0001 to 0.0005 in (0.0025 to 0.0127 mm) can be held with slow metal removal rates. In machining some steels, tool wear can be minimized by reversing the polarity and using copper tools. This is known as "no-wear EDM.

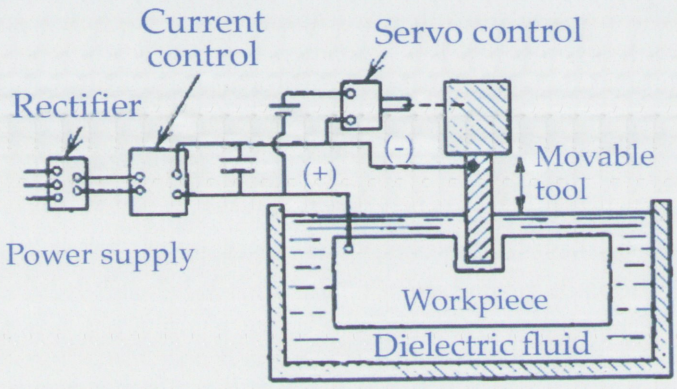


Figure 6.22: Schematic diagram of the electric-discharge machining process.

The electric-discharge machining process has numerous applications, such as machining cavities and dies, cutting small-diameter holes, blanking parts from sheets, cutting off rods of materials with poor machinability, and flat or form grinding. It is also applied to sharpening tools, cutters, and broaches. The process can be used to generate almost any geometry if a suitable tool can be fabricated and brought into close proximity to the workpiece. Thick plates may be cut with wire EDM. A slowly moving wire travels a prescribed path along the workpiece and cuts the metal with the sparks acting like saw teeth. The wire, usually about 0.01 in (0.25 mm) in diameter, is made of brass, copper, or tungsten and is generally used only once. The process is also used in making tools and dies from hard materials, provided that they are electrically conducting.

Electric-Discharge Grinding (EDG)

It is similar to the electric-discharge machining process with the exception that the electrode is in the form of a grinding wheel. Removal rates are up to 1.5 in^3/h (25 cm^3/h) with practical tolerances on the order of 0.001 in (0.025 mm). A graphite or brass electrode wheel is operated around 100 to 600 surface ft/min (30 to 180 m/min) to minimize splashing of the dielectric fluid. Typical applications of this process are in grinding of carbide tools and dies, thin slots in hard materials, and production grinding of intricate forms.

Electrochemical Machining (ECM)

Electrochemical machining (ECM) process (Figure 6.23) uses electrolytes which dissolve the reaction products formed on the workpiece by electrochemical action; it is similar to a reverse electroplating process. The electrolyte is pumped at high velocities through

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the tool. A gap of 0.005 to 0.020 in (0.13 to 0.5 mm) is maintained. A dc power supply maintains very high current densities between the tool and the workpiece. In most applications, a current density of 1,000 to 5,000 A is required per in2 of active cutting area. The rate of metal removal is proportional to the amount of current passing between the tool and the workpiece.

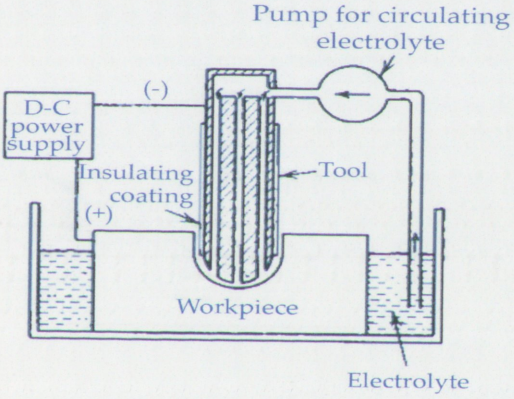


Figure 6.23: Schematic diagram of the electrochemical machining process.

Removal rates up to 1 in^3/min (16 cm^3/min) can be obtained with a 10,000-A power supply. The penetration rate is proportional to the current density for a given workpiece material. The process leaves a burr-free surface. It is also a cold machining process and does no thermal damage to the surface of the workpiece. Electrodes are normally made of brass or copper; stainless steel, titanium, sintered copper-tungsten, aluminum, and graphite have also been used. The electrolyte is usually a sodium chloride solution up to 2.5 lb/gal (300 g/L); other solutions and proprietary mixtures are also available. The amount of overcut, defined as the difference between hole diameter and tool diameter, depends upon cutting conditions. For production applications, the average overcut is around 0.015 in (0.4 mm). The rate of penetration is up to 0.750 in/min (20 mm/min). Very good surface finishes may be obtained with this process. However, sharp square corners or sharp corners and flat bottoms cannot be machined to high accuracies. The process is applied mainly to round or odd-shaped holes with straight parallel sides. It is also applied to cases where conventional methods produce burrs which are costly to remove. The process is particularly economical for materials with a hardness above 400 HB.

Electrochemical Grinding (ECG)

Electrochemical grinding (ECG) process (Figure 6.24) is a combination of electrochemical machining and abrasive cutting where most of the metal removal results from the

electrolytic action. The process consists of a rotating cathode, a neutral electrolyte, and abrasive particles in contact with the workpiece. The equipment is similar to a conventional grinding machine except for the electrical accessories. The cathode usually consists of a metal-bonded diamond or aluminum oxide wheel.



