LECTURE NOTES

ON

AIRCRAFT MATERIALS AND PRODUCTION

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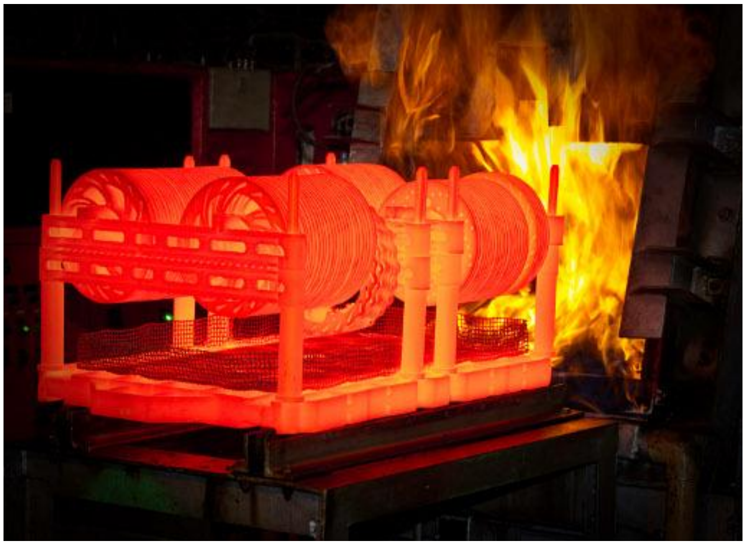
UNIT - I

AIRCRAFT ENGINEERING MATERIALS

Introduction

- **Heat treating** is a group of industrial and metalworking processes used to alter the physical, and sometimes chemical, properties of a material.
- The most common application is metallurgical.
- Heat treatments are also used in the manufacture of many other materials, such as glass. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material.
- Heat treatment techniques include annealing, case hardening, precipitation, strengthening, temperingand quenching.
- It is noteworthy that while the term heat treatment applies only to processes where the heating and cooling are done for the specific purpose of altering properties intentionally, heating and cooling often occur incidentally during other manufacturing processes such as hot forming or welding.



Heat Treating Plate

Annealing

Annealing is a rather generalized term. Annealing consists of heating a metal to a specific temperature and then cooling at a rate that will produce a refined microstructure. The rate of cooling is generally slow. Annealing is most often used to soften a metal for cold working, to improve machinability, or to enhance properties like electrical conductivity.

In ferrous alloys, annealing is usually accomplished by heating the metal beyond the upper critical temperature and then cooling very slowly, resulting in the formation of pearlite. In both pure metals and many alloys that cannot be heat treated, annealing is used to remove the hardness caused by cold working. The metal is heated to a temperature where recrystallization can occur, thereby repairing the defects caused by plastic deformation. In these metals, the rate of cooling will usually have little effect. Most non-ferrous alloys that are heat-treatable are also annealed to relieve the hardness of cold working. These may be slowly cooled to allow full precipitation of the constituents and produce a refined microstructure.

Ferrous alloys are usually either "full annealed" or "process annealed." Full annealing requires very slow cooling rates, in order to form coarse pearlite. In process annealing, the cooling rate may be faster; up to, and including normalizing. The main goal of process annealing is to produce a uniform microstructure. Non-ferrous alloys are often subjected to a variety of annealing techniques, including "recrystallization annealing," "partial annealing," "full annealing," and "final annealing." Not all annealing techniques involve recrystallization, such as stress relieving.

Normalizing

Normalizing is a technique used to provide uniformity in grain size and composition throughout an alloy. The term is often used for ferrous alloys that have been austenitized and then cooled in open air. Normalizing not only produces pearlite, but also bainite sometimes martensite, which gives harder and stronger steel, but with less ductility for the same composition than full annealing.

Stress relieving

Stress relieving is a technique to remove or reduce the internal stresses created in a metal. These stresses may be caused in a number of ways, ranging from cold working to non-uniform cooling. Stress relieving is usually accomplished by heating a metal below the lower critical temperature and then cooling uniformly.

Aging

Some metals are classified as precipitation hardening metals. When a precipitation hardening alloy is quenched, its alloying elements will be trapped in solution, resulting in a soft metal. Aging a "solutionized" metal will allow the alloying elements to diffuse through the microstructure and form intermetallic particles. These intermetallic particles will nucleate and fall out of solution and act as a reinforcing phase, thereby increasing the strength of the alloy. Alloys may age "naturally" meaning that the precipitates form at room temperature, or they may age "artificially" when precipitates only form at elevated temperatures. In some applications, naturally aging alloys may be stored in a freezer to prevent hardening until after further operations - assembly of rivets, for example, may be easier with a softer part.

Examples of precipitation hardening alloys include 2000 series, 6000 series, and 7000 series aluminium alloy, as well as some super alloys and some stainless steels. Steels that harden by aging are typically referred to as maraging steels, from a combination of the term "martensite aging."

Quenching

Quenching is a process of cooling a metal at a rapid rate. This is most often done to produce a martensite transformation. In ferrous alloys, this will often produce a harder metal, while non-ferrous alloys will usually become softer than normal.

To harden by quenching, a metal (usually steel or cast iron) must be heated above the upper critical temperature and then quickly cooled. Depending on the alloy and other considerations (such as concern for maximum hardness vs. cracking and distortion), cooling may be done with forced air or other gases, (such as nitrogen). Liquids may be used, due to their better thermal conductivity, such as oil, water, a polymer dissolved in water, or a brine. Upon being rapidly cooled, a portion of austenite (dependent on alloy composition) will transform to martensite, a hard, brittle crystalline structure. The quenched hardness of a metal depends on its chemical composition and quenching method. Cooling speeds, from fastest to slowest, go from fresh water, brine, polymer (i.e. mixtures of water + glycol polymers), oil, and forced air. However, quenching a certain steel too fast can result in cracking, which is why high-tensile steels such as AISI 4140 should be quenched in oil, tool steels such as ISO 1.2767 or H13 hot work tool steel should be quenched in forced air, and low alloy or medium-tensile steels such as XK1320 or AISI 1040 should be quenched in brine.

However, most non-ferrous metals, like alloys of copper, aluminum, or nickel, and some high alloy steels such as austenitic stainless steel (304, 316), produce an opposite effect when these are quenched: they soften. Austenitic stainless steels must be quenched to become fully corrosion resistant, as they work-harden significantly.

Tempering

Untampered martensitic steel, while very hard, is too brittle to be useful for most applications. A method for alleviating this problem is called tempering. Most applications require that quenched parts be tempered. Tempering consists of heating steel below the lower critical temperature, (often from 400 to 1105 ˚F or 205 to 595 ˚C, depending on the desired results), to impart some toughness. Higher tempering temperatures (may be up to 1,300 ˚F or 700 ˚C, depending on the alloy and application) are sometimes used to impart further ductility, although some yield strength is lost.

Tempering may also be performed on normalized steels. Other methods of tempering consist of quenching to a specific temperature, which is above the martensite start temperature, and then holding it there until pure bainite can form or internal stresses can be relieved. These include austempering and martempering.

Tempering colors of steel

Steel that has been freshly ground or polished will form oxide layers when heated. At a very specific temperature, the iron oxide will form a layer with a very specific thickness, causing thin-film interference. This causes colors to appear on the surface of the steel. As temperature is increased, the iron oxide layer grows in thickness, changing the color.[19] These colors, called tempering colors, have been used for centuries to gauge the temperature of the metal. At around 350˚F (176˚C) the steel will start to take on a very light, yellowish hue. At 400˚F (204˚C), the steel will become a noticeable light-straw color, and at 440˚F (226˚C), the color will become dark-straw. At 500˚F (260˚C), steel will turn brown, while at 540˚F (282˚C) it will turn purple. At 590˚F (310˚C) the steel turns a very deep blue, but at 640˚F (337˚C) it becomes a rather light blue.

The tempering colors can be used to judge the final properties of the tempered steel. Very hard tool steel is often tempered in the light to dark straw range, whereas spring steel is often tempered to the blue. However, the final hardness of the tempered steel will vary, depending on the composition of the steel. The oxide film will also increase in thickness over time. Therefore, steel that has been held at 400˚F for a very long time may turn brown or purple, even though the temperature never exceeded that needed to produce a light straw color. Other factors affecting the final outcome are oil films on the surface and the type of heat source used.

Many heat treating methods have been developed to alter the properties of only a portion of an object. These tend to consist of either cooling different areas of an alloy at different rates, by quickly heating in a localized area and then quenching, by thermochemical diffusion, or by tempering different areas of an object at different temperatures, such as in differential tempering.

Differential hardening

A differentially hardened katana. The bright, wavy line following the hamon, called the nioi, separates the martensitic edge from the pearlitic back. The inset shows a close-up of the nioi, which is made up of individual martensite grains (niye) surrounded by pearlite. The wood-grain appearance comes from layers of different composition.

Some techniques allow different areas of a single object to receive different heat treatments. This is called differential hardening. It is common in high quality knives and swords. The Chinese jian is one of the earliest known examples of this, and the Japanese katana may be the most widely known. The Nepalese Khukuri is another example. This technique uses an insulating layer, like layers of clay, to cover the areas that are to remain soft. The areas to be hardened are left exposed, allowing only certain parts of the steel to fully harden when quenched.

Flame hardening

Flame hardening is used to harden only a portion of a metal. Unlike differential hardening, where the entire piece is heated and then cooled at different rates, in flame hardening, only a portion of the metal is heated before quenching. This is usually easier than differential hardening, but often produces an extremely brittle zone between the heated metal and the unheated metal, as cooling at the edge of this heat affected zone is extremely rapid.

Induction hardening

Induction hardening is a surface hardening technique in which the surface of the metal is heated very quickly, using a no-contact method of induction heating. The alloy is then quenched, producing a martensite transformation at the surface while leaving the underlying metal unchanged. This creates a very hard, wear resistant surface while maintaining the proper toughness in the majority of the object. Crankshaft journals are a good example of an induction hardened surface.

Case hardening

Case hardening is a thermochemical diffusion process in which an alloying element, most commonly carbon or nitrogen, diffuses into the surface of a monolithic metal. The resulting interstitial solid solution is harder than the base material, which improves wear resistance without sacrificing toughness.

Laser surface engineering is a surface treatment with high versatility, selectivity and novel properties. Since the cooling rate is very high in laser treatment, metastable even metallic glass can be obtained by this method.

Cold and cryogenic treating

Although quenching steel causes the austenite to transform into martensite, all of the austenite usually does not transform. Some austenite crystals will remain unchanged even after quenching below the martensite finish (Mf) temperature. Further transformation of the austenite into martensite can be induced by slowly cooling the metal to extremely low temperatures. Cold treating generally consists of cooling the steel to around -115 ˚F (-81 ˚C), but does not eliminate all of the austenite. Cryogenic treating usually consists of cooling to much lower temperatures, often in the range of -315 ˚F (-192 ˚C), to transform most of the austenite into martensite.

Cold and cryogenic treatments are typically done immediately after quenching, before any tempering, and will increase the hardness, wear resistance, and reduce the internal stresses in the metal but, because it is really an extension of the quenching process, it may increase the chances of cracking during the procedure. The process is often used for tools, bearings, or other items that require good wear resistance. However, it is usually only effective in high-carbon or high-alloy steels in which more than 10% austenite is retained after quenching.

Decarburization

The heating of steel is sometimes used as a method to alter the carbon content. When steel is heated in an oxidizing environment, the oxygen combines with the iron to form an iron-oxide layer, which protects the steel from decarburization. When the steel turns to austenite, however, the oxygen combines with iron to form slag, which provides no protection from decarburization. The formation of slag and scale actually increases decarburization, because the iron oxide keeps oxygen in contact with the decarburization zone even after the steel is moved into an oxygen-free environment, such as the coals of a forge. Thus, the carbon atoms begin combining with the surrounding scale and slag to form both carbon monoxide and carbon dioxide, which is released into the air.

Steel contains a relatively small percentage of carbon, which can migrate freely within the gamma iron. When austenized steel is exposed to air for long periods of time, the carbon content in the steel can be lowered. This is the opposite from what happens when steel is heated in a reducing environment, in which carbon slowly diffuses further into the metal. In an oxidizing environment, the carbon can readily diffuse outwardly, so austenized steel is very susceptible to decarburization. This is often used for cast steel, where a high carbon-content is needed for casting, but a lower carbon-content is desired in the finished product. It is often used on cast-irons to produce malleable cast iron, in a process called "white tempering." This tendency to decarburize is often a problem in other operations, such as blacksmithing, where it becomes more desirable to austenize the steel for the shortest amount of time possible to prevent too much decarburization.

Specification

Usually the end condition is specified instead of the process used in heat treatment.

Case hardening

A modern, fully computerized case hardening furnace.

Case hardening is specified by hardness and case depth. The case depth can be specified in two ways: total case depth or effective case depth. The total case depth is the true depth of the case. For most alloys, the effective case depth is the depth of the case that has a hardness equivalent of HRC50; however, some alloys specify a different hardness (40-60 HRC) at effective case depth; this is checked on a Tukonmicrohardness tester. This value can be roughly approximated as 65% of the total case depth; however the chemical composition and hardenability can affect this approximation. If neither type of case depth is specified the total case depth is assumed.

For case hardened parts the specification should have a tolerance of at least ±0.005 in (0.13 mm). If the part is to be ground after heat treatment, the case depth is assumed to be after grinding.

The Rockwell hardness scale used for the specification depends on the depth of the total case depth, as shown in the table below. Usually hardness is measured on the Rockwell "C" scale, but the load used on the scale will penetrate through the case if the case is less than 0.030 in (0.76 mm). Using Rockwell "C" for a thinner case will result in a false reading.

Rockwell scale required for various case depths

Total case depth, min. [in]	Rockwell scale
0.030	C
0.024	A
0.021	45N
0.018	30N
0.015	15N
Less than 0.015	"File hard"

For cases that are less than 0.015 in (0.38 mm) thick a Rockwell scale cannot reliably be used, so file hard is specified instead. File hard is approximately equivalent to 58 HRC.

When specifying the hardness either a range should be given or the minimum hardness specified. If a range is specified at least 5 points should be given.

Through hardening

Only hardness is listed for through hardening. It is usually in the form of HRC with at least a five point range.

Annealing

The hardness for an annealing process is usually listed on the HRB scale as a maximum value. It is a process to refine grain size, improve strength, remove residual stress and affect the electromagnetic properties.

UNIT - II

CASTING,
WELDING
&
INSPECTION TECHNIQUES

1.1 Introduction to Aircraft production technology

Production of modern aircrafts involves the manufacture of several thousands of individual parts to precise dimensions and assembling them together with brought out components. The parts to be manufactured include those required for the airframe structure and basketry, pipelines, electric cable runs etc. for installing aircraft systems. The individual parts of the aircraft structure are assembled in several stages such as minor subassemblies, sub-assemblies and major assemblies to form the aircraft structure.

Unlike mass manufacturing practices prevalent in general engineering industries, aircraft are produced in relatively small quantities. Very high standards of quality control are required to meet the stringent design specifications and ensure safety of human lives. All raw material and components should comply with airworthiness standards and traceable throughout the process of manufacture and service usage to enable proper analysis of defects / flying accidents. Extensive specific to type production tooling is employed for achieving the required close dimensions and tolerances, surface finish and interchangeability of components. Many manufacturing processes and production machines have been specially developed for aircraft industry, such as, heat treatment and surface treatment processes, CNC machines etc. some of these are later adopted in general engineering industries. Sophisticated management system has been evolved in aircraft industry to cope with the complex technologies, high risk and investment, long gestation periods for design, development and production for series preparation and prolonged pay back periods.

Manufacturing:

Manufacturing implies making of articles or goods and providing services to meet the human needs. It creates value by useful application of physical and mental labor in the process. This, however, is too inadequate a definition to give a clear picture of domain of manufacturing which is more complex and broad based than what it appears from this definition.

It can be defined as a chain of interrelated activities and operations as
Order processing → Design → Drawing → Selection of materials Process planning → Production →
Production control → Quality control → Management → Marketing. Etc.

Most of the metals used in industry are obtained as ores. These ores are subjected to suitable reducing or refining processes which convert the metal into a molten form. This molten metal is poured into moulds to give commercial castings, called ingots. These ingots are further subjected to one or more processes to obtain usable metal products of different shapes and sizes. All these further processes used for changing the ingots into usable products can be classified as follows

Classification Manufacturing Process

They are mainly classified into six groups:

Primary Shaping (or) forming process: Primary shaping is manufacturing of a solidbody from molten or gaseous state or forms an amorphous material. Amorphous materials are liquid, gaseous, powders, fibers, chips, melts and like. A primary shaping or forming tool contains a hollow space, which, with the allowance for contraction usually corresponds to the form of the product. Here, cohesion is normally created among particles. Some of the important primary shaping processes are

1. Casting
2. Powder metallurgy
3. Plastic technology

Deforming processes:

Deforming processes make use of suitable stresses likecompression, tension, and shear or combined stresses to cause deformation of the materials to produce required shapes without changing its mass or material composition. In forming, no material is removed; they deformed and displaced. Some of the deforming processes are;

1. Forging
2. Extrusion
3. Rolling
4. Sheet metal working
5. Rotary swaging
6. Thread Rolling
7. Explosive forming
8. Electromagnetic forming

Machining (or) removing processes:

The principle used in all machiningprocesses is to generate the surface required by providing suitable relative motion between the work piece and the tool. In these processes material is removed from the unwanted regions of the input material. In this work material is subjected to a lower stress as compared to forming processes. Some of the machining processes are;

1. Turning
2. Drilling
3. Milling
4. Grinding
5. EDM
6. ECM
7. Shaping & Planning
8. Ultra sonic machining

Joining processes: In this two or more metal parts are united together tomake sub-assembly or final product. The joining processes are carried out by fusing, pressing, rubbing, riveting or any other means of assembling. Some of the joining processes are;

1. Pressure welding
2. Diffusion welding
3. Brazing

4.Resistance welding
5.Explosive welding
6. Soldering

Surface finish processes:

These processes are utilized to provide intendedsurface finish on the metal surface of a job. By imparting surface finishing processes, dimension of the part is not changed functionally, either negligible amount of the metal is removed from or certain material is added to the surface of the job. Surface cleaning processes is also accepted as surface finishing processes. Some of the surface finishing processes are

1. Plastic coating
2. Metallic coating
3. Organic finishes
4. Anodizing
5. Buffing
6. Inorganic finishes

7.Honing
8.Tumbling
9.Electro-plating
10.Lapping
11.Sanding

Material properties modification processes

1. Heat and surface treatment
2. Annealing
3. Stress relieving

Casting:

Casting is a manufacturing process by which a liquid material is (usually) poured into amold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solid casting is then ejected or out to complete the process. Casting may be used to form hot liquid metals or various materials that *cold set* after mixing of components (such as epoxies, concrete, plaster and clay). Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods.

Casting is a 6000 year old process. The casting process is subdivided into two distinct subgroups: expendable and non-expendable mold casting.

Advantages of Castings

- Intricate can be achieved, molten metal can be made to flow into any small section in the moulds cavity and as such any intricate shapes internal or external can be made with the casting process
- Castings of ferrous and nonferrous metals are practically possible
- Necessary tools required for casting moulds are simple and inexpensive. As a result, for trial production or of a small lot, it is an ideal method it is possible in casting process, to the amount of material where exactly require. As a result, weight reduction in design can be achieved
- Castings are generally cooled uniformly from all sides and therefore they are expected to have no directional properties
- Castings of and weight, even up to two hundred tones can be made.

Steps involved in Casting are

1) Pattern making
2) Mould and core preparation (or)making
3) Making the provisions like gating, riser, runner, sprue
4) Melting and pouring the metal
5) Allow the mould to solidify
6) Fettling i.e. Cleaning
7) Testing and inspection of the casting

Casting terms

Pattern: Pattern is the replica of the final object to be made with some modifications.Themoulds cavity is made with the help of the pattern.

Parting line: This is a line dividing the moulding flasks that makes up the sand mould. Insplit pattern it is also the dividing between the two halves of the pattern

Bottom board: This the board normally made of wood which is used at the start of themould making. The pattern is first kept on the board, sand is sprinkled on it and then ramming is done in the drag.

Facing sand: the small amount of carbonaceous material sprinkled on the inner surface ofthemouldcavity to give a better surface finish to the castings.

Moulding sand: it is mixture of silica, clay and moisture in appropriate proportions to getthe desired results and it surrounds the pattern while making the mould cavity.

Backing sand: It constitutes the refractory material found in the mould. This is made up ofburnt sand.

Molding box and materials

Flask: A moulding flask is one which holds the sand mould intact. Depending upon the position of the flask in mould structure it is referred to by various names -

Drag – lower moulding flask cope –
upper moulding flask
Cheek – intermediate moulding flask

A multi-part molding box (known as a casting flask, the top and bottom halves of which are known respectively as the cope and drag) is prepared to receive the pattern. Molding boxes are made in segments that may be latched to each other and to end closures. For a simple object—flat on one side—the lower portion of the box, closed at the bottom, will be filled with prepared casting sand or green sand—a slightly moist mixture of sand and clay. The sand is packed in through a vibratory process called ramming and, in this case, periodically screened level. The surface of the sand may then be stabilized with a sizing compound. The pattern is placed on the sand and another molding box segment is added. Additional sand is rammed over and around the pattern. Finally a cover is placed on the box and it is turned and unlatched, so that the halves of the mold may be parted and the pattern with its sprue and vent patterns removed. Additional sizing may be added and any defects introduced by the removal of the pattern are corrected. The box is closed again. This forms a "green" mold which must be dried to receive the hot metal. If the mold is not sufficiently dried a steam explosion can occur that can throw molten metal about. In some cases, the sand may be oiled instead of moistened, which makes possible casting without waiting for the sand to dry. Sand may also be bonded by chemical binders, such as furnace resins or amine-hardened resins.