Elastomer is a polymer with viscoelasticity and very weak intermolecular forces, generally having low Young's modulus and high failure strain compared with other materials.

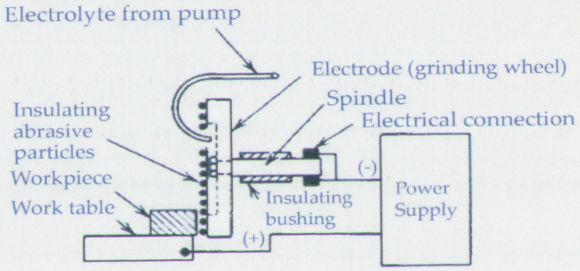


Figure 6.24: Schematic diagram of the electrochemical grinding process.

An important function of the abrasive grains is to maintain a space for the electrolyte between the wheel and workpiece. Surface finish, precision, and metal-removal rate are influenced by the composition of the electrolyte. Aqueous solutions of sodium silicate, borax, sodium nitrate, and sodium nitrite are commonly used as electrolytes. The process is primarily used for tool and cutter sharpening and for machining of high-strength materials. A combination of the electric-discharge and electrochemical methods of material removal is known as electrochemical discharge grinding (ECDG). The electrode is a pure graphite rotating wheel which electrochemically grinds the workpiece. The intermittent spark discharges remove oxide films that form as a result of electrolytic action. The equipment is similar to that for electrochemical grinding. Typical applications include machining of fragile parts and resharpening or form grinding of carbides and tools such as milling cutters.

Chemical Machining (CM)

Chemical machining (CM) material is removed by chemical or electrochemical dissolution of preferentially exposed surfaces

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of the workpiece. Selective attack on different areas is controlled by masking or by partial immersion. There are two processes involved: chemical milling and chemical blanking. Milling applications produce shallow cavities for overall weight reduction, and are also used to make tapered sheets, plates, or extrusions. Masking with paint or tapes is common. Masking materials may be **elastomers** (such as butyl rubber, neoprene, and styrene-butadiene) or plastics (such as polyvinyl chloride, polystyrene, and polyethylene). Typical blanking applications are decorative panels, printed-circuit etching, and thin stampings. Etchants are solutions of sodium hydroxide for aluminum, and solutions of hydrochloric and nitric acids for steel.

SUMMARY

- Machining is a term used to describe a variety of material removal processes in which a cutting tool removes unwanted material from a workpiece to produce the desired shape.
- Conventional machining processes are often placed in three categories - single point cutting, multi-point cutting, and abrasive machining.
- Built-up edge chips consist of a mass of metal which adheres to the tool face while the chip itself flows continuously along the face.
- Turning is a machining operation for all types of metallic and nonmetallic materials and is capable of producing circular parts with straight or various profiles.
- Turret lathes are used for the production of parts in moderate quantities and produce interchangeable parts at low production cost.
- Boring is a machining process for producing internal straight cylindrical surfaces or profiles, with process characteristics and tooling similar to those for turning operations.
- Chemical machining (CM) material is removed by chemical or electrochemical dissolution of preferentially exposed surfaces of the workpiece.

KNOWLEDGE CHECK

1. **Which one of the following process is not a machining process?**

   a. Planing

   b. Boring

   c. Turning

   d. Forging

2. **The angle made between the rake face of a tool and the normal to a workpiece is called**

   a. Clearance angle

   b. Rake angle

   c. Lip angle

   d. Helix angle

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3. **Which of the following tool is used for turning?**
   a. Multi point cutting tool
   b. Single point cutting tool
   c. Hand tool
   d. End cutting tool

4. **Which of the following is a conventional machining process?**
   a. Chemical machining
   b. Ultrasonic machining
   c. Turning operation
   d. Abrasive jet machining

5. **In turning metal removal takes place by**
   a. Plastic deformation
   b. Plastic deformation and shearing
   c. Shearing
   d. None of these.

REVIEW QUESTIONS

1. What do you understand by gear manufacturing?
2. Discuss the uses of common cutting tool material.
3. How to classify cutting fluids? Discuss.
4. Write short note on electric-discharge machining (EDM).
5. What are material removal processes?

CHECK YOUR RESULT

1. (d) 2. (b) 3. (b) 4. (c) 5. (c)

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Level: Beginner to Advanced
Subject: Engineering and Technology

Basic Manufacturing Processes

Manufacturing processes are the steps through which raw materials are transformed into a final product. The manufacturing process begins with the creation of the materials from which the design is made. These materials are then modified through manufacturing processes to become the required part. Manufacturing processes can include treating, machining, or reshaping the material. The manufacturing process also includes tests and checks for quality assurance during or after the manufacturing, and planning the production process prior to manufacturing. Manufacturing takes turns under all types of economic systems. In a free market economy, manufacturing is usually directed toward the mass production of products for sale to consumers at a profit. In a collectivist economy, manufacturing is more frequently directed by the state to supply a centrally planned economy. In mixed market economies, manufacturing occurs under some degree of government regulation. Modern manufacturing includes all intermediate processes required the production and integration of a product's components.

Key features:

- This Textbook provides all the concise information needed to identify the ideal process for a specific manufacturing requirement.
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- Illustrative examples of varying difficulties, wherever needed, are presented to enhance the interest of students.
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