Chills

To control the solidification and metallurgical structure of the metal, it is possible to place metal plates—chills— in the mold. The associated rapid local cooling will form a finer-grained structure and may form a somewhat harder metal at these locations. In ferrous castings the effect is similar to quenching metals in forge work. The inner diameter of an engine cylinder is made hard by a chilling core. In other metals chills may be used to promote directional solidification of the casting. In controlling the way a casting freezes it is possible to prevent internal voids or porosity inside castings.

Cores

To produce cavities within the casting—such as for liquid cooling in engine blocks and cylinder heads—negative forms are used to produce cores. Usually sand-molded, cores are inserted into the casting box after removal of the pattern. Whenever possible, designs are made that avoid the use of cores, due to the additional set-up time and thus greater cost.

FIGURE - Two sets of castings (bronze and aluminum) from the above sand mold

With a completed mold at the appropriate moisture content, the box containing the sand mold is then positioned for filling with molten metal—typically iron, steel, bronze, brass, aluminum, magnesium alloys, or various pot metal alloys, which often include lead, tin, and zinc. After filling with liquid metal the box is set aside until the metal is sufficiently cool to be strong. The sand is then removed revealing a rough casting that, in the case of iron or steel, may still be glowing red. When casting with metals like iron or lead, which are significantly heavier than the casting sand, the casting flask is often covered with a heavy plate to prevent a problem known as floating the mold. Floating the mold occurs when the pressure of the metal pushes the sand above the mold cavity out of shape, causing the casting to fail.

FIGURE - Left: - Core box, with resulting (wire reinforced) cores directly below. Right: - Pattern (used with the core) and the resulting casting below (the wires are from the remains of the core

After casting, the cores are broken up by rods or shot and removed from the casting. The metal from the sprue and risers is cut from the rough casting. Various heat treatments may be applied to relieve stresses from the initial cooling and to add hardness—in the case of steel or iron, by quenching in water or oil. The casting may be further strengthened by surface compression treatment—like shot peening—that adds resistance to tensile cracking and smooth's the rough surface.

Cores:

Cores are separate shapes of sand that are generally required to form hollow interiors of the casting or a hole through the casting. Sometimes cores also used to shape those parts of the casting that are not otherwise practical or physically obtainable by mould produced directly from the pattern. The core is left in the mould in castings and is removed after the casting.

Requirements:

1. Cores must be strong enough to retain its shape without deforming, to withstand handling and to resist erosion and deformation during filling of the mould
2. Cores must be permeable to allow the core gases to escape easily
3. Cores should be highly refractory in nature to withstand high temperature of the molten metal
4. Cores must be sufficiently low in residual gas-forming materials to prevent excess gas entering the metal
5. Cores must be stable with a minimum of contraction and expansion to make a true form of casting
6. Cores should be sufficiently collapsible, i.e., they should disintegrate and collapsible after the metal solidifies, to minimize strains on the castings and to facilitate removal of the core from the castings during shakeout.

Types of cores:

1. Horizontal cores: This is a most common type of core which is usually cylindrical in form and is laid horizontally at the parting line of the mould. The ends of the core rest in the seats provided by the core prints on the pattern.
2. Vertical core: This is placed in a vertical position both in cope and drag halves of the mold. Usually top and bottom of the core are provided with a taper, but the amount of taper on the top is greater than that at the bottom.
3. Balanced core: when the casting is to have an opening only one side and only on core print is available on the pattern a balanced core is suitable. The core print in such cases should be large enough to give proper bearing to the core. In case the core is sufficiently long it may be supported at the free end by means of a chaplet (Rods with flat or curved plates riveted to give support).
4. Hanging and cover core: If the core hangs from the cope and does not have any support at the bottom of the drag, it is referred to as hanging core. In this case, it may be necessary to fasten the core with a wire or rod that may extended through the cope. On the other hand, if it has its support on the drag it is called cover core. In this case the core serves as a cover for the mould, and also as a support for hanging the main body of the core.
5. Wing core: A wing core is used when a hole or recess is to be obtained in the castings either above or below the parting line. In this case the side of the core print is given sufficient amount of taper so that the core can be placed readily in the mould. This core is sometimes designated as drop core, tail core chair core and saddle core according to its shape and position in the mould.
6. Ram-up core: It is sometimes necessary to set a core with the pattern before the mould is rammed up. Such a core is located in an inaccessible position in both interior and exterior portions of castings.
7. Kiss core: When the pattern is not provided with a core print and consequently no seat is available for the core, the core is held in position between the cope and drag simply by pressure of the cope. They are suitable when a number of holes of less dimensional accuracy with regard to the relative position of the holes are required.

Design requirements

The part to be made and its pattern must be designed to accommodate each stage of the process, as it must be possible to remove the pattern without disturbing the molding sand and to have proper locations to receive and position the cores. A slight taper, known as draft, must be used on surfaces perpendicular to the parting line, in order to be able to remove the pattern from the mold. This requirement also applies to cores, as they must be removed from the core box in which they are formed. The sprue and risers must be arranged to allow a proper flow of metal and gasses within the mold in order to avoid an incomplete casting. Should a piece of core or mold become dislodged it may be embedded in the final casting, forming a *sand pit*, which may render the casting unusable. Gas pockets can cause internal voids. These may be immediately visible or may only be revealed after extensive machining has been performed. For critical applications, or where the cost of wasted effort is a factor, non-destructive testing methods may be applied before further work is performed.

Pattern

Pattern is the replica of the component to be produced by casting process and isused to prepare mould cavity. The success of a casting process depends a lot on the quality and the design of pattern.

Pattern Materials generally pattern are prepared using

1. Wood
2. Metal
3. Plastic
4. Plaster & Polyurethane foam
5. Wax or Mercury.

1. **Wood** Most popular material for pattern making reasons for using wood as patternmaterial.
    - i. Cheapness
    - ii. Availability
    - iii. Ease of Fabrication in various forms
    - iv. Lightness
    - v. Easiness in sanding to smooth surface
    - vi. Preservation of its surface by application of shellac coating

    Wood pattern has limited life because of distortion and dimensional change willoccur as it is having less resistance.

Types of wood used for pattern making

(a) Pine wood:
-softwood
-Close grain structure
-Easy to work
-low cost.

(b)Teak wood:
-Light straight grained wood
-Easy to shape
-Tendency to warp
- Moderate cost.

(c) Mahogany
-Hard wood
- Most suitable for patterns
-More durable than above woods
-Uniform grain structure -Easy to shape

-Costlier than above woods.

Indian woods: Deodar, walnut, kali,andcherryply wood do not required any seasoning.

2. Metal

-Most suitable for mass production

-Not affected by moisture and No warp page.

- Less wear
- Suitable for precision and intricate -High strength

Disadvantages of metallic pattern are:

- Expensive than wood
- Higher weight
- Tendency to get rusted

Most commonly used metals as pattern materials:-

Aluminum Alloys Higher preferred Metal Grey cast Iron Carbon 2 to 4 %, Si 3.5%

Steel si, mg, s, ph.

1. Low carbon less the 0.3 to .08
2. Medium carbon less the 0.3 to 0.6
3. Higher carbon greater than 0.6 Brass and Bronze
4. **Properties of various pattern materials**

S.NO	PROPERTY	WOOD	MILD STEEL	ALUMINUM ALLOYS	PLASTIC
1	Machinability	Superior	Good	Good	Good
2	Wear resistance	Poof	Superior	Good	Average
3	Strength	Average	Superior	Good	Good
4	Weight	Superior	Poof	Good	Good
5	Corrosion due to moisture	Superior	Poof	Superior	Superior
6	Swelling due to moisture	Poof	Superior	Superior	Superior
7	Reparability	Superior	good	Poof`	average

3. Plaster:

- gypsum cement (plaster of Paris)high compressive strength-300 kgcm^{2}controlled expansion on solidification

Types:-

1. Ultrcal
2. Hydrocal
3. Hydrostone
4. **Plastics**: - Phenolic thermos setting plastic.

Plastic pattern is made from plaster of Paris.

5. **Waxes**: - used in Investment casting

Types

1. Paraffin wax; bees wax
2. Carnauba wax; ceresin wax
3. Shellac wax.

Types of patterns

1. There are various types of patterns depending upon the complexity of the job, the no of castings require and the moulding procedure adoptedFrom the design, provided by an engineer or designer, a skilled pattern maker builds a pattern of the object to be produced, using wood, metal, or plastic; other materials such as expanded polystyrene. Sand can even be ground, swept or even stricken into shape.
2. The metal to be cast will contract during solidification, and this may be non-uniform due to uneven cooling. Therefore, the pattern must be slightly larger than the finished product, a difference known as contraction allowance. Pattern-makers are able to produce suitable patterns using 'Contraction rules' (these are sometimes called "shrink allowance rulers" where the ruled markings are deliberately made to a larger spacing according to the percentage of extra length needed). Different scaled rules are used for different metals because different metals / alloys contract by differing amounts.
3. Patterns also have core prints; these create registers within the molds, into which are placed sand 'cores. Such cores, sometimes reinforced by wires, are used to create undercut profiles and cavities which cannot be molded with the cope and drag, such as the interior passages of valves or cooling passages in motor blocks.
4. Paths for the entrance of metal, during the pouring (casting) process into the mold cavity constitute the runner system and include the sprue, various feeders which maintain a good metal 'feed' and 'runners', and in-gates which attach the runner system to the casting cavity. Gas and steam generated during casting exit through the permeable sand or via the riser, are added either in the pattern itself, or as separate pieces.

TYPES OF CASTING

Sand casting

Sand casting is one of the most popular and simplest types of casting that has been used for centuries. Sand casting allows for smaller batches to be made compared to permanent mold casting and a very reasonable cost. Not only does this method allow for manufacturers to create products for a good cost there are other benefits to sand casting such as there are very little size operations. From castings that fit in the palm of your hand to train beds (one casting can create the entire bed for one rail car) it can be done with sand casting. Sand casting also allows for most metals to be cast depending in the type of sand used for the molds.

Sand casting requires a lead time of days for production at high output rates (1-20 pieces/hrs.-mold), and is unsurpassed for large-part production. Green (moist) sand has almost no part weight limit, whereas dry sand has a practical part mass limit of 2300-2700 kg. Minimum part weight ranges from 0.075-0.1 kg. The sand is bonded together using clays (as in green sand) or chemical binders, or polymerized oils (such as motor oil.) Sand in most operations can be recycled many times and requires little additional input.

A sand casting is a cast part, which is produced by forming a mold out of a sand mixture and pouring a casting liquid (often molten metal) into the mold. The mold is then air-cooled until the metal solidifies, and the mold is removed. Sand Casting is basically done in these steps:

1. Place a pattern in sand to create a mold
2. Incorporate a gating system
3. Remove the pattern
4. Fill the mold cavity with molten metal

5. Allow the metal to cool
6. Break away the sand mold and remove the casting.

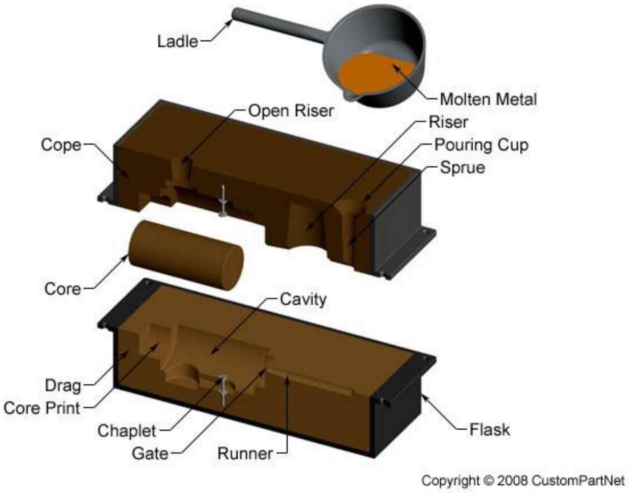


FIG: Sand moulding open

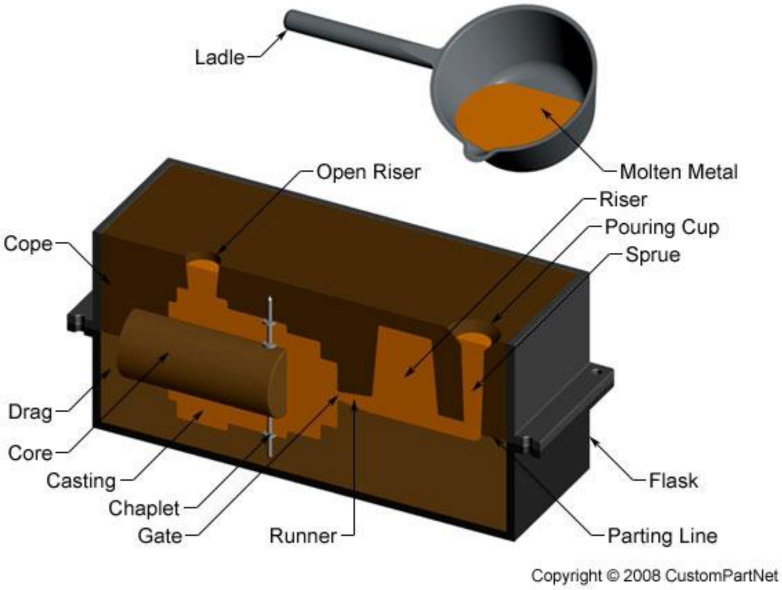


FIG: Sand Mould closed

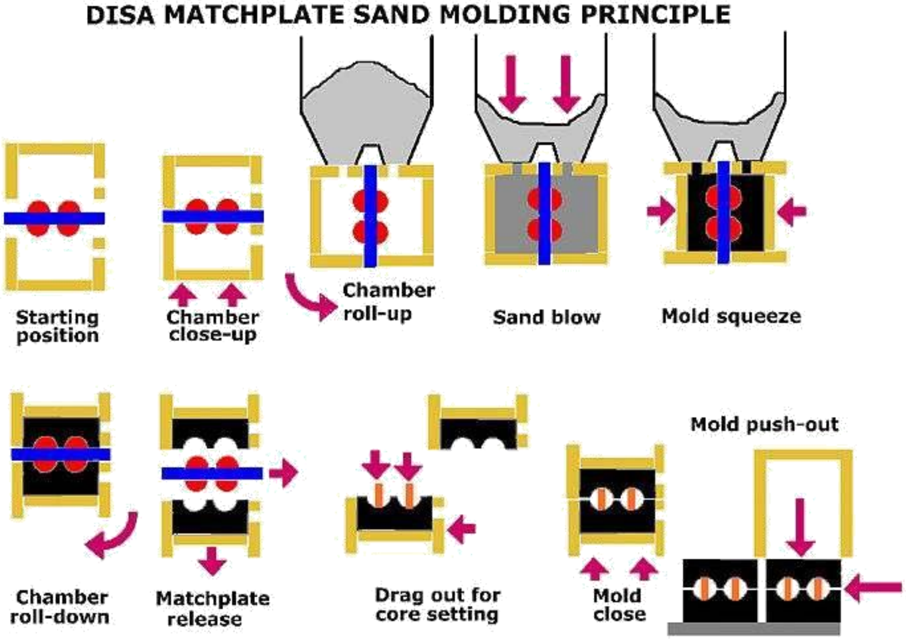


FIGURE – Disa Match plate sand moulding principle

Shell molding

Shell moulding process is an efficient, economical method of producing steel castings. The shell process is ideally suited for medium to high volume production of castings ranging in weight from a few ounces up to 80 pounds.

Shell moulding is a process for producing simple or complex near net shape castings, maintaining tight tolerances and a high degree of dimensional stability. Shell moulding is a method for making high quality castings. These qualities of precision can be obtained in a wider range of alloys and with greater flexibility in design than die-casting and at a lower cost than investment casting. The process was developed and patented by Croning in Germany during World War II and is sometimes referred to as the Croning shell process.

Sand Mixture used:

Generally, dry and fine sand (90 to 140 GFN) which is completely free of clay is used for preparing the sand. The grain size to be chosen depends upon the surface finish desired on the casting. Too fine a grain size requires large amount of resin which makes the mould expensive.

The synthetic resins used in shell moulding are mostly thermosetting resins, which get hardened irreversibly by heat. The resin most widely used, are the phenol formaldehyde resins. Combined with sand, they have very high strength and resistance to heat. The phenolic resins used are of two stage type that is the resin has excess phenol and acts like thermoplastic material. During coating with the sand resin is combined with a catalyst such as hexa-methylene-tetra mine (hexa) in a proportion of about 14 to 16 % so as to develop the thermosetting characteristics. The curing temperature for these would be around 150°C and the time required would be 50 to 60 s.

There are a dozen different stages (steps) in shell mold processing that include:

1. Initially preparing a metal-matched plate
2. Mixing resin and sand

3. Heating pattern, usually to between 505-550 K
4. Inverting the pattern (the sand is at one end of a box and the pattern at the other, and the box is inverted for a time determined by the desired thickness of the mill)
5. Curing shell and baking it
6. Removing investment
7. Inserting cores
8. Repeating for other half
9. Assembling mold
10. Pouring mold
11. Removing casting
12. Cleaning and trimming.

Procedure:

- Preparing the shell mould by mixing the sand in such a way that each sand grain is thoroughly coated with resin, which is done by mixing all dry sand, additives if any and hexa are mixed in a muller for 1 min and then liquid resin is added and mixed in muller for 3 min. To this cold or warm air is introduced and the mixing is continued till all the liquid is removed from the mixture and coating of the grains is achieved to the desired degree.
- Then the mixture is cooled at 150°C temperature, only metal patterns with the associated gating are used. The metallic pattern is heated to a temperature of 200 to 300 ° so that temperature variation across the whole pattern is within 25 to 40°C depending on the size. A silicone release agent is sprayed on the pattern and the metal plate. The heated pattern is securely fixed to a dump box, of necessary thickness is already filled in.
- Then the dump box is rotated at 45° so that the sand falls on the heated pattern. The heat from the pattern melts the resin adjacent to it thus causing the sand mixture to adhere to the pattern.
- Then the dump box is turned to the initial position so the excess sand falls back in to the box leaving the formed shell intact with the pattern.
- The shell along with the pattern is kept in a gas fired oven for curing.
- The shells thus prepared are joined together by adhesive bonding to get complete pattern. Now the molten metal is sent in to the shell and allow to solidify and then the shell

Advantages

- Better surface finish
- Better dimensional tolerances.
- Reduced Machining.
- Less foundry space required.
- Semi-skilled operators can handle the process.
- The process can be mechanized.
- Castings are dimensionally accurate than sand castings. It is possible to obtain a tolerance of ±0.25 mm foe steel castings and ±0.35 mm for grey cast iron castings under normal working conditions.
- Permeability of the shell is high and therefore no gas inclusions occur.
- Very small amount of sand needs to be used.
- Mechanization is readily possible because of the simple processing involved in shell moulding.
- Very thin sections (up to 0.25mm) of the type air cooled cylinder heads can be readily made because of the high strength of the sand used.

Disadvantages

- The raw materials are relatively expensive.
- The process generates noxious fumes which must be removed.
- The size and weight range of castings is limited.

- The patterns are expensive and therefore are economically used in large scale production.
- Complicated shapes cannot be made.

Applications

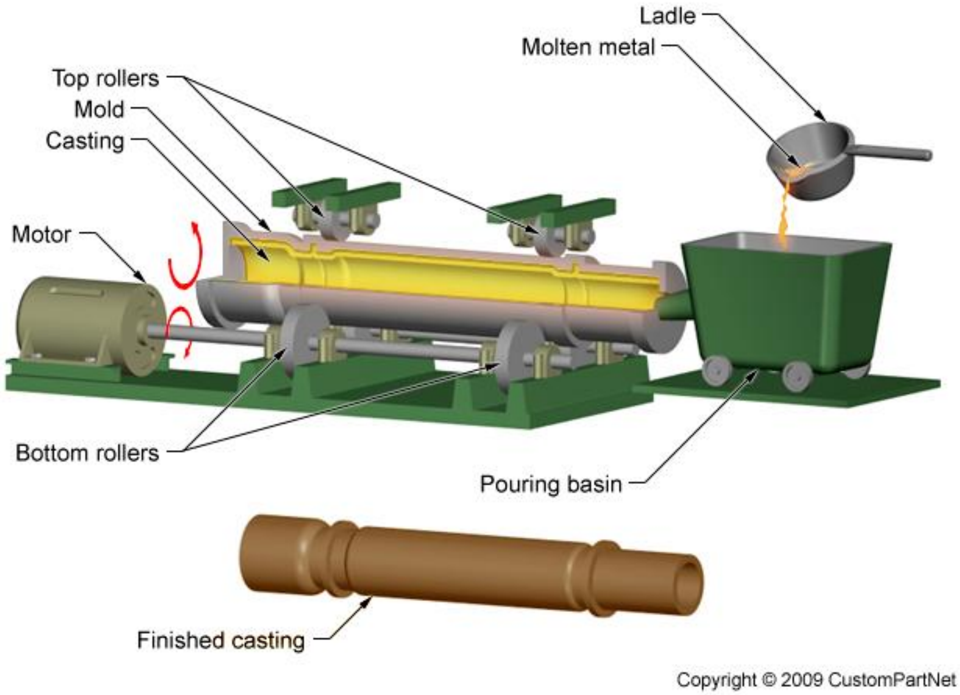
- Crankshaft fabrication
- Steel casting parts, fittings
- Mouldedtubing fabrication
- Hydraulic control housing fabrication

CENTRIFUGAL CASTING

Centrifugal casting, sometimes called rotocasting, is a metal casting process that uses centrifugal force to form cylindrical parts. This differs from most metal casting processes, which use gravity or pressure to fill the mold. In centrifugal casting, a permanent mold made from steel, cast iron, or graphite is typically used. However, the use of expendable sand molds is also possible. The casting process is usually performed on a horizontal centrifugal casting machine (vertical machines are also available) and includes the following steps:

1. Mold preparation - The walls of a cylindrical mold are first coated with a refractory ceramic coating, which involves a few steps (application, rotation, drying, and baking). Once prepared and secured, the mold is rotated about its axis at high speeds (300-3000 RPM), typically around 1000 RPM.
2. Pouring - Molten metal is poured directly into the rotating mold, without the use of runners or a gating system. The centrifugal force drives the material towards the mold walls as the mold fills.
3. Cooling - With all of the molten metal in the mold, the mold remains spinning as the metal cools. Cooling begins quickly at the mold walls and proceeds inwards.
4. Casting removal - After the casting has cooled and solidified, the rotation is stopped and the casting can be removed.
5. Finishing - While the centrifugal force drives the dense metal to the mold walls, any less dense impurities or bubbles flow to the inner surface of the casting. As a result, secondary processes such as machining, grinding, or sand-blasting, are required to clean and smooth the inner diameter of the part.

Centrifugal casting is used to produce axis-symmetric parts, such as cylinders or disks, which are typically hollow. Due to the high centrifugal forces, these parts have a very fine grain on the outer surface and possess mechanical properties approximately 30% greater than parts formed with static casting methods. These parts may be cast from ferrous metals such as low alloy steel, stainless steel, and iron, or from non-ferrous alloys such as aluminum, bronze, copper, magnesium, and nickel. Centrifugal casting is performed in wide variety of industries, including aerospace, industrial, marine, and power transmission. Typical parts include bearings, bushings, coils, cylinder liners, nozzles, pipes/tubes, pressure vessels, pulleys, rings, and wheels



Advantages:

- Can form very large parts
- Good mechanical properties
- Good surface finish and accuracy
- Low equipment cost
- Low labor cost
- Little scrap generated

Disadvantages:

- Limited to cylindrical parts
- Secondary machining is often required for inner diameter
- Long lead time possible

Applications:

Pipes, wheels, pulleys, nozzles

DIE CASTING

Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable molds, called dies. The die casting process involves the use of a furnace, metal, die casting machine, and die. The metal, typically a non-ferrous alloy such as aluminum or zinc, is melted in the furnace and then injected into the dies in the die casting machine. There are two main types of die casting machines - hot chamber machines (used for alloys with low melting temperatures, such as zinc) and cold chamber machines (used for alloys with high melting temperatures, such as aluminum). The differences between these machines will be detailed in the sections on equipment and tooling. However, in both machines, after the molten metal is injected into the dies, it rapidly cools and solidifies into the final part, called the casting. The steps in this process are described in greater detail in the next section.

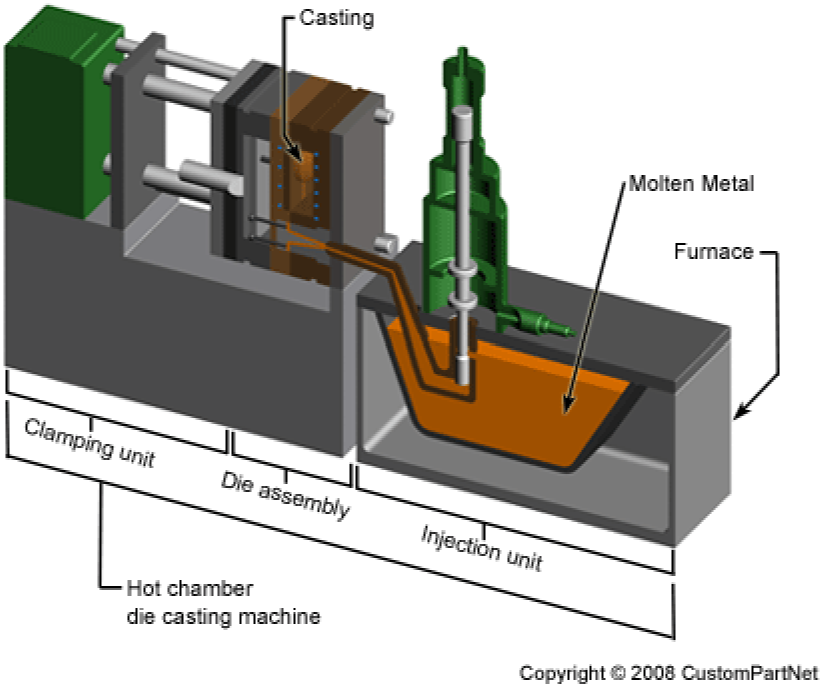


FIGURE – Die casting hot chamber machine overview

The process cycle for die casting consists of five main stages, which are explained below. The total cycle time is very short, typically between 2 seconds and 1 minute.

1. Clamping
   - The first step is the preparation and clamping of the two halves of the die. Each die half is first cleaned from the previous injection and then lubricated to facilitate the ejection of the next part. The lubrication time increases with part size, as well as the number of cavities and side-cores. Also, lubrication may not be required after each cycle, but after 2 or 3 cycles, depending upon the material. After lubrication, the two die halves, which are attached inside the die casting machine, are closed and securely clamped together. Sufficient force must be applied to the die to keep it securely closed while the metal is injected. The time required to close and clamp the die is dependent upon the machine - larger machines (those with greaterclamping forces) will require more time. This time can be estimated from the dry cycle time of the machine.
2. Injection
   - The molten metal, which is maintained at a set temperature in the furnace, is next transferred into a chamber where it can be injected into the die. The method of transferring the molten metal is dependent upon the type of die casting machine, whether a hot chamber or cold chamber machine is being used. The difference in this equipment will be detailed in the next section. Once transferred, the molten metal is injected at high pressures into the die. Typical injection pressure ranges from 1,000 to 20,000 psi. This pressure holds the molten metal in the dies during solidification. The amount of metal that is injected into the die is referred to as the shot. The injection time is the time required for the molten metal to fill all of the channels and cavities in the die. This time is very short, typically less than 0.1 seconds, in order to prevent early solidification of any one part of the metal. The proper injection time can be determined by the thermodynamic properties of the material, as well as the wall thickness of the casting. A greater wall thickness will require a longer injection time. In the case where a cold chamber die casting machine is

being used, the injection time must also include the time to manually ladle the molten metal into the shot chamber.

3. Cooling
   - The molten metal that is injected into the die will begin to cool and solidify once it enters the die cavity. When the entire cavity is filled and the molten metal solidifies, the final shape of the casting is formed. The die cannot be opened until the cooling time has elapsed and the casting is solidified. The cooling time can be estimated from several thermodynamic properties of the metal, the maximum wall thickness of the casting, and the complexity of the die. A greater wall thickness will require a longer cooling time. The geometric complexity of the die also requires a longer cooling time because the additional resistance to the flow of heat.
4. Ejection
   - After the predetermined cooling time has passed, the die halves can be opened and an ejection mechanism can push the casting out of the die cavity. The time to open the die can be estimated from the dry cycle time of the machine and the ejection time is determined by the size of the casting's envelope and should include time for the casting to fall free of the die. The ejection mechanism must apply some force to eject the part because during cooling the part shrinks and adheres to the die. Once the casting is ejected, the die can be clamped shut for the next injection.
5. Trimming
   - During cooling, the material in the channels of the die will solidify attached to the casting. This excess material, along with any flash that has occurred, must be trimmed from the casting either manually via cutting or sawing, or using a trimming press. The time required to trim the excess material can be estimated from the size of the casting's envelope. The scrap material that results from this trimming is either discarded or can be reused in the die casting process. Recycled material may need to be reconditioned to the proper chemical composition before it can be combined with non-recycled metal and reused in the die casting process.

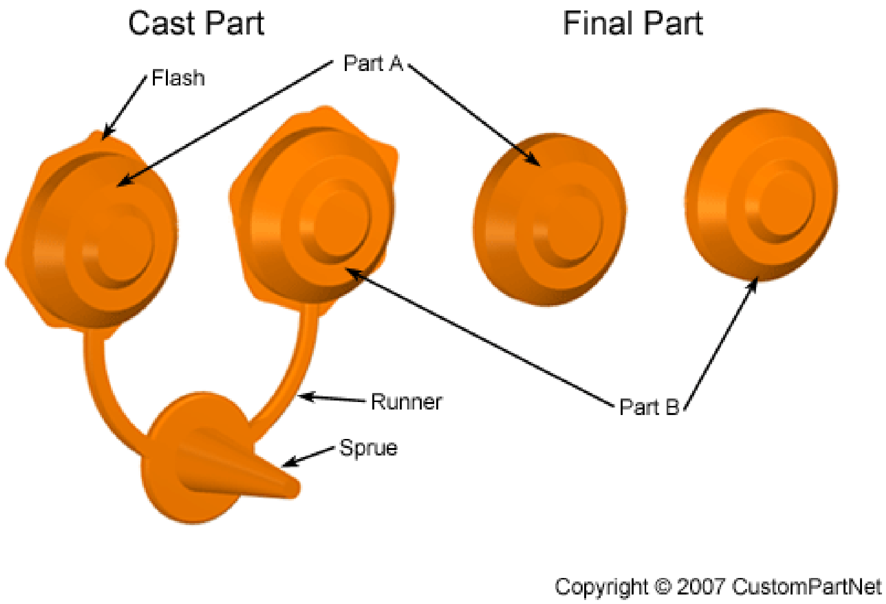


FIGURE – Die casting part

Advantages:

- Can produce large parts
- Can form complex shapes

- High strength parts
- Very good surface finish and accuracy
- High production rate
- Low labor cost
- Scrap can be recycled

Disadvantages:

- Trimming is required
- High tooling and equipment cost
- Limited die life
- Long lead time

Applications:

- Engine components
- Pump components
- Appliance housing

INVESTMENT CASTING

Investment casting is one of the oldest manufacturing processes, dating back thousands of years, in which molten metal is poured into an expendable ceramic mold. The mold is formed by using a wax pattern - a disposable piece in the shape of the desired part. The pattern is surrounded, or "invested", into ceramic slurry that hardens into the mold. Investment casting is often referred to as "lost-wax casting" because the wax pattern is melted out of the mold after it has been formed. Lox-wax processes are one-to-one (one pattern creates one part), which increases production time and costs relative to other casting processes. However, since the mold is destroyed during the process, parts with complex geometries and intricate details can be created.

Investment casting can make use of most metals, most commonly using aluminum alloys, bronze alloys, magnesium alloys, cast iron, stainless steel, and tool steel. This process is beneficial for casting metals with high melting temperatures that cannot be molded in plaster or metal. Parts that are typically made by investment casting include those with complex geometry such as turbine blades or firearm components. High temperature applications are also common, which includes parts for the automotive, aircraft, and military industries.

Investment casting requires the use of a metal die, wax, ceramic slurry, furnace, molten metal, and any machines needed for sandblasting, cutting, or grinding. The process steps include the following:

1. Pattern creation - The wax patterns are typically injection molded into a metal die and are formed as one piece. Cores may be used to form any internal features on the pattern. Several of these patterns are attached to a central wax gating system (sprue, runners, and risers), to form a tree-like assembly. The gating system forms the channels through which the molten metal will flow to the mold cavity.

2. Mold creation - This "pattern tree" is dipped into a slurry of fine ceramic particles, coated with more coarse particles, and then dried to form a ceramic shell around the patterns and gating system. This process is repeated until the shell is thick enough to withstand the molten metal it will encounter. The shell is then placed into an oven and the wax is melted out leaving a hollow ceramic shell that acts as a one-piece mold, hence the name "lost wax" casting.

3. Pouring - The mold is preheated in a furnace to approximately 1000°C (1832°F) and the molten metal is poured from a ladle into the gating system of the mold, filling the mold cavity. Pouring is typically

achieved manually under the force of gravity, but other methods such as vacuum or pressure are sometimes used.

4. Cooling - After the mold has been filled, the molten metal is allowed to cool and solidify into the shape of the final casting. Cooling time depends on the thickness of the part, thickness of the mold, and the material used.
5. Casting removal - After the molten metal has cooled, the mold can be broken and the casting removed. The ceramic mold is typically broken using water jets, but several other methods exist. Once removed, the parts are separated from the gating system by either sawing or cold breaking (using liquid nitrogen).
6. Finishing - Often times, finishing operations such as grinding or sandblasting are used to smooth the part at the gates. Heat treatment is also sometimes used to harden the final part.

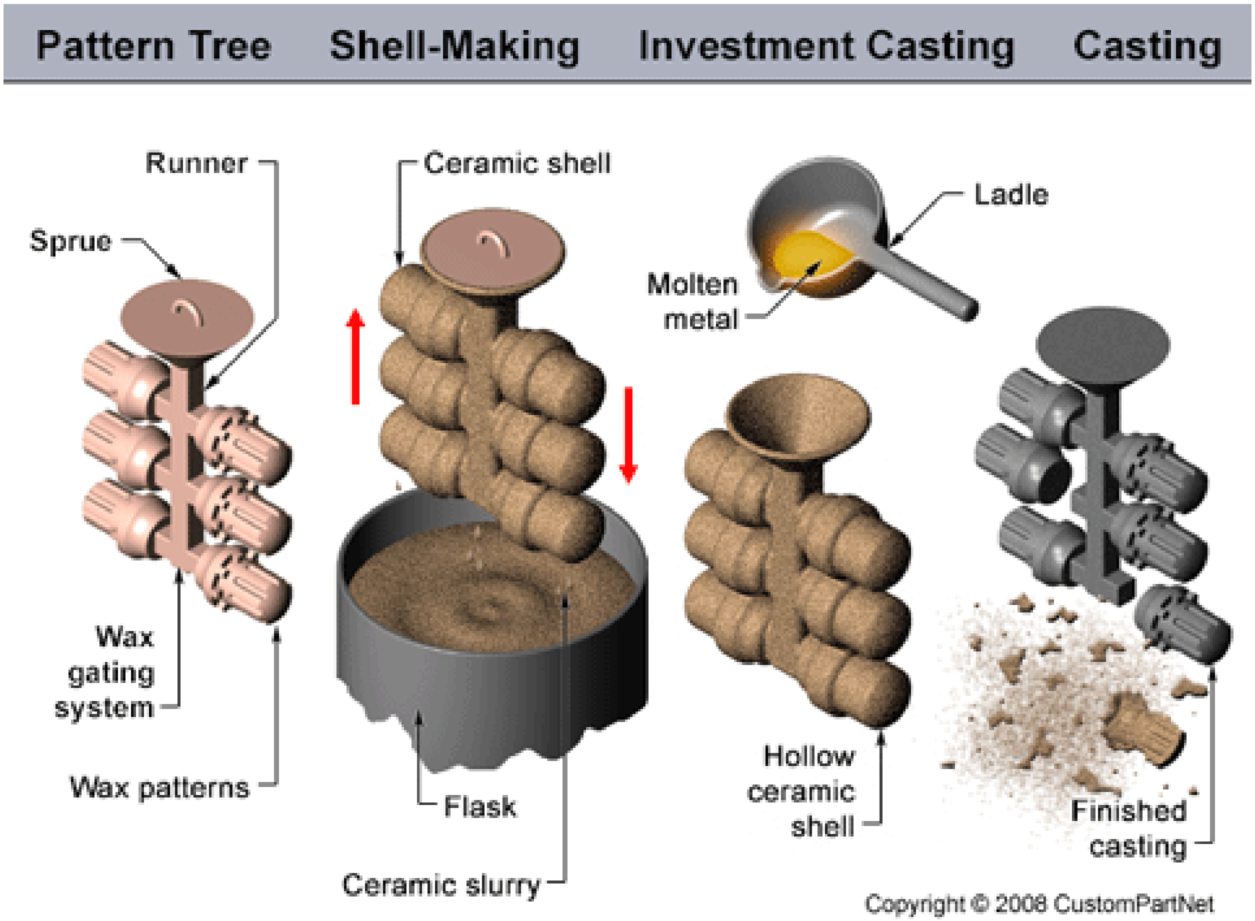


FIGURE - Investment Casting

Advantages:

- Can form complex shapes and fine details
- Many material options
- High strength parts
- Very good surface finish and accuracy

- Little need for secondary machining

Disadvantages:

- Time-consuming process
- High labor cost
- High tooling cost
- Long lead time possible

Applications:

- Turbine blades
- armament parts,
- pipe fittings
- lock parts,
- handtools
- jewelry

WELDING

1. Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causingcoalescence. This is often done by melting the work pieces and adding a filler material to form a pool of molten material (the weld puddle) that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting-point material between the work pieces to form a bond between them, without melting the work pieces
2. Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, underwater and in space. Regardless of location, however, welding remains dangerous, and precautions must be taken to avoid burns, electric shock, eye damage, poisonous fumes, and overexposure to ultraviolet light.
3. Until the end of the 19th century, the only welding process was forge welding, which blacksmiths had used for centuries to join metals by heating and pounding them. Arc welding and oxyfuel welding were among the first processes to develop late in the century, and resistance welding followed soon after.
4. Welding technology advanced quickly during the early 20th century as World War I and World War II drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding, flux-cored arc welding and electroslag welding. Developments continued with the invention of laser beam welding and electron beam welding in the latter half of the century. Today, the science continues to advance. Robot welding is becoming more commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality and properties.

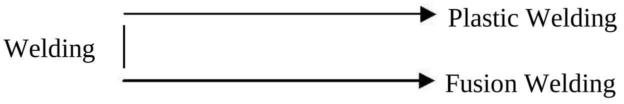
FIGURE – Welding operation

Welding can be broadly classified into

Fusion welding: Is the processes of joining two pieces by application of heat. The two parts to be joined are placed together, heated often with the addition of filler metal, until they, solidify on cooling.

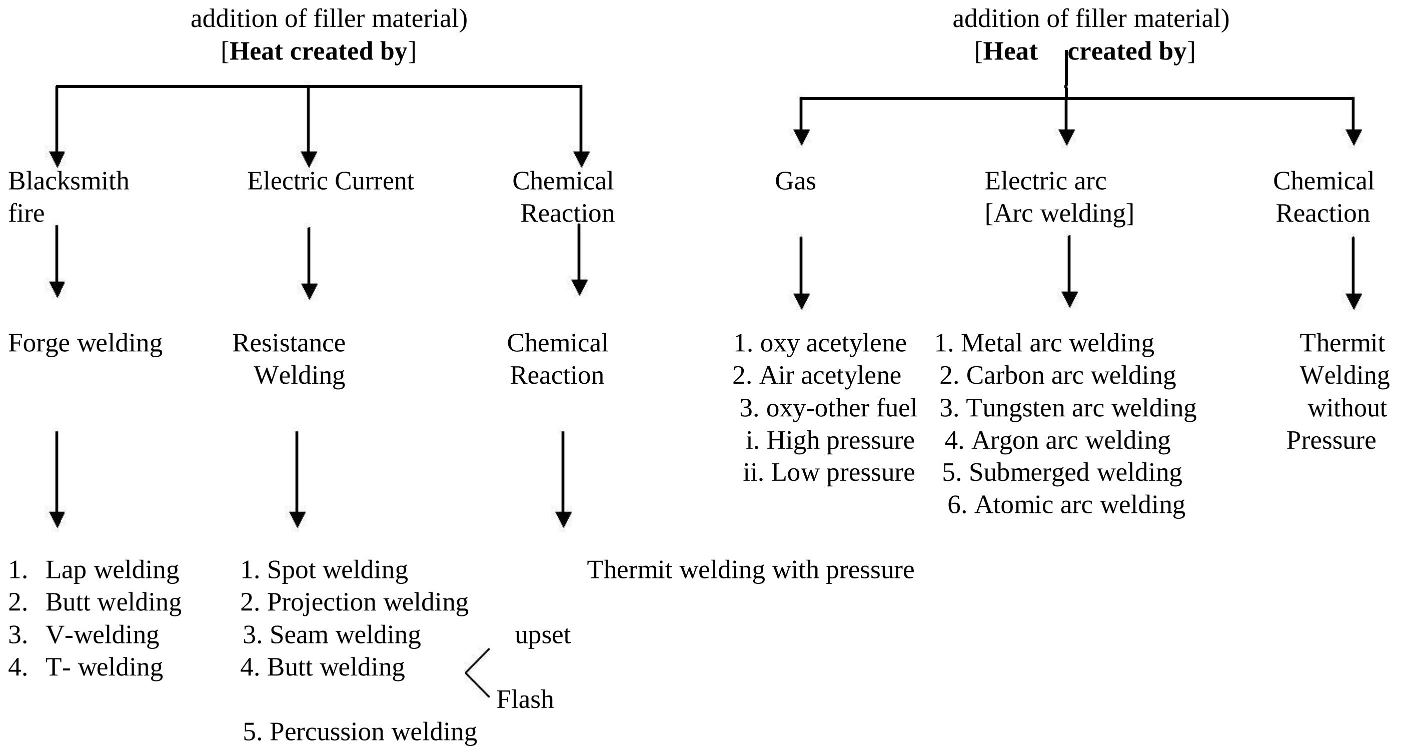
Solid state welding: Welds are produced by bringing the clean faces of components into intimate contact to produce a metallic bond with or without application of heat, but application of pressure is essential to induce plastic flow.

Plastic welding: the Pieces of metal to be joined are heated to the plastic state and these forced together by external pressure without the addition of filler material.



Plastic Welding
(Under Pressure, without

Fusion welding
(No Pressure, with the



Solid state welding:

- Like the first welding process, forge welding, some modern welding methods donot involve the melting of the materials being joined. One of the most popular, ultrasonic welding is used to connect thin sheets or wires made of metal or thermoplastic by vibrating them at high frequency and under high pressure.
- The equipment and methods involved are similar to that of resistance welding, but instead of electric current, vibration provides energy input. Welding metals with this process does not involve melting the materials; instead, the weld is formed by introducing mechanical vibrations horizontally under pressure.
- When welding plastics, the materials should have similar melting temperatures, and the vibrations are introduced vertically. Ultrasonic welding is commonly used for making electrical connections out of aluminum or copper, and it is also a very common polymer welding process.
- Another common process, explosion welding, involves the joining of materials by pushing them together under extremely high pressure. The energy from the impact plasticizes the materials, forming a weld, even though only a limited amount of heat is generated. The process is commonly used for welding dissimilar materials, such as the welding of aluminum with steel in ship hulls or compound plates.
- Other solid-state welding processes include co-extrusion welding, cold welding, diffusion welding, friction welding (including friction stir welding), high frequency welding, hot pressure welding, induction welding, and roll welding.

Arc welding:

These processes use a welding power supply to create and maintain an electric arc between an electrode and the base material to melt metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is sometimes protected by some type of inert or semi-inert gas, known as a shielding gas, and filler material is sometimes used as well.

- In this case, heat is liberated at the arc terminals and this heat is used to melt the metals to be welded at the points of contact, so that they will flow together and form an integral mass. Thus different parts may be joined.

- A filler material is also added to the surface of the metal. A tremendous heat is liberated and the temperature of the arc is of the order of 3600°C. This heat causes a small pool of metal to melt in the work.
- When additional metal is required for welding, a welding rod is used which is melted by the heat of the arc and deposited into this small pool in the molten state. The molten metal in the pool is agitated by the action of the arc, and thus the parent and added metal are thoroughly mixed and refined so that after cooling, a sound joint is formed Fig. 9.30 shows the welding circuit for an electric-arc welding process.
- Arc is created by low voltage, high current supply. Flux coated electrodes are used which on melting form a protective gas shield around the electrode tip and molten weld pool. On cooling, to reduce of this flux solidifies to form a slag on the surface of the weld, which is subsequently chipped away.
- Arc initiation voltage is of the order of 60 – 100 V and arc maintenance voltage is of the order of 25 – 40 V. Power source may be a.c. or d.c. supply. In a.c. supply, it does not matter whether work or electrode is positive but with D.C. source, polarity is important. A gap of about 3mm is maintained for producing sound weld.

Source of Electric Supply for Arc Welding.

The current and voltage requirements during arcwelding process vary considerably. In arc welding, short circuits keep on taking place place frequently. For example, whenever the operator touches the electrode to the work in order to strike an arc, short circuit is created.

Similarly when the molten globules of weld metal cross the arc, electric short circuits 9aroudn 20 nos. per sec.) Are caused.Under short circuit condition, current drawn in excessively high because resistance falls to very low value.Excessive heat caused by high current surges results in excessive spatter and sticking of the electrode. A good arc-welding generator is designed to limit those instantaneous surges of current.

When short-circuit is there, voltage falls almost to zero, but when it is cleared, considerable voltage is required is required to keep the arc alive. Similarly if arc length is quickly changed, adequate recovery of voltage instantaneously is called for.

Thus electric supply source of arc welding should provide sufficient current depending on size of electrode, a suitable voltage for striking and maintaining the arc, and of suitable characteristics to provide stability for the arc. The voltage across the arc may vary from 20 to 45 volts and current from 75 to 600 amperes.

Various sources of electric supply for arc welding process are:
(i) D.C. generator with variable voltage characteristics.
(ii) D.C. generator with constant voltage characteristics.
(iii) D.C. power line in conjunction with resistors to reduce the voltage and current.
(iv) Speciala.c. generator or transformer.

For most steel welding applications, a.c. source is normally used because of use of cheap a.c. transformers. D.C. supply is preferred for welding sheet metal, non-ferrous metals and stainless steel through it requires transformer-rectifier

The welding circuit consists of a welding machine, two leads, and electrode holder, an electrode and the work itself.

From the figure the voltage-current relationship exists for arc welding process. It would be noted that for a given spacing and the electrode material, voltage reduces up to current of 50 A and starts increasing gradually and very slowly with further increase in current. This relationship determines the characteristics of the power source. The electric power supply usually has a drooping characteristic, i.e. with increase in current, voltage drops. The drop may be either sharply drooping (suited for manual arc welding) or nearly flat (suited for semi-automatic arc welding) depending on type of power supply source. The operating point is determined where two curves intersect. The stable operating point is obtained on the right hand side because any disturbance is automatically opposed and operating point returns to the original value.

From the figure the potential difference across arc is distributed. Anode spot is the area on the anode surface where the electrons are absorbed. Anode space is the gaseous region (around 10 Zm thick) adjacent to the anode surface where a sharp drop in voltage takes place. Arc column is the visible portion of the arc consisting of plasma where the voltage drop is not sharp. Cathode space is the gaseous region adjacent to the anode surface where a sharp drop in voltage takes place. Arc column is the visible portion of the arc consisting of plasma where the voltage drop is not sharp. Cathode space is the gaseous region adjacent to the cathode (around 10 Zm) thick). Sharp voltage drop in this region is necessary as the electrons have to be pulled up from this region. Relative voltage drops in various zones re dependent on the spacing current, and electrode materials.

Power supplies

To supply the electrical energy necessary for arc welding processes, a number of different power supplies can be used. The most common classification is constant current power supplies and constant voltage power supplies. In arc welding, the length of the arc is directly related to the voltage, and the amount of heat input is related to the current. Constant current power supplies are most often used for manual welding processes such as gas tungsten arc welding and shielded metal arc welding, because they maintain a relatively constant current even as the voltage varies. This is important because in manual welding, it can be difficult to hold the electrode perfectly steady, and as a result, the arc length and thus voltage tend to fluctuate. Constant voltage power supplies hold the voltage constant and vary the current, and as a result, are most often used for automated welding processes such as gas metal arc welding, flux cored arc welding, and submerged arc welding. In these processes, arc length is kept constant, since any fluctuation in the distance between the wire and the base material is quickly rectified by a large change in current. For example, if the wire and the base material get too close, the current will rapidly increase, which in turn causes the heat to increase and the tip of the wire to melt, returning it to its original separation distance.

The type of current used in arc welding also plays an important role in welding. Consumable electrode processes such as shielded metal arc welding and gas metal arc welding generally use direct current, but the electrode can be charged either positively or negatively. In welding, the positively charged anode will have a greater heat concentration, and as a result, changing the polarity of the electrode has an impact on weld properties. If the electrode is positively charged, the base metal will be hotter, increasing weld penetration and welding speed. Alternatively, a negatively charged electrode results in more shallow welds. No consumable electrode processes, such as gas tungsten arc welding, can use either type of direct current, as well as alternating current. However, with direct current, because the electrode only creates the arc and does not provide filler material, a positively charged electrode causes shallow welds, while a negatively charged electrode makes deeper welds. Alternating current rapidly moves between these two, resulting in medium-penetration welds. One disadvantage of AC, the fact that the arc must be re-ignited after every zero crossing, has been addressed with the invention of special power units that produce a square wave pattern instead of the normal sine wave, making rapid zero crossings possible and minimizing the effects of the problem.

Arc Welding Equipment. The most commonly used tools for a welding process are listed below:
(1) A.C. or D.C. machines
(2) Electrode (bare or coated)
(3) Electrode-holder
(4) Cables and its connectors
(5) Chipping hammer

(6) Earthling clamps
(7) Wire-brush
(8) Helmet
(9) Safety goggles
(10) Hand gloves
(11) Aprons, sleeves etc.

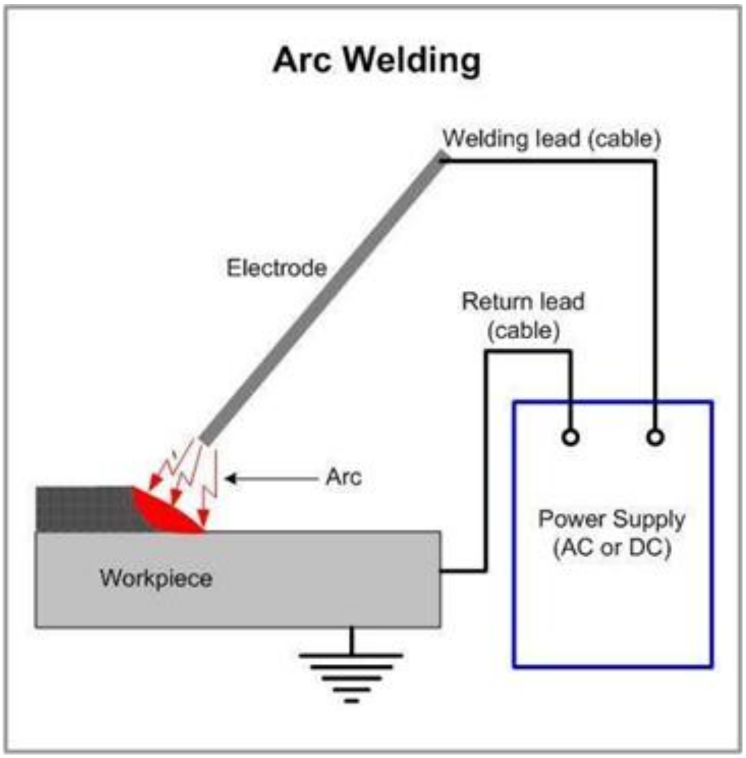


FIGURE- ARC Welding process

Gas metal arc welding (GMAW)

1. Gas metal arc welding (GMAW), also known as metal inert gas or MIG welding, is a semi-automatic or automatic process that uses a continuous wire feed as an electrode and an inert or semi-inert gas mixture to protect the weld from contamination.
2. As with SMAW, reasonable operator proficiency can be achieved with modest training. Since the electrode is continuous, welding speeds are greater for GMAW than for SMAW. Also, the smaller arc size compared to the shielded metal arc welding process makes it easier to make out-of-position welds (e.g., overhead joints, as would be welded underneath a structure).
3. The equipment required to perform the GMAW process is more complex and expensive than that required for SMAW, and requires a more complex setup procedure. Therefore, GMAW is less portable and versatile, and due to the use of a separate shielding gas, is not particularly suitable for outdoor work.
4. However, owing to the higher average rate at which welds can be completed, GMAW is well suited to production welding. The process can be applied to a wide variety of metals, both ferrous and non-ferrous.
5. A related process, flux-cored arc welding (FCAW), uses similar equipment but uses wire consisting of a steel electrode surrounding a powder fill material. This cored wire is more expensive than the standard solid wire and can generate fumes and/or slag, but it permits even higher welding speed and greater metal penetration.

Gas tungsten arc welding (GTAW)

Gas tungsten arc welding (GTAW), or tungsten inert gas (TIG) welding (also sometimes erroneously referred to as heliarc welding), is a manual welding process that uses a non-consumable tungsten electrode, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds.

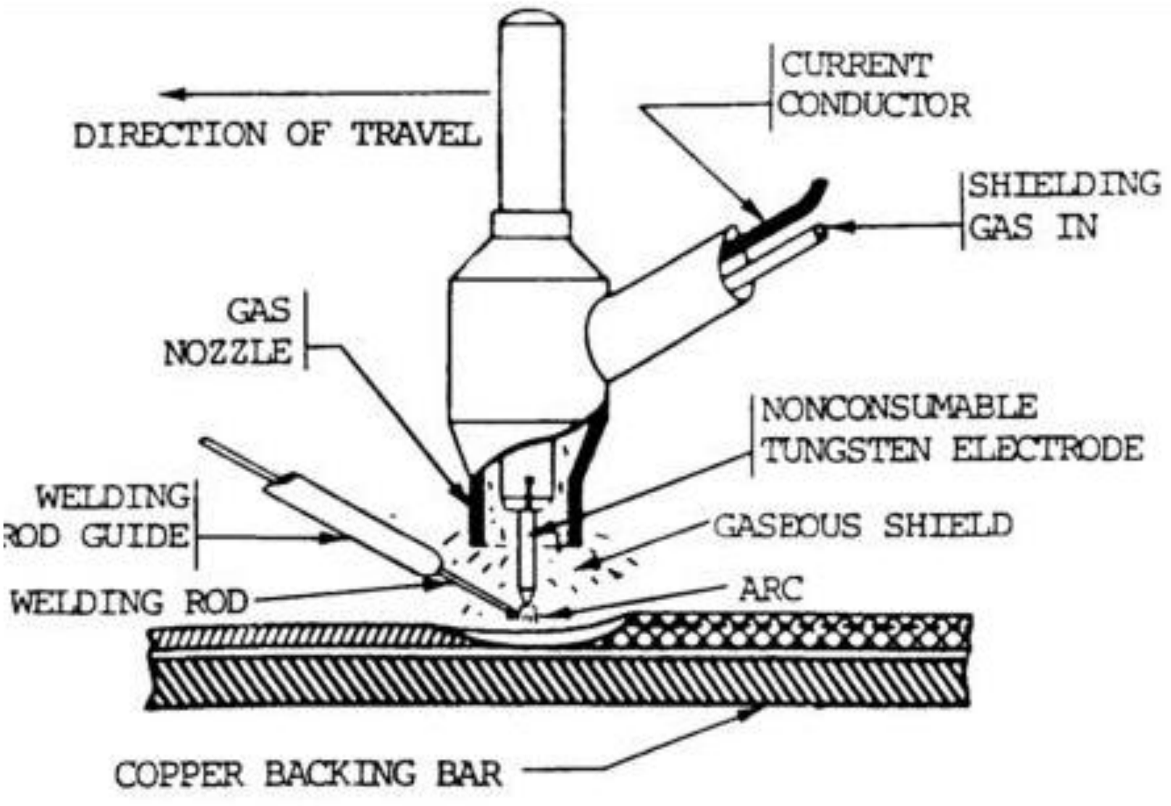


FIGURE- Gas welding

Air during welding, (viz. oxygen, hydrogen, nitrogen and water vapour) tends to reduce the quality of weld. Inert gases are used to keep contaminants away from contacting the metal, and also to remove the contaminants from the metal surfaces as the contaminants like air, dust and metal oxides also reduce the weld quality considerably. Inert arc gas welding is faster, produces cleaner weld and can weld considered to be difficult or impossible to weld.
Earlier GTAW was called as:

TIG welding. (Tungsten inert gas welding): It uses a non-consumable electrode and a separatefiller metal with an inert shielding gas supply, and tubing for water for cooling the torch. The shape of torch is characteristic, having a cap at the back and to protect the rather long tungsten electrode against accidental breakage.
In an arc welding process, three elements (current, voltage and speed of travel) have to be controlled to

obtain satisfactory welding operation.

In automatic welding, all these variables are present and controlled by the welding equipment.

The important statements about are welding principles which require due consideration in study of welding machines are reviewed here.

(i) A welding arc has two electrodes, one being the welding rod, and the other being the work-piece to be welded. If direct current is used for arc welding, there are two possibilities (or polarities, as they are called). One is direct current straight polarity (DCSP) in which the work-piece is connected to the positive terminal of the welding machine. The other is DCRP (reverse polarity) in which the work piece is made negative

(ii) Arc-voltage is the voltage drop across the arc between the two electrodes. It increases with arc length. If the electrode is shorted to the work-piece, the voltage drop across the arc is zero.

(iii) Penetration is deepest for DCSP (because the electron stream flows to the work, thus concentrating the heat at the work), less for A.C. and least for DCRP. In the case of DCRP good cleaning action is obtained. Due to less penetration in case of DCRP process, it is best suited for thin sections of aluminum, magnesium and other hard-to-weld materials using tungsten electrodes.

(iv) In an arc welding process using direct current, about two-thirds of useful arc heat appears at the anode, and about one-third at the cathode. In A.C. welding the welding heat will be distributed equally between the welding rod and the work-piece.

(v) Deposition rate of filler metal increases with current.

Gas Tungsten Arc Welding (GTAW) or TIG (tungsten inert gas) welding used a non-consumable tungsten electrode to heat and melt the work-piece. Filler metal can be fed. Molten puddle is shielded from the atmosphere with an inert gas supply feeding from the torch cup.

Advantages of GTAW Process.

(a) It welds more different types of metals and alloys (carbon steel,stainless steel, nickel steels, aluminum, magnesium, brass, copper, bronze, titanium.

(b) Unlike metals can be welded to each other like mild steel stainless steel, brass to copper.

(c) Heat-affected zone (weak area for failure of sound weld) is very low.

(d) Filler metal need not pass through the superheated electric arc.

(e) Requires no clean up because of absence of slag or spatter.

Generally the water hose, inert gas hose, and welding leads are all in one jacket and form one head. Common practice is to flow the outlet water along the electrode lead. This water cooling permits using a smaller diameter lead, which provides a lighter weight torch.

And greater flexibility. The arc welding machine may be either a motor-generator unit, or a rectifier unit, or a rectifier unit. Most of the welding machines use a high frequency superimposed current in the circuits to aid in starting the arc. The use of GTAW is confined mainly to the welding of relatively thin materials upto about 7 mm. It is especially suited for welding aluminum and magnesium-based alloys, stainless steel, titanium, etc.

GTAW Tungsten Electrodes. Five types of electrodes are given below and the color by which thecase identified is also indicated in bracket:

(i) Pure tungsten (W) (green)
(ii) 1% Thoriated W (yellow)
(iii) 2% Thoriated W (red)
(iv) Striped W (blue)
(v) Zirconium W (brown)

Pure tungsten electrode is used only on ACHF and designed for aluminum and Mg welding only:

1% Thoriated tungsten electrode is used for copper and copper alloys.

2% Thoriated tungsten electrode can be used for almost any metal.

Striped tungsten electrode combines pure tungsten and a stripe of 2% Thoriated tungsten. Thoriat helps to keep a stabilized arc and increase melting temperature.

Zirconium tungsten reduces the contamination effects of dipping the tungsten into the molten puddle while welding Al and Mg.

For starting the unit it should be ensured that sufficient water (as that the temperature rise is about 5^oC) and inert gas are flowing (gas flow may be controlled by relays and solenoid valves automatically also).

The extension of electrode out of the cup should, be approximately equal to the inside diameter of the cup of slightly more in case of fillet welds, otherwise the shielding effect will be reduced.

Preventing tungsten contamination. For preventing tungsten contamination, it should be shieldedfrom the atmosphere and should not touch the weld puddle. To achieve this:

- Inert gas flow must be sufficient.
- Laminar flow of shielding gas must be achieved.
- Post-purge should be long enough to allow tungsten to cool to a non-reactive state.

For striking the arc the torch is held horizontally over the metal starting block or work (or best on the used tungsten electrode) and very quickly tilted and swung to the upright position with the electrode reaching a point about 3 mm above the metal : the arc will jump this gap. With A.C. the unit needs superimposed high frequency. The tungsten electrode torch should then be warmed by practicing on a scrap piece of metal, before starting the weld in order to get good starting results on the job. The correct positions of the tungsten electrode and the filler wire in manual gas tungsten arc welding are shown in Fig. 9.44.

Shielding gases for GTAW. Various gases and gas mixtures used are:

Argon. This being heavier than air produces a superior shield. Its low resistance to electricityionization at (17 V) it produces a higher volume of heat in the arc stream and thus a wide, deeper penetration puddle.

Argon – Helium. It combines the characteristics of excellent shielding of argon and the wider arestream and wider/deeper puddle of helium.

Argon – H_2. The addition of H_2increase the wetting action (fluidity) and makes low thermalconductivity metals to be welded faster and easier.

Argon – CO_2. It is used for carbon steels only.

Usually argon is used as the shielding gas. Sometimes helium is used for welding thicker sections since light arc voltages are possible with this gas helium is, of course, a costly gas.

GTAW can be used to produce welds in the flat, horizontal, vertical and overhead positions. Progress in normally downward when welding in a vertical position. In several uses of GTAW a higher degree of operator skill is required.

The important points requiring due attention for obtaining best results in the GTAW are

Tungsten electrodes should be kept clean and straight and their ends in the proper condition. Correct size electrodes should be used. If it is too small the end of the tungsten will form into a molten ball larger than the electrode, and this ball may fall into the weld. If it is too large, the arc will wander from one side of the electrode to the other. A discolored tungsten electrode usually means that it has been exposed to the air while still very hot. Gas connections must be tight or else leaks may result. Electrodes should not extend beyond the cup by less than a bare minimum amount even though it may interfere to some extent with the vision of the weld puddle. Steel welding rods should not be copper coated, as the copper coating will cause spatter and may contaminate the tungsten electrode.

The most common gas welding process is oxy-fuel welding, also known as oxyacetylene welding. It is one of the oldest and most versatile welding processes, but in recent years it has become less popular in industrial applications. It is still widely used for welding pipes and tubes, as well as repair work. It is also frequently well-suited, and favored, for fabricating some types of metal-based artwork. Oxyfuel equipment is versatile, lending itself not only to some sorts of iron or steel welding but also to brazing, braze-welding, metal heating (for bending and forming), and also ox fuel cutting.

Definition:
Gas welding is the fusion welding process. It joins metals using heat of combustion of an oxygen / air and fuel gas mixture. The intense heat thus produced melts and fuses together the parts to be welded, generally with the addition of filler material.

The gases are mixed in proper proportions in a welding blowpipe (torch). For controlling the welding flame, there are two regulators on the torch by which the quantity of either gas can be regulated.

S:NO	**FUEL GAS**	**GAS FOR BURNING**	**TEMPERATURE RANGE**
1	Acetylene	Oxygen	3200 – 3300^{o}C
2	MAPP (methyl acetate prop diene)	Oxygen	2600^o-2900^{o}C
3	Propylene	Oxygen	2500^o-2850^{o}C
4	propane	Oxygen	2450^o-2775^{o}C
5	natural gas/methane	Oxygen	2350^o-2750^{o}C
6	Hydrogen	oxygen	2500-2550 ^{o}C

In gas welding the two surfaces to be welded are properly prepared and placed near each other. The metal in the joint is brought to melting temperature by heat from the flame and then weld is completed by supplying additional metal as the filler metal obtained by a filler rod.

Oxyacetylene welding. In oxyacetylene welding, the two gases used for producing flame are oxygenand acetylene. Oxygen is used to support and intensify combustion. Its component parts by rectification. From factories, it can be obtained under high pressure in cylinders which are fitted with pressure regulators to get oxygen at desired pressure for welding. Each cylinder is connected to the blow pipe by flexible hoses. The exact pressure used depends on the blowpipe nozzle size and thickness of the plate to be welded.

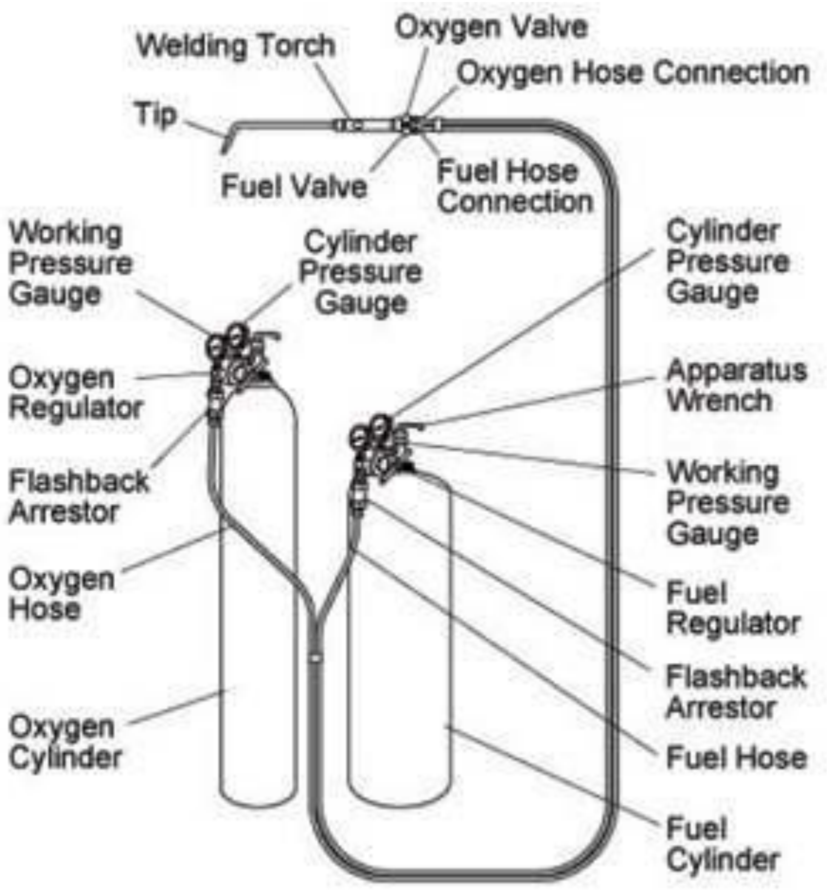


Figure – Oxy acetylene welding

Acetylene Production: Acetylene can be easily produced by the chemical reaction between water andcalcium carbide (CaC_2). It has to be produced and used at only low pressures as at high pressures explosion might be there. Generally it is prepared in two ways i.e. either by dropping CaC2 on water or by dropping water on CaC_2. The pressure is kept same by placing constant weight on the cover of the container in which it is being produced and stored. The reaction between water and CaC_2 is given below:

CaC_2	$+ 2H_2O \rightarrow$	C_2H_2	$+ Ca(OH)_2$
Calcium Carbide	Water	Acetylene	Hydrated lime

Types of Flame.This is the phenomenon produced at the surface of the nozzle tip where two gasesmeet and undergo combustion with the evolution of heat and some light. The chemical reaction for complete combustion of oxygen and acetylene is as follows:

$2C_2H_2$	$+5O_2$	$\rightarrow$	$4CO_2$	$+ 2H_2O$
Acetylene	Oxygen		Carbon Dioxide	Water vapour

Thus for complete combustion, ratio of oxygen to acetylene is 2½ to 1. The temperature of flame is dependent upon the relative proportion of the two gases. But temperature and complete combustion are not the only factors for welding because for different purposes, different ratios of gases have given best results e.g., for normal welding most suitable mixture is generally obtained by having equal proportions of oxygen and acetylene. This mixture produces a neutral flame which is neither oxidizing nor carburizing and is very suitable for welding. Under this condition the following chemical actions take place

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

Acetylene Oxygen Carbon monoxide Hydrogen

$$2CO \quad + O_2 \quad \rightarrow \quad 2CO_2$$

Carbon Monoxide Oxygen Carbon Dioxide

$$2H2 + O2 \quad \rightarrow \quad 2H2O$$

Hydrogen Oxygen Water vapour

From the above equations it is obvious that complete combustion takes place in two phases. From the oxygen and acetylene as obtained from torch, incomplete combustion takes place producing carbon monoxide. This reaction takes place at the inner core of the flame where the highest temperature is developed and it can be clearly seen as well-defined white inner cone. Further reactions take place in outer cone and get their oxygen from surrounding atmosphere. The above form of flame with temperature distribution.

Neutral flame:

This flame is obtained by mixing equal quantities of acetylene and oxygen (the acetylene and oxygen ratio is 1:1.1).The temperature is 3260 ^{o}C.

It has a nicely defined inner cone which is whitish blue or light blue in color. It is surrounded by an outer envelope produced by the combination of oxygen in the air and superheated carbon monoxide and hydrogen gases from the inner cone. This is darker blue in color.

It is named so because it does not affect chemical changes on the molten metal and therefore will not oxidize or carburize the metal.

Commonly used for:

1. Copper
2. Mild steel
3. Cast iron
4. Aluminum
5. Stainless steel

Reducing flame:

If the volume of oxygen supply is reduced the resulting flame will be carburizing (obtained by more quantity of acetylene).

Temperature range is 3038 ^{o}C

It has an inner cone is surrounded by a secondary luminous zone called the acetylene feather and extends into the outer envelope which is longer and brighter when compared to neutral flame.

The complete carbon is not consumed due to the insufficient oxygen. Some part of the remaining carbon burns with oxygen present in atmosphere and forms acetylene feather and other remaining carbon is forced in to the metal and forms iron carbide.

Used for steel rods, nonferrous metals, high carbon steels.

LASER BEAM WELDING

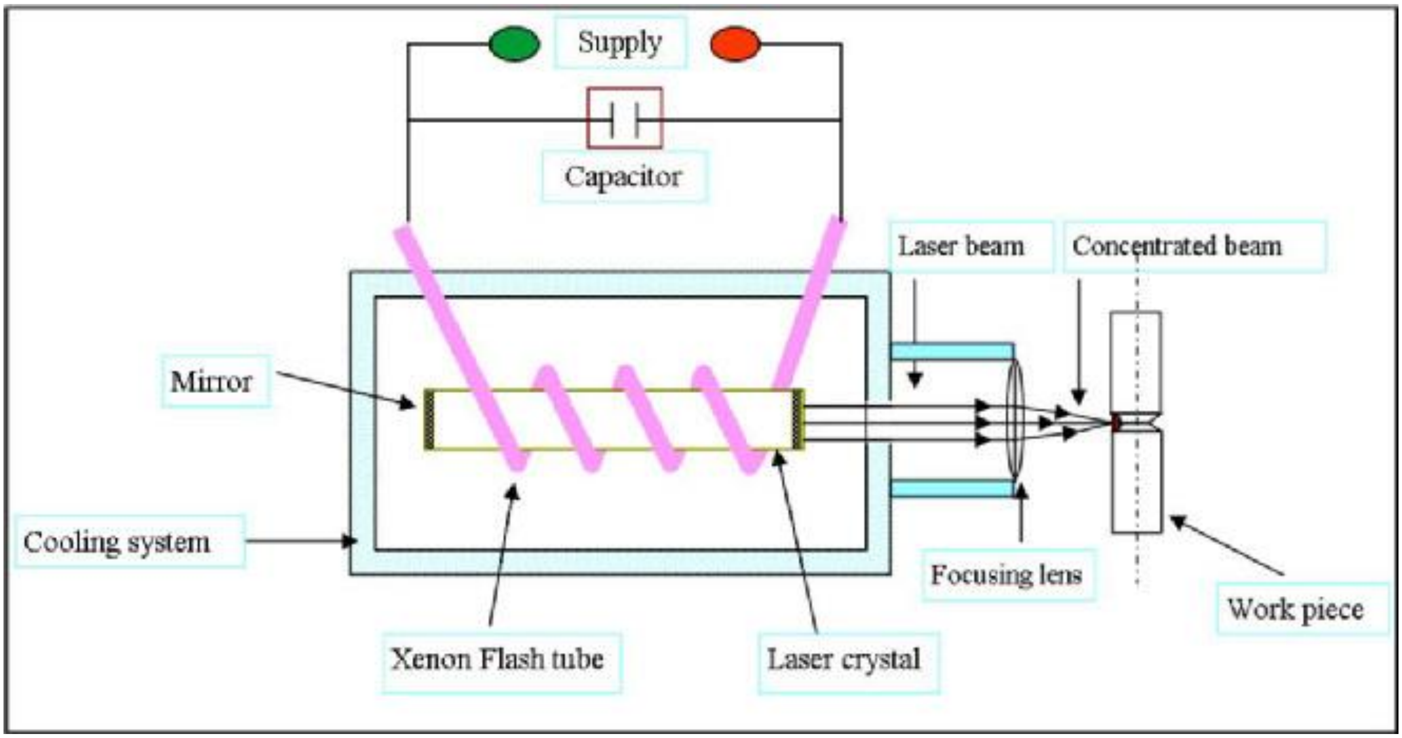


FIGURE – LASER BEAM WELDING

Principle of laser beam welding

A laser beam is produced inside of the Ruby Crystal. The Ruby Crystal is made of aluminum oxide with chromium dispersed throughout it. Which is forming about 1/2000 of crystal, this less than natural ruby. Silver coated mirrors are fitted internally in the both side of crystal. The one side of mirror has a tiny hole, a beam is come out through this hole.

A flash tube is placed around the Ruby Crystal, which is filled with xenon inert gas. The flash is specially designed such as which is made flash rate about thousands flashes per seconds. The electrical energy is converted into light energy, this is worked by flash tube.

The capacitor is provided for storage the electrical energy and supply the high voltage to flash tube for performed appropriately.

The electrical energy discharged from capacitor and xenon transform the high energy into white flash light rate of 1/1000 per second.

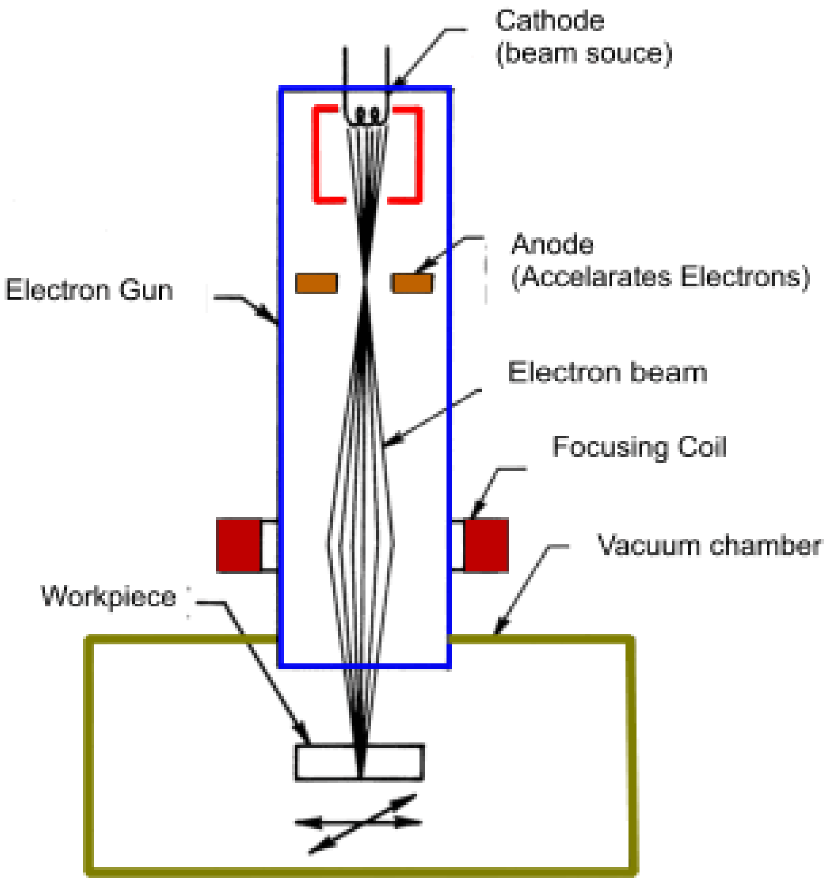
The chromium atoms of Ruby Crystal are excited and pumped into high energy. Due to heat generating the some of this energy is lost. But some light energy reflected mirror to mirror and again chromium atoms are excited until loss their extra energy simultaneously to form a narrow beam of coherent light. Which is come out through the one end tiny hole of crystal’s mirror.

This narrow beam is focused by an optical focusing lens to produce a small intense of laser on the job.

Advantage of laser beam welding

- A different type of material can be welded, which material cannot be weld by ordinary welding process that also be welded by laser welding process.
- High melting point and hard material can be weld.
- By laser welding process different thickness and different diameter materials are welded.
- Due to its high beam energy both operation welding and cutting can be made very effortlessly.
- This can be used for micro welding purposes.

ELECTRON BEAM WELDING



In this process a concentrated beam of electrons bombards the base metal, causing it to melt and fuse. The process is most efficient when done in a vacuum. Therefore the size of the vacuum chamber limits the size of the work pieces that can be welded. Advantages include the ability to produce welds of extremely high purity, ability to melt any known material, ability to weld dissimilar metals and the ability to make welds with depths as great as 150mm.

Electron beam welding is costly for two reasons,

1) The high cost of equipment and
2) The time lost in pumping out the vacuum chamber between welds.

When the welds are not made in a vacuum, many advantages of the process are reduced.

Electron beam welding equipment

Electron beam welder

Since the publication of the first practical electron beam welding equipment by Steigerwald in 1958, electron beam welding has spread rapidly in all branches of engineering where welding can be applied. To cover the various requirements, countless welder types have been designed, differing in construction, working space volume, work piece manipulators and beam power. Electron beam generators (electron guns) designed for welding applications can supply beams with power ranging from a few watts up to about one hundred kilowatts. "Micro-welds" of tiny components can be realized, as well as deep welds up to 300 mm (or even more if needed). Vacuum working chambers of various design may have a volume of only a few liters, but vacuum chambers with the volume of several hundred cubic meters have also been built.

Specifically, the equipment comprises:

1 Electron gun, generating the electron beam,

2 Working chamber, mostly evacuated to "low" or "high" vacuum,

3 Work piece manipulator (positioning mechanism),

4 Power supply and control and monitoring electronics.

Electron gun

In the electron gun, the free electrons are gained by thermo-emission from a hot metal strap (or wire). They are then accelerated and formed into a narrow convergent beam by an electric field produced by three electrodes: the electron emitting strap, the cathode connected to the negative pole of the high (accelerating) voltage power supply (30 - 200 kV) and the positive high voltage electrode, the anode. There is a third electrode charged negatively with respect to the cathode, called the Wehnelt or control electrode. Its negative potential controls the portion of emitted electrons entering into the accelerating field, i.e., the electron beam current.

Working chamber

Since the appearance of the first electron beam welding machines at the end of the 1950s, the application of electron beam welding spread rapidly into industry and research in all highly developed countries. Up to now, uncountable numbers of various types of electron beam equipment have been designed and realized. In most of them the welding takes place in a working vacuum chamber in a high or low vacuum environment.

The vacuum working chamber may have any desired volume, from a few liters up to hundreds of cubic meters. They can be provided with electron guns supplying an electron beam with any required power up to 100 kW, or even more if needed. In micro-electron beam devices, components with dimensions in tenths of a millimeter can be precisely welded. In welders with electron beams of high enough power, welds up to 300 mm deep can be realized.

There are also welding machines in which the electron beam is brought out of vacuum into the atmosphere. With such equipment very large objects can be welded without huge working chambers.

Work piece manipulators

Electron beam welding can never be "hand-manipulated", even if not realized in vacuum, as there is always strong X-radiation. The relative motion of the beam and the work piece is most often achieved by rotation or linear travel of the work piece. In some cases the welding is realized by moving the beam with the help of a computer controlled deflection system. Work piece manipulators are mostly designed individually to meet the specific requirements of the welding equipment.

Power supply and control and monitoring electronics

Electron beam equipment must be provided with an appropriate power supply for the beam generator. The accelerating voltage may be chosen between 30 and 200 kV. Usually it is about 60 or 150 kV, depending on various conditions. With rising voltage the technical problems and the price of the equipment rapidly increase, hence, whenever it is possible a lower voltage of about 60 kV is to be chosen. The maximum power of the high voltage supply depends on the maximum depth of weld required.

The high-voltage equipment must also supply the low voltage, above 5 V, for the cathode heating, and negative voltage up to about 1000 V for the control electrode.

The electron gun also needs low-voltage supplies for the correction system, the focusing lens, and the deflection system. The last mentioned may be very complex if it is to provide computer controlled imaging, engraving, or similar beam applications.

Complex electronics may also be needed to control the work piece manipulator.

RESISTANCE WELDING

Resistance welding is defined as a process whereby force is applied to surfaces in contact and in which the heat for welding is produced by the passage of electric current through the electrical resistance at, and adjacent to, these surfaces.

Resistance welding is a well-established process, having an excellent track record for producing quality joints in sheet materials.

In the European automotive industry alone, over 150 million resistance spot welds are made each day.

Many variations of the resistance welding process exist; commonly resistance welding techniques are divided into the following categories:

- Resistance spot welding
- Resistance projection welding
- Resistance seam welding
- Flash and resistance butt welding
- High frequency welding
- Micro and miniature resistance welding

Resistance Welding

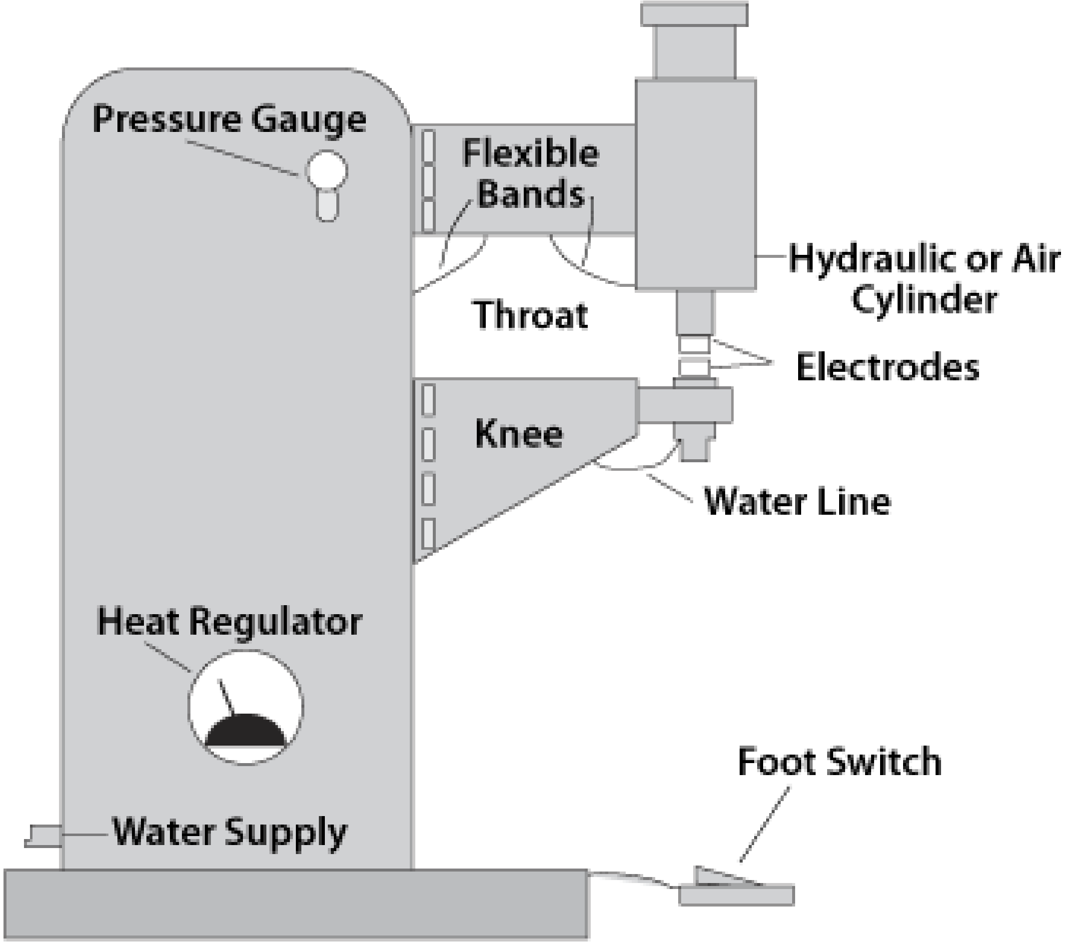


FIGURE- RESISTANCE WELDING

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Industrial applications

Resistance welding is used in applications across a wide range of industry sectors including white goods, automotive, heating and ventilation, aerospace and construction.

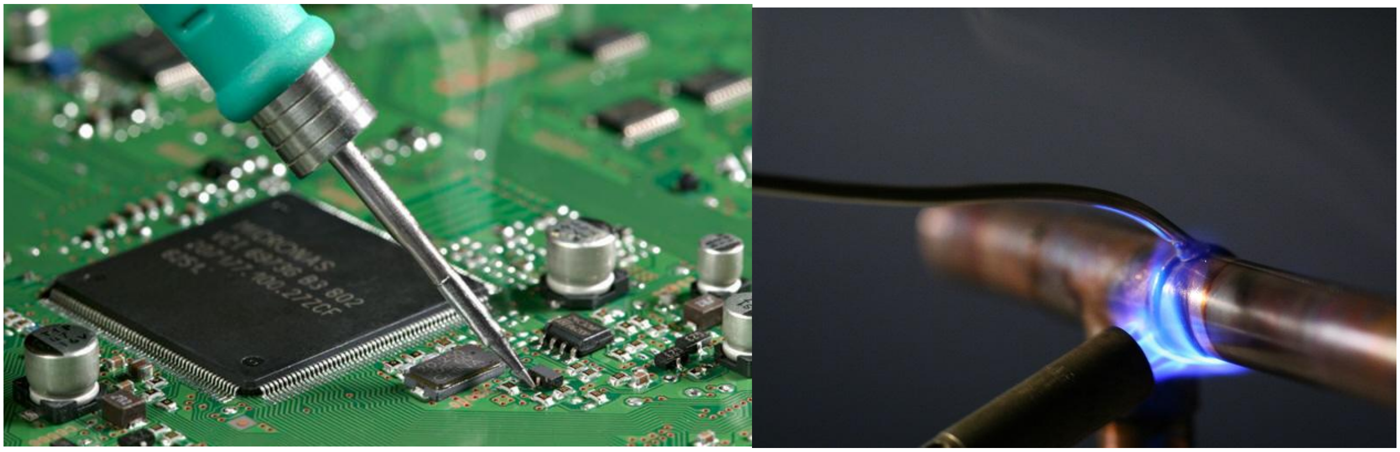
Due to its high speed and reliability resistance welding is particularly suited to mass production, the most commonly used process variant is resistance spot welding. Spot welding is primarily used to join metal sheet, the process can accommodate a wide range of materials and thicknesses, usually between 0.5 – 5.0mm. Materials that can be spot welded include: low carbon steels high strength steels, press hardened steels, stainless steels, nickel alloys, aluminum alloys, titanium alloys, copper and its alloys, magnesium and some refractory metals.

Resistance welding

Name	Characteristics	Applications
Resistance spot welding	Two pointed electrodes apply pressure and current to two or more thin work pieces	Automobile industry, Aerospace industry
Resistance seam welding	Two wheel-shaped electrodes roll along work pieces, applying pressure and current	Aerospace industry, steel drums, tubing
Projection welding	Semi-Automatic, Automatic, Welds are localized at predetermined points.	
Flash welding		
Upset welding	Butt joint surfaces heated and brought together by force	

1.5 Soldering

Soldering is a process in which two or more metal items are joined together by melting and flowing afiller metal into the joint, the filler metal having a relatively low melting point. Soft soldering is characterized by the melting point of the filler metal, which is below 400 °C. The filler metal used in the process is called solder.



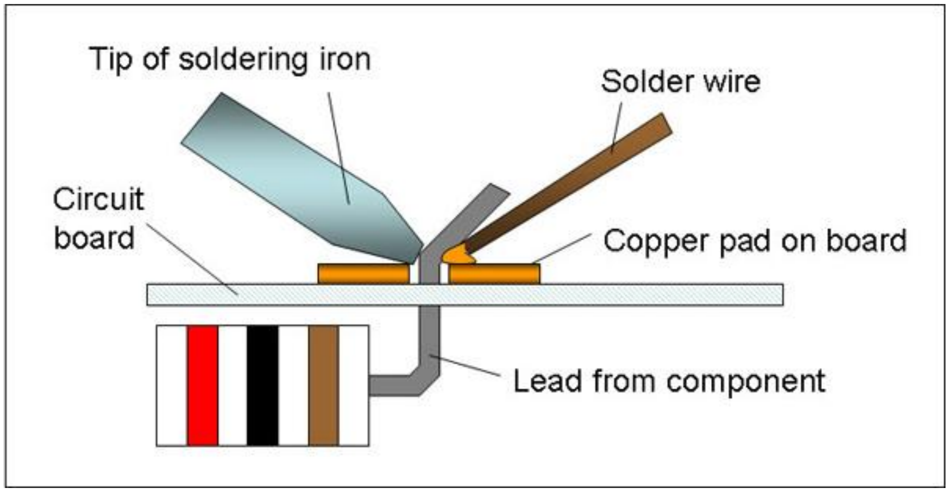


FIGURE- Soldering process

Soldering is distinguished from brazing by use of a lower melting-temperature filler metal; it is distinguished from welding by the base metals not being melted during the joining process. In a soldering process, heat is applied to the parts to be joined, causing the solder to melt and be drawn into the joint by capillary action and to bond to the materials to be joined by wetting action. After the metal cools, the resulting joints are not as strong as the base metal, but have adequate strength, electrical conductivity, and water-tightness for many uses.

Applications

The most frequent application of soldering is assembling electronic components to printed circuit boards (PCBs). Another common application is making permanent but reversible connections between copper pipes in plumbing systems. Joints in sheet metal objects such as food cans, roof flashing, rain gutters and automobile radiators have also historically been soldered, and occasionally still are. Jewelry and small mechanical parts are often assembled by soldering. Soldering is also used to join lead came and copper foil in stained glass work. Soldering can also be used to effect a semi-permanent patch for a leak in a container cooking vessel.

FIGURE: Soldering process

1.6 BRAZING

Brazing is a joining process whereby a non-ferrous filler metal or alloy is heated to melting temperature above 450°C (842°F), or, by the traditional definition that has been used in the United States, above 800°F (425°C) and distributed between two or more close-fitting parts by capillary action. At its liquid temperature, the molten filler metal and flux interacts with a thin layer of the base metal, cooling to form an exceptionally strong, sealed joint due to grain structure interaction.

Certain metals, such as Cusil (Copper-Silver alloy), have a low temperature eutectic. This leads to the bonding of the two metals at a point that can be substantially lower than their respective melting temperatures. The brazed joint becomes a sandwich of different layers, each metallurgical linked to the adjacent layers. Common brazements are about 1/3 as strong as the materials they join because the metals partially dissolve each other at the interface and usually the grain structure and joint alloy is uncontrolled. To create high-strength brazes, sometimes a brazement can be annealed, or cooled at a controlled rate, so that the joint's grain structure and alloying is controlled. It is also at 1/3 strength because the metal used to braze is usually weaker than the substrate metal because it melts at a lower temperature, ensuring the substrate does not melt.

Definition

Brazing is a somewhat nebulous term with several different definitions. The exact temperature difference between brazing and soldering is open to discussion. There are definite metallurgical reasons to use the 840°F figure. Others are used but this is the official American Welding Society definition.

Braze alloy is often used to define an alloy that flows in thin joints while braze filler metal is used for thicker joints and for gap filling.

One definition of brazing is “joining of two materials using a third, dissimilar material at higher temperatures than soldering."

Flux

In most cases, flux is required to prevent oxides from forming while the metal is heated and also helps to spread out the metal that is used to seal the joint. The most common fluxes for bronze brazing are borax-based. The flux can be applied in a number of ways. It can be applied as a paste with a brush directly to the parts to be brazed. Commercial pastes can be purchased or made up from powder combined with water (or in some cases, alcohol). Brazing pastes are also commercially available, combining filler metal powder, flux powder, and a non-reacting vehicle binder. Alternatively, brazing rods can be heated and then dipped into dry flux powder to coat them in flux. Brazing rods can also be purchased with a coating of flux, or a flux core. In either case, the flux flows into the joint when the rod is applied to the heated joint. Using a special torch head, special flux powders can be blown onto the work piece using the torch flame itself. Excess flux should be removed when the joint is completed. Flux left in the joint can lead to corrosion. During the brazing process, flux may char and adhere to the work piece. Often this is removed by quenching the still-hot work piece in water (to loosen the flux scale), followed by wire brushing the remainder.

Many types of brazing flux contain toxic chemicals, sometimes very toxic. Silver brazing flux often contains Cadmium, which can cause very fast onset of metal fume fever (within minutes in extreme cases), especially if brazing fumes are inhaled due to inadequate ventilation. Due care must be taken with these materials to protect persons working, and also the environment.

Filler materials

A variety of alloys of metals, including silver, tin, zinc, copper and others are used as filler for brazing processes. There are specific brazing alloys and fluxes recommended, depending on which metals are to be joined. Metals such as aluminum can be brazed, although aluminum requires more skill and special fluxes. It conducts heat much better than steel and is more prone to oxidation. Some metals, such as titanium, cannot be brazed because they are insoluble with other metals, or have an oxide layer that forms too quickly at high temperatures.

However Titanium can be prepared to be successfully brazed if the tendency for oxidation is allowed for. If the material is deoxidized and protected by plating, vacuum or other means then you have a chemically active surface that can make for very strong joints. This is not true with unprepared Titanium and the braze joint is a chemical join that is not dependent on the metal solubility.

Brazing filler material is commonly available as flux-coated rods, very similar to stick-welding electrodes. Typical sizes are 3 mm (1/8") diameter. Some widely available filler materials are:

•Nickel-Silver: Usually with blue flux coating. 600 MPa (85,000 psi) tensile strength, 680 - 950°C (1250-1750°F) working temperature. Used for carbon and alloy steels and most metals not including aluminum.

•Bronze: Available with white borax flux coating. 420 MPa (60,000 psi) tensile strength.870°C (1600°F) working temperature.Used for copper, steel, galvanized metal, and other metals not including aluminum.

•Brass: Uncoated plain brass brazing rod is often used, but requires the use of some type of additional flux.

Nb Flux coating colors are manufacturer specific and do not indicate specific alloy types.

Advantages of brazing

Although there is a popular belief that brazing is an inferior substitute for welding, it has advantages over welding in many situations. For example, brazing brass has a strength and hardness near that of mild steel and is much more corrosion-resistant. In some applications, brazing is highly preferred. For example, silver brazing is the customary method of joining high-reliability, controlled-strength corrosion-resistant piping such as a nuclear submarine's seawater coolant pipes. Silver brazed parts can also be precisely machined after joining, to hide the presence of the joint to all but the most discerning observers, whereas it is nearly impossible to machine welds having any residual slag present and still hide joints.

•The lower temperature of brazing and brass-welding is less likely to distort the work piece, significantly change the crystalline structure (create a heat affected zone) or induce thermal stresses. For example, when large iron castings crack, it is almost always impractical to repair them with welding. In order to weld cast-iron without recracking it from thermal stress, the work piece must be hot-soaked to 870°C (1600 °F). When a large (more than 50 kg (100 lb)) casting cracks in an industrial setting, heat-soaking it for welding is almost always impractical.

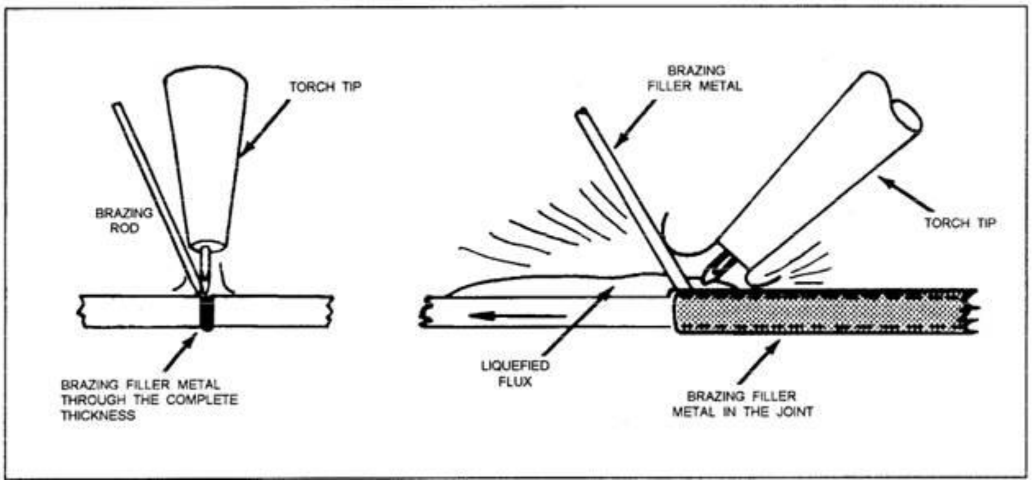


Figure – Brazing a filler metal in a joint

Often the casting only needs to be watertight, or take mild mechanical stress. Brazing is the preferred repair method in these cases.

•The lower temperature associated with brazing vs. welding can increase joining speed and reduce fuel gas consumption.

•Brazing can be easier for beginners to learn than welding.

•For thin work pieces (e.g., sheet metal or thin-walled pipe) brazing is less likely to result in burn-through.

•Brazing can also be a cheap and effective technique for mass production. Components can be assembled with preformed plugs of filler material positioned at joints and then heated in a furnace or passed through heating stations on an assembly line. The heated filler then flows into the joints by capillary action.

•Braze-welded joints generally have smooth attractive beads that do not require additional grinding or finishing. The most common filler materials are gold in color, but fillers that more closely match the color of the base materials can be used if appearance is important.

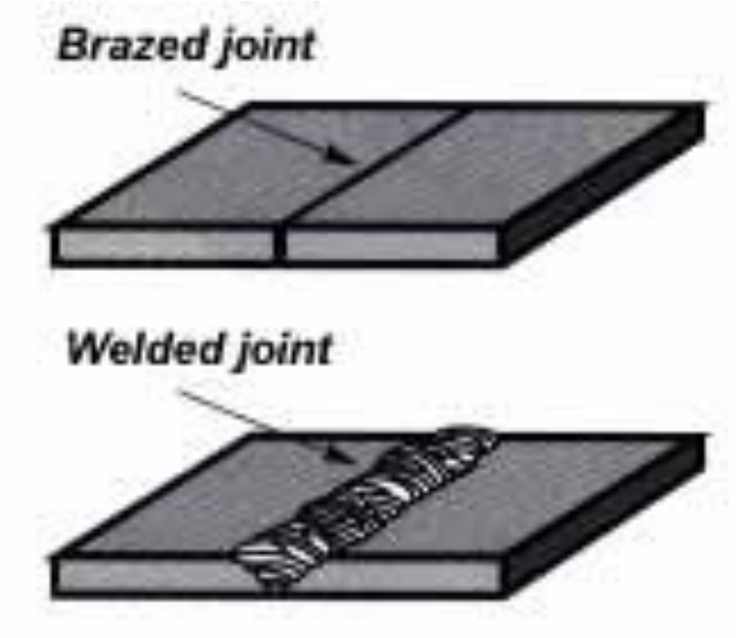


FIGURE- Difference between a brazed and weld joint

UNIT III
SHEET METAL PROCESSES IN AIRCRAFT INDUSTRY

SHEET METAL OPERATIONS

Sheet Metal Classification

There are 3 major classes of processes of sheet metal working.

Cutting:

Cutting is the use of shearing forces to remove material from a work piece. Technically not a metal forming process, but of extreme industrial importance.

Bending:

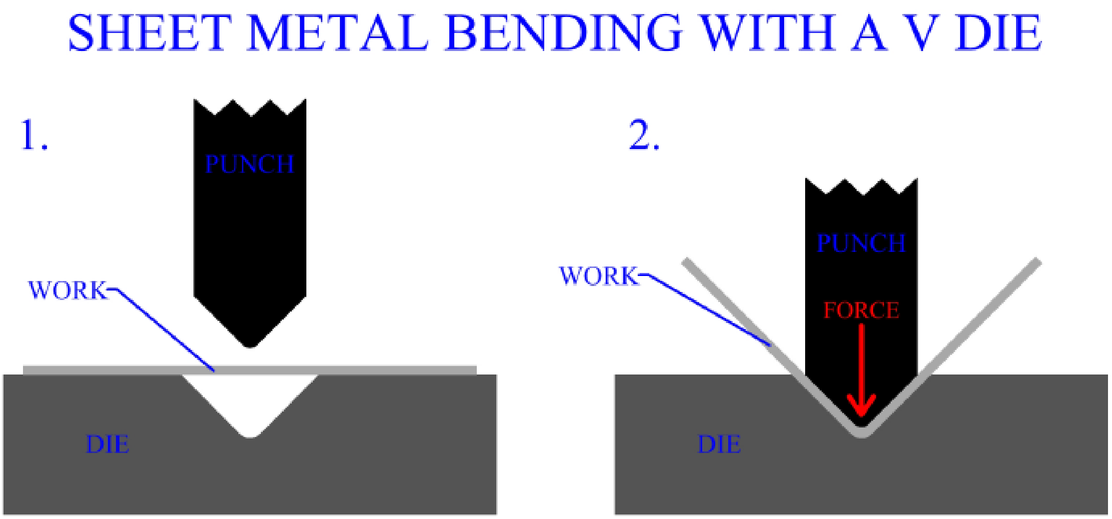
Bending is the forming of a sheet metal work about an axis.

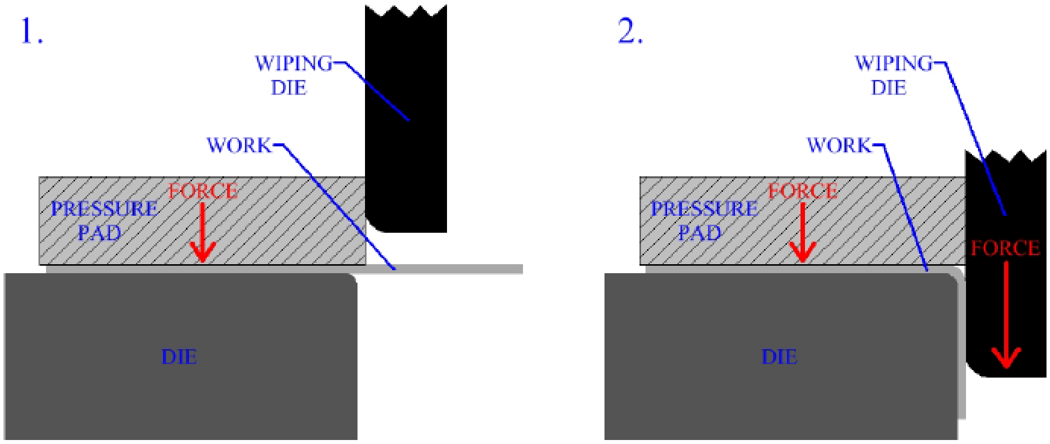
Deep Drawing:

Deep drawing is the forming of a cup or box with a flat base and Straight walls, from a sheet metal blank.

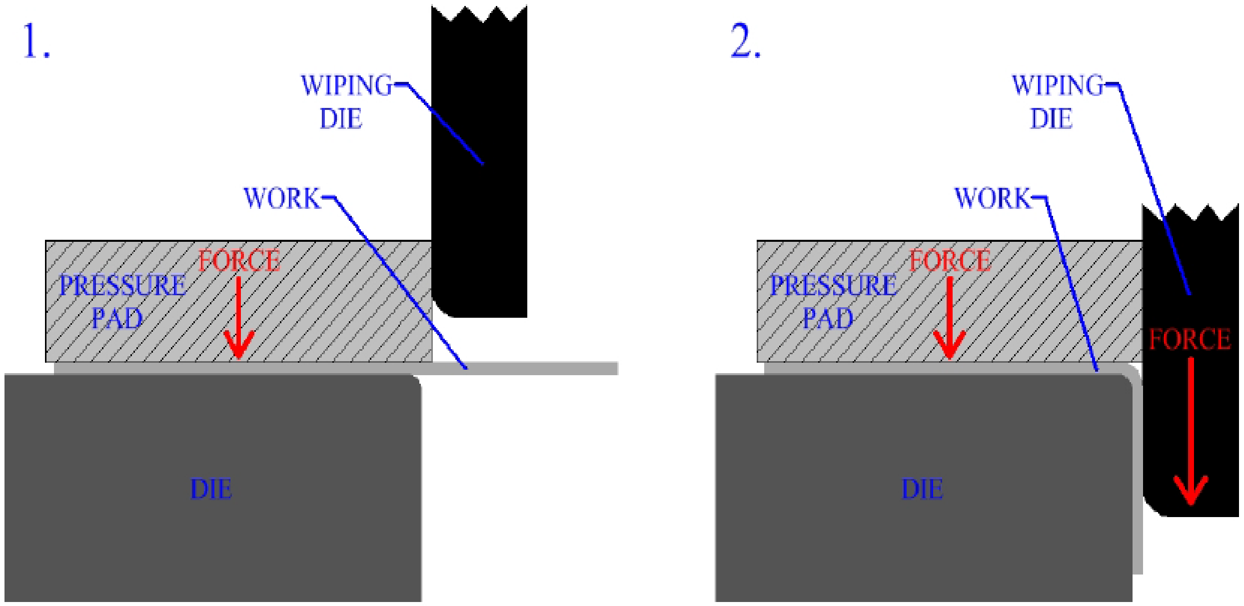
Other Processes:

Other sheet metal working processes such as ironing, spinning, Rubber forming and high energy rate forming are also discussed in latter sections.

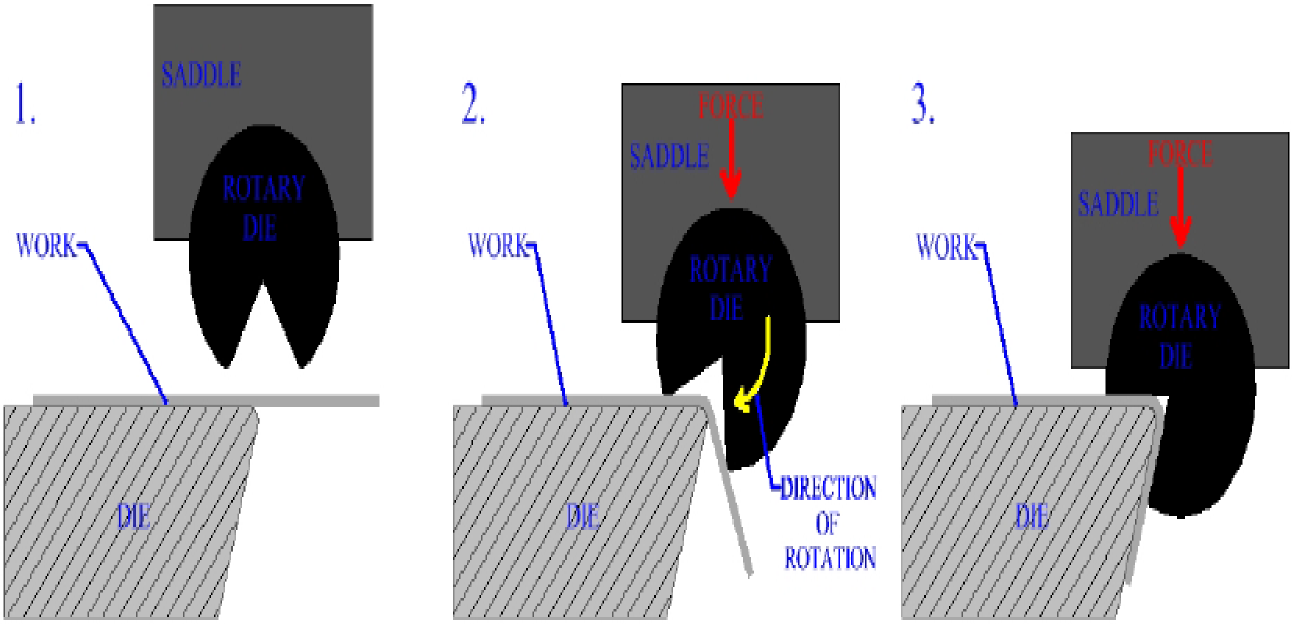

SHEET METAL BENDING WITH A V DIE



EDGE BENDING WITH WIPING DIE

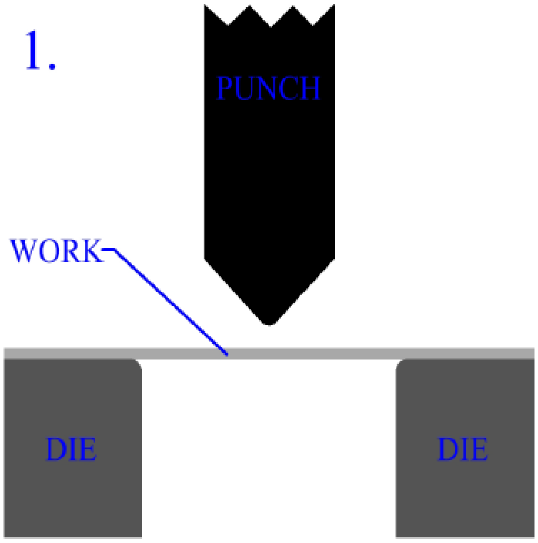


ROTARY BENDING OF SHEET METAL



AIR BENDING

1.



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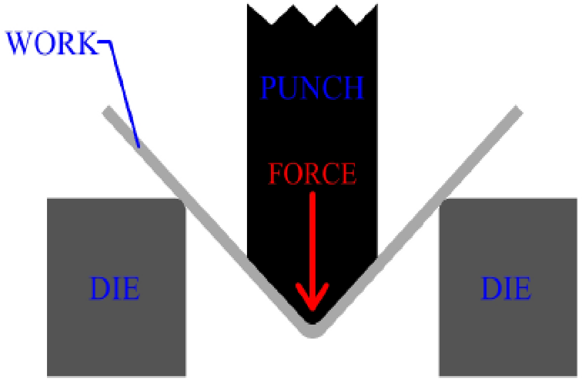
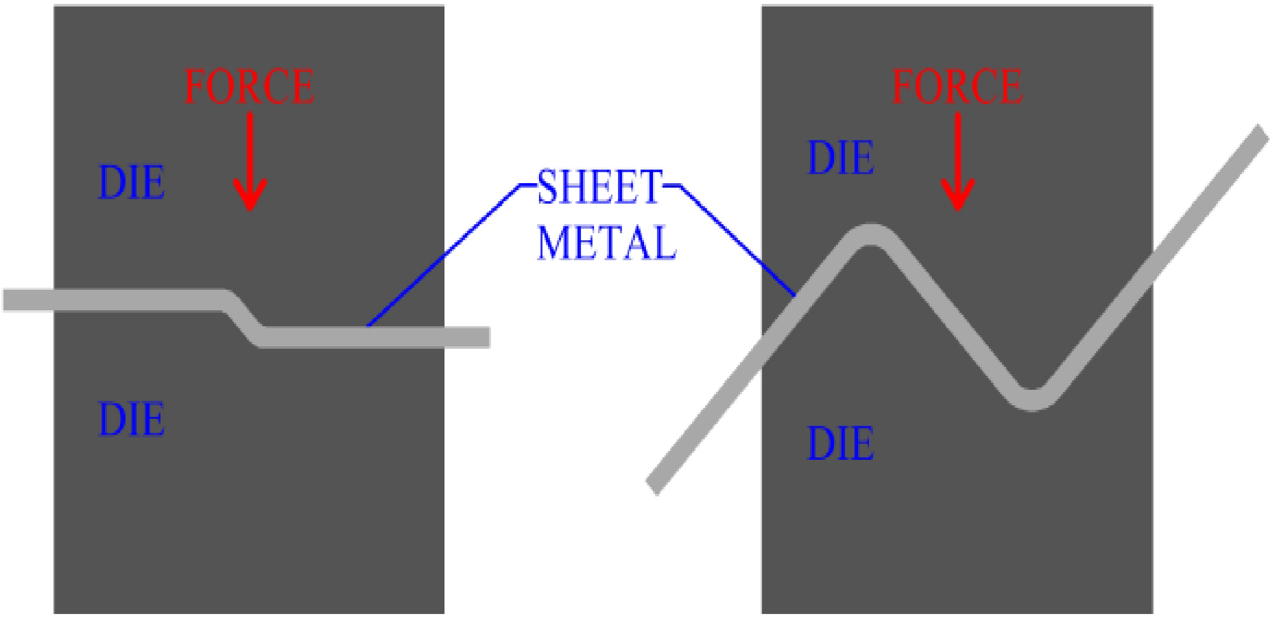
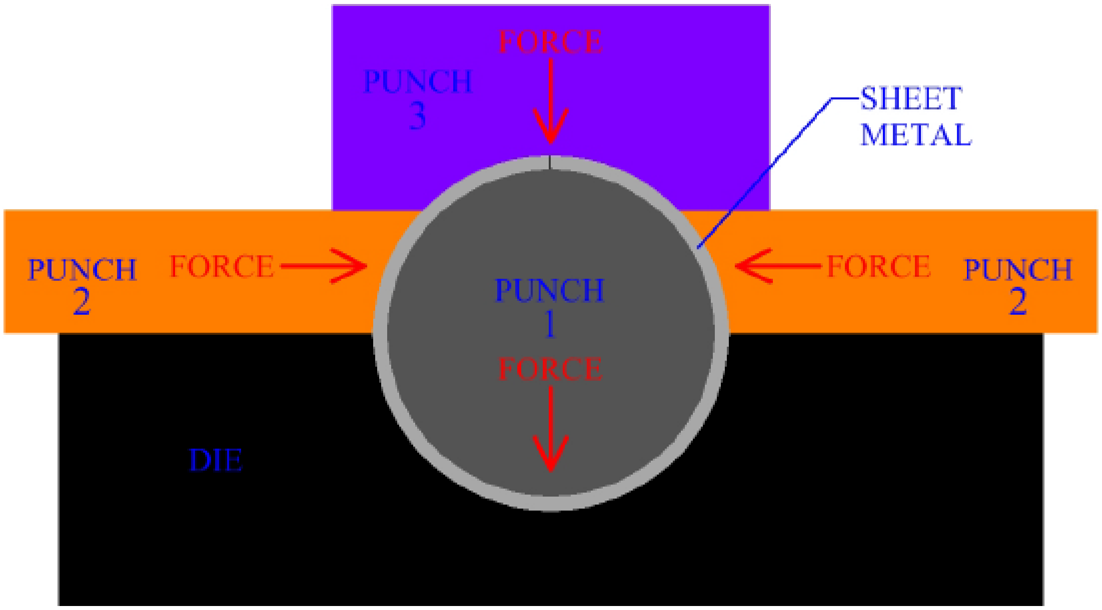


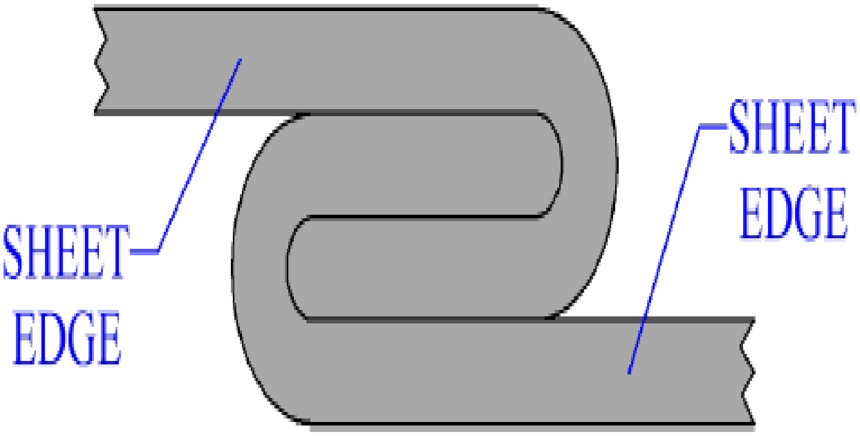
OFFSET BENDING SHEET METAL



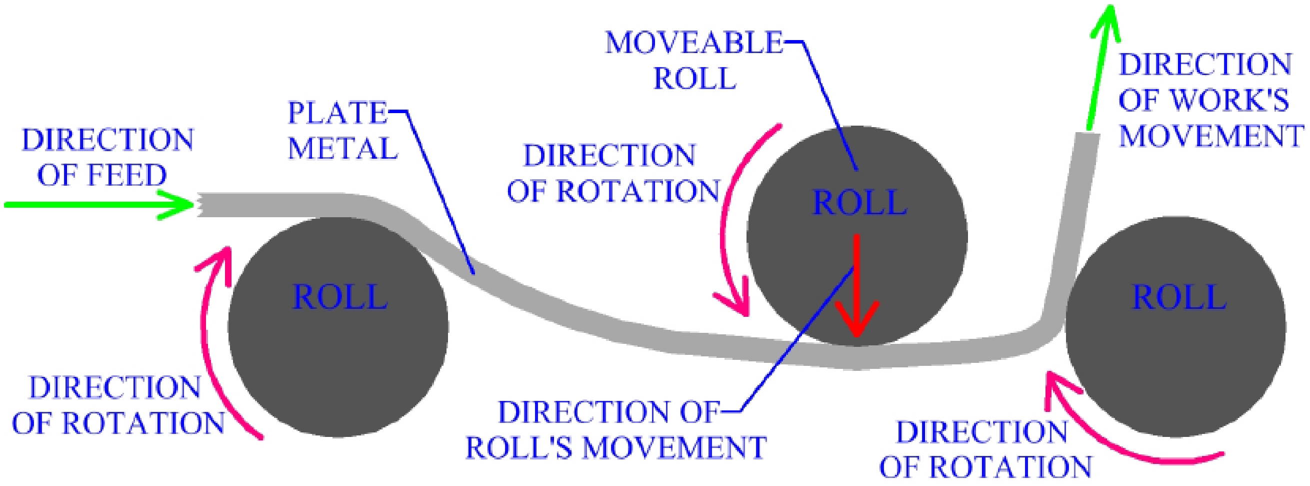
FORMING A HOLLOW TUBE



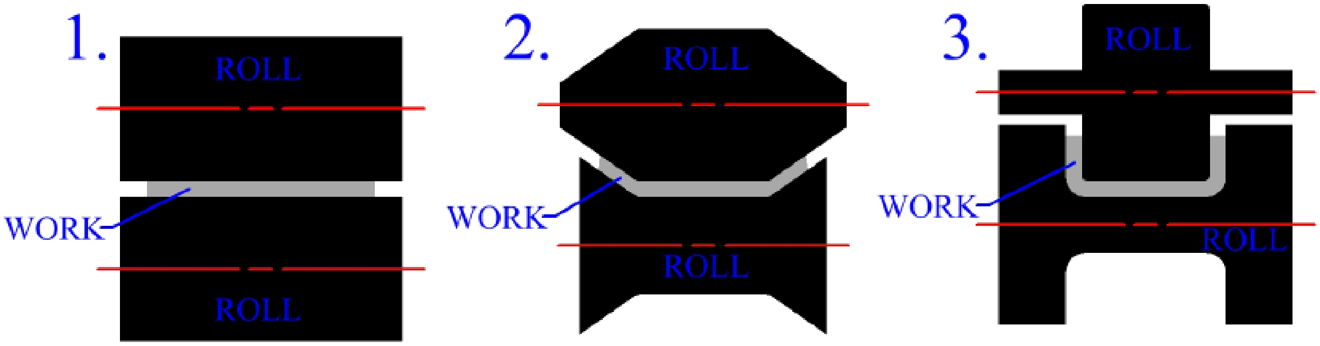
SEAMING OF SHEET METAL



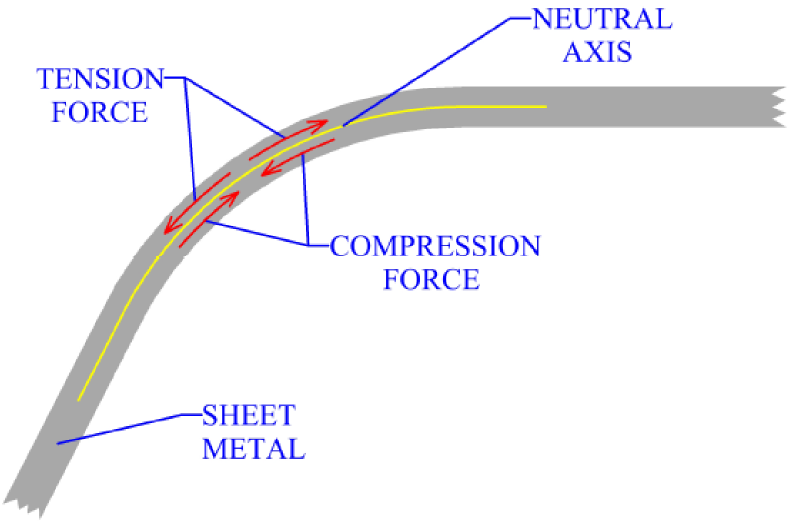
ROLL BENDING



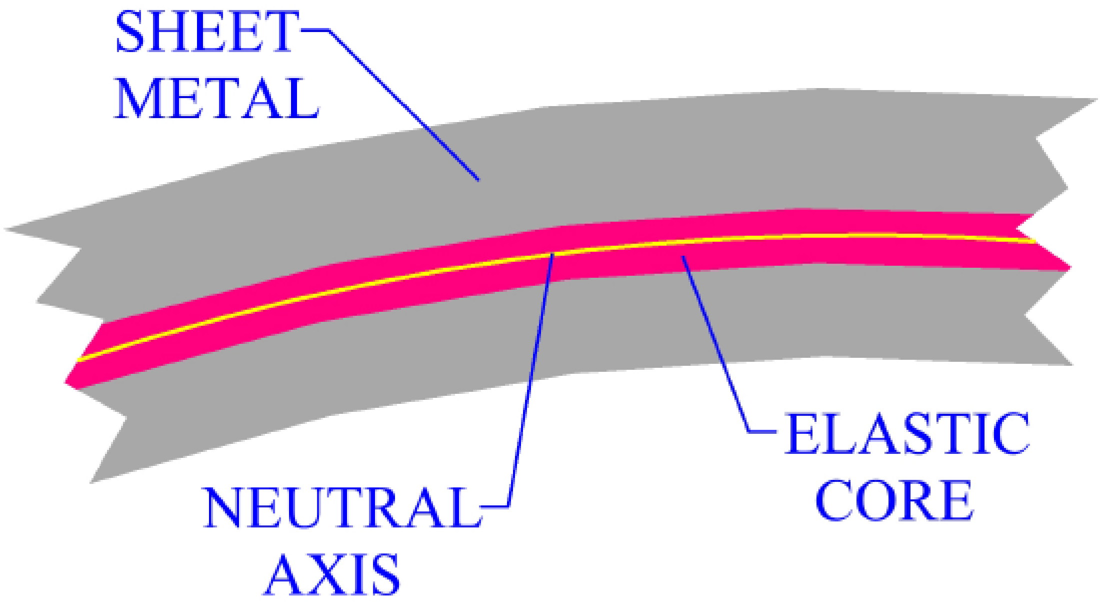
ROLL FORMING SHEET METAL



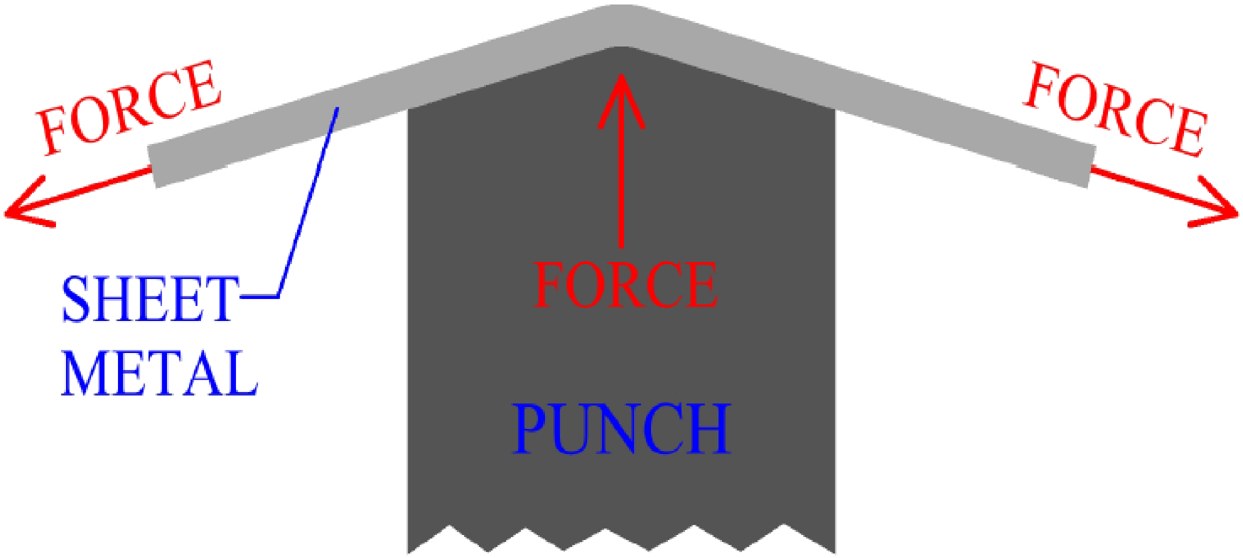
FORCE DISTRIBUTION DURING BENDING



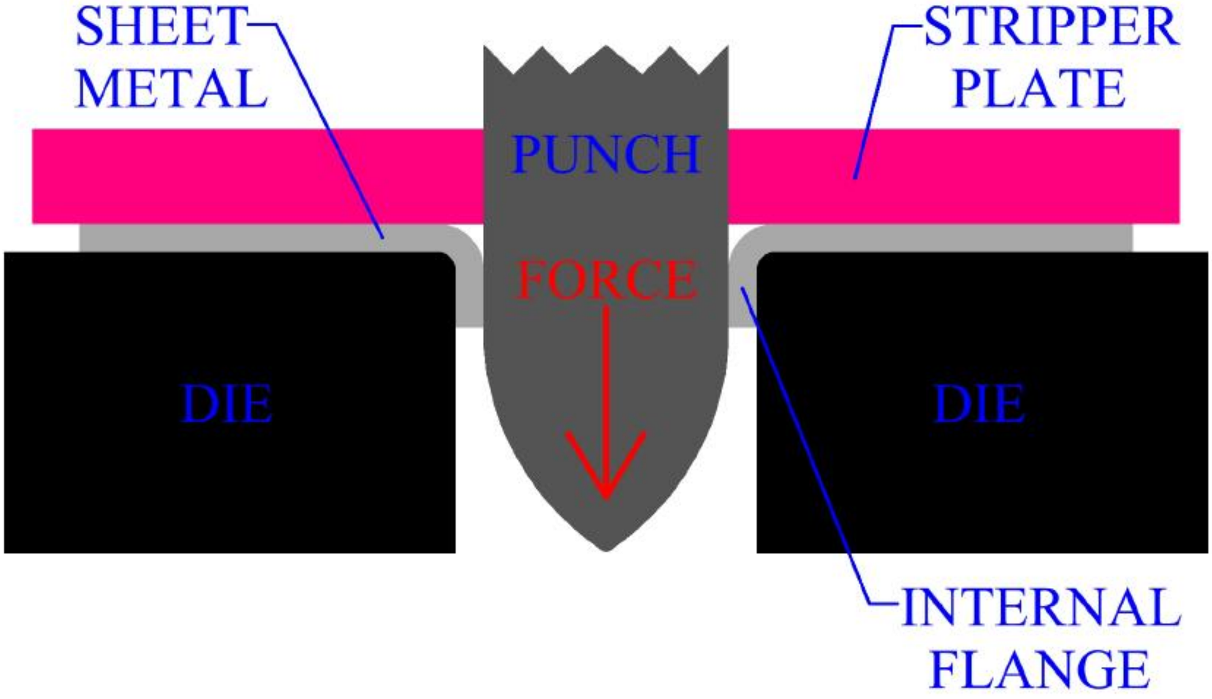
ELASTIC CORE DURING BENDING



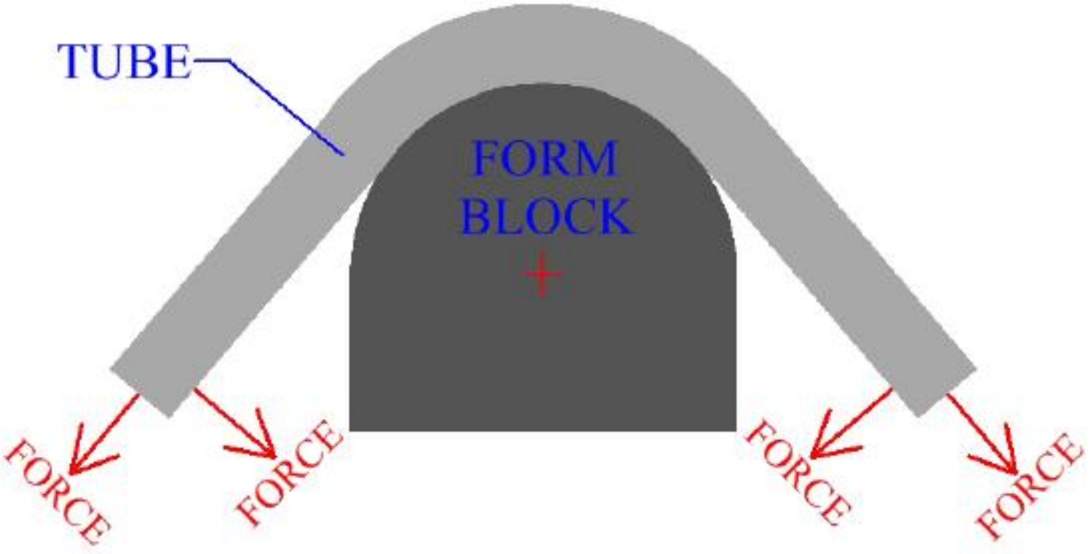
STRETCH FORMING



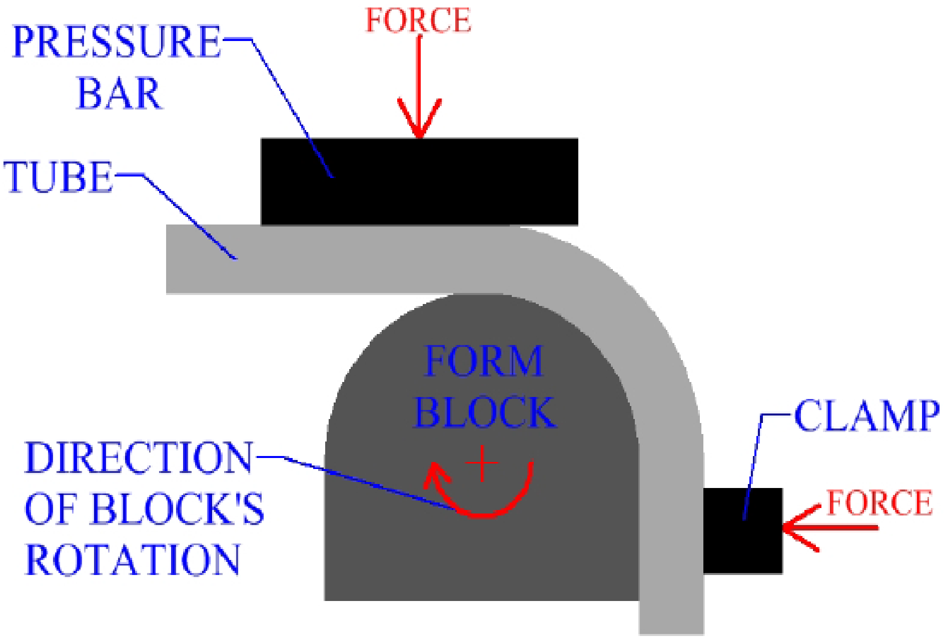
PIERCING



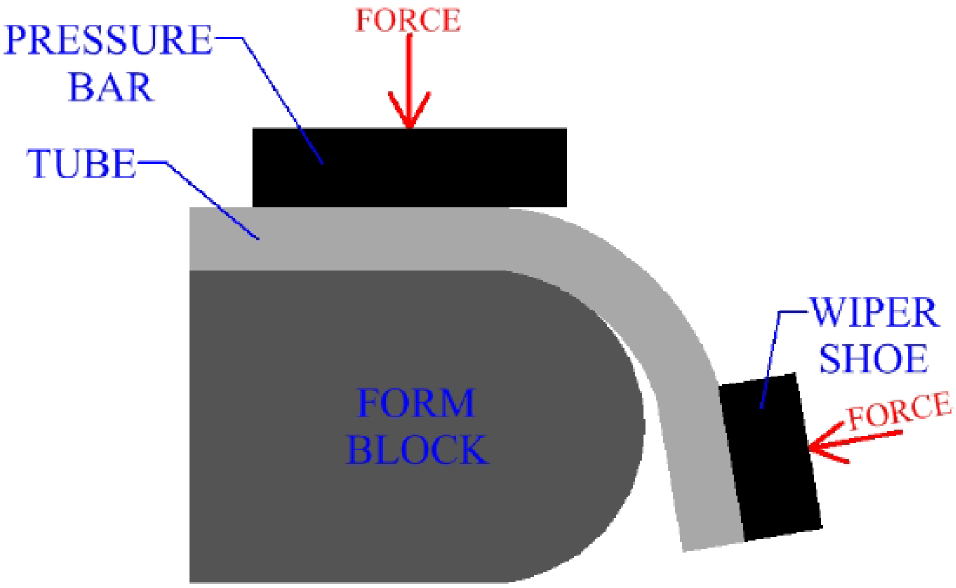
STRETCH BENDING



DRAW BENDING



COMPRESSION BENDING



UNIT IV

CONVENTIONAL AND UNCONVENTIONAL MACHINING PROCESSES

Metal cutting is the predominant processes employed for manufacture of the majority of the parts of an aircraft. These processes produce required shape in the work piece by removal of metal from selected areas to define depths. Machining processes commonly used in aircraft industry employing conventional machines. Conventional machining, one of the most important material removal methods, is a collection of material-working processes in which power-driven machine tools, such as lathes, milling machines, and drill presses are used with a sharp cutting tool to mechanically cut the material to achieve the desired geometry. Machining is a part of the manufacture of almost all metal products. It is not uncommon for other materials to be machined. A person who specializes in machining is called a machinist. Machining is also a hobby. A room, building, or company where machining is done is called a machine shop.

Machining operations

There are many kinds of machining operations, each of which is capable of generating a certain part geometry and surface texture. The three principal machining processes are classified as

Turning
Drilling
Milling

Other operations falling into miscellaneous categories include

Shaping
Planning
Broaching
Sawing.

2.1 LATHES

Lathe is the oldest machine tool invented. The principle form of surface produced in a lathe is the cylindrical surface. This is achieved by rotating the work piece while the single point cutting tool removes the material by traversing direction parallel to the axis of rotation called turning. Although we have number of modern machine tools, still the lathe maintains its existence as an indispensable machine. It still proves to be vital necessity in all modern tool rooms, repair shops and training workshops.

Principle:

The lathe can be defined as a machine tool which holds the work between two rigid supports, called centers, or in a chuck or face plate while work revolves. The chuck or the face plate is mounted on the projected end of the machine spindle. The cutting tool is rigidly held and supported in a tool post and fed against the revolving work. While the work revolves about its own axis the tool is made to move either parallel to or at an inclination with axis to cut the desired material. In doing so it produces cylindrical surfaces, if it is fed parallel to the axis. Or will produce a tapered surface if fed at an inclination.

Lathes can be classified as:

- Bench lathe
- Central lathe
- Speed lathe
- Engine lathe
- Tool room lathe
- Capstan and turret lathe
- Special purpose lathes
- Automatic lathe

Some smaller ones are bench mounted and semi-portable. The larger lathes are floor mounted and may require special transportation if they must be moved. Field and maintenance shops generally use a lathe that can be adapted to many operations and that is not too large to be moved from one work site to another. The engine lathe is ideally suited for this purpose. A trained operator can accomplish more machining jobs with the engine lathe than with any other machine tool.

Turret lathes and special purpose lathes are usually used in production or job shops for mass production or specialized parts, while basic engine lathes are usually used for any type of lathe work.

Lathe carries the following main parts:

- Bed
- Head Stock
- Tail Stock
- Carriage
- Feed Mechanism
- Legs

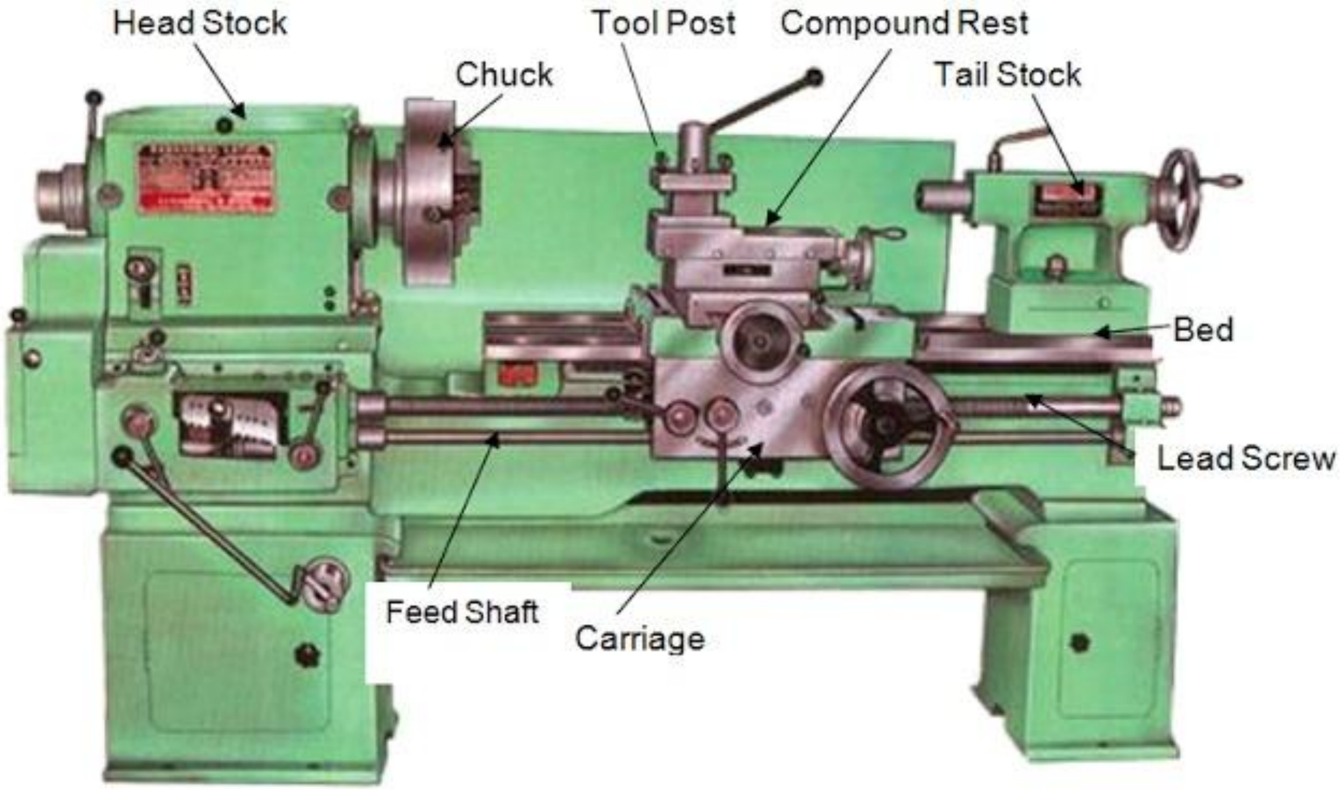


FIGURE- Parts of Lathe

Bed

The bed acts as the base on which the different fixed and operating parts of the lathe are mounted. This facilitates the correct relative location of the fixed parts and at the same time provides for a well guided and controlled movement of the operating parts (carriage). Also it has to with-stand various forces exerted by the cutting tool during the operation. They are generally made as single piece casting or semi-steel (i.e. toughened cast iron), with the addition of small quantity of steel scrap to the cast iron during melting; the material Cast iron facilitates easy sliding action.

An important point to be noted is that an accurate location proper leveling of the bed, during installation and afterwards plays an important role. Even strong beds are observed to be distorted if they are placed on unleveled flooring.

Head Stock

The head stock is that part of the lathe which serves as housing for the power source, power transmission, driving pulleys the gear box, provides bearing for the spindle and keeps the latter in alignment with the bed. It is towards the left most ends on the bed and is fixed to it.

It consists of:

- Cone pulley
- Back gears and back gear lever
- Main spindle or head stock spindle
- Live center
- Feed reverse lever

The back-geared head stock consists of a casing accommodation the main spindle, the three or four step-cone-pulley and the back gears. The internal mechanism of this type of headstock is shown in the figure. In this a step cone pulley is mounted on the main spindle, which carries a spur gear G1 at its one end and a pinion P1 at the other. Gear G1 is firmly keyed to the spindle so that it can never revolve free of the same. The spindle carries a sleeve over it which is a loose fit. The cone pulley is firmly secured to this sleeve. This arrangement forces the pinion P1 to revolve with the cone pulley under all conditions. A spring knob K engages the gear G1 with the cone pulley. The cone pulley is driven by means of a belt, through a countershaft, by an electric motor as shown in figure. This enables 4 speeds of the spindle.

Use of back gears:

The back gears are used for effecting reduction in spindle speeds, thereby facilitating a wider range of speeds. The back gears are mounted on an eccentric shaft which is operated by means of a hand lever known as back gear engaging lever (L). The back gear consists of a spur gear G2 (opposite to P1) and a pinion P2 (opposite to G1). When speed reduction is required, the knob is pulled out to make the cone pulley free of gear G1 and hence spindle. The back gears are put into mesh with the spindle gears by pulling in the eccentric shaft. Now, the sequence of transmission of motion and power is such that the cone pulley is driven by the motor through belt. With the result, the pinion P1 revolves. This being in mesh with gear G2, transfers the motion to latter which in turn, revolves the eccentric shaft and hence pinion P2. This further being in mesh with gear G1, transmits the motion to the latter and hence to the spindle.

Speed ratios: Now the countershaft is the driving shaft and lathe spindle is the driven shaft.

Spindle speed = Counter speed x Dia of the step on counter shaft

Spindle: The spindle of the lathe is in the form of a hollow shaft and revolves in two bearings fixed one each at the front and rear ends of the head stock. The inside hole runs through the entire length of the spindle and at the front end it is made tapered to accommodate the live centers. Also at the front end the outside surface of the spindle is made threaded to receive the job holding devices such as chuck, face plate or driving plate.

Live center:
It is the center support which is fitted into the tapered inside portion of the spindle nose while using a driver plate. No such center is used if work is held in a chuck. It acts as a bearing support for the work during the operation. It is usually softer than the dead center fitted in tail stock, for the reason that there are no chances of wear occurring on its surface as it always revolves along the work piece. It is only due to its revolving with the work that the name livecenter is given to it.

Feed reversal lever:
This is fitted on the left hand side of the head stock and has three positions. Central – it disengages and feed to the carriage is given by hand.

Top & Bottom – it engages to give power feed to the carriage but one allows carriage to move left to right and the other in reverse direction.
This is mostly used for left and right hand threads. It should not be operated when spindle is moving.

Tail Stock:
It also called as puppet head or loose head stock fitted on the bed on the right side of the lathe. It is capable of sliding along the bed maintaining its alignment with the head stock. And its main function is to provide bearing and support to the job which is being worked between the centers.

Carriage:
This serves the purpose of supporting, guiding and feeding the tool against the job during the operation on the lathe. It consists various parts like –

Saddle:
Which slides along the bed ways and supports the cross slide.

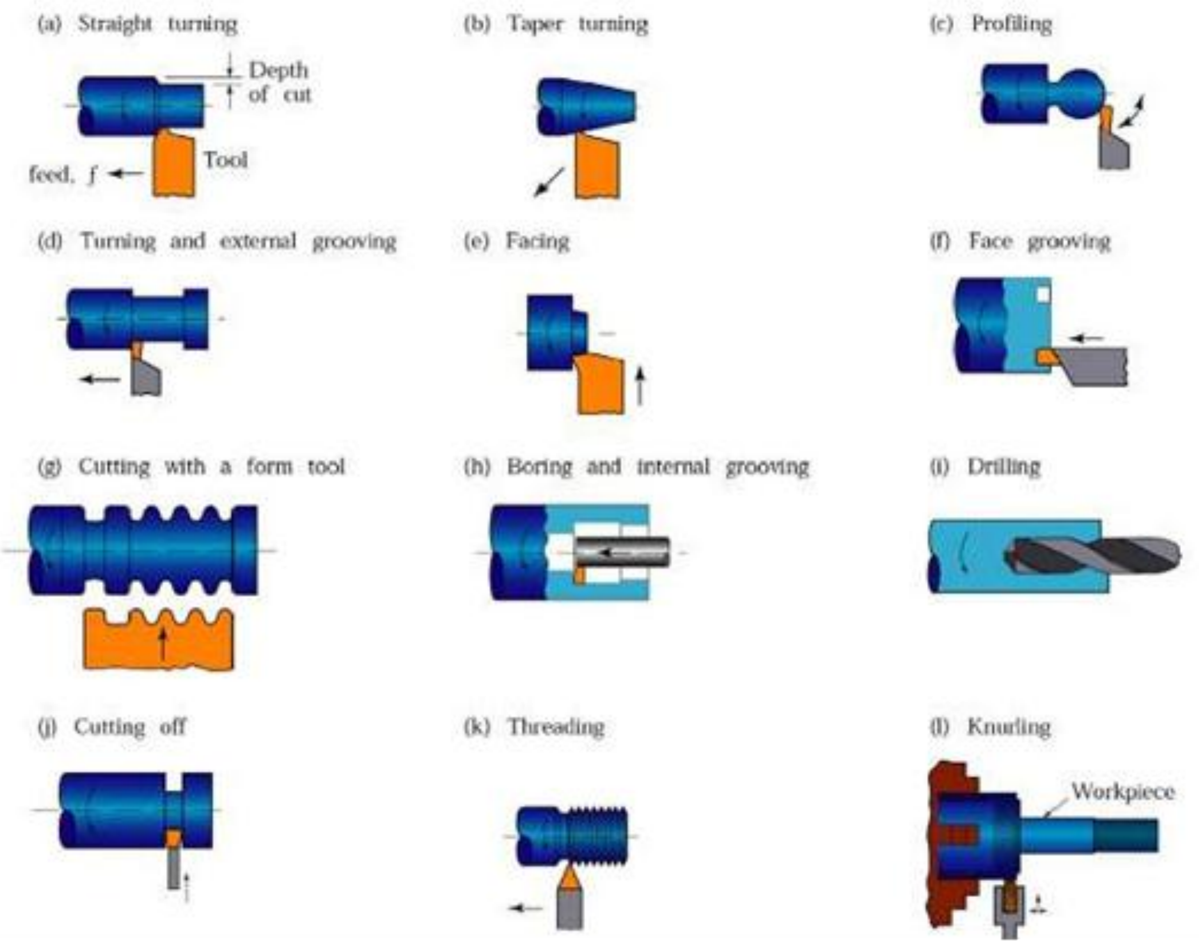
Cross slide:
Mounted on the top of the saddle and moves in the direction perpendicular to the main spindle. This can be moved by hand or power.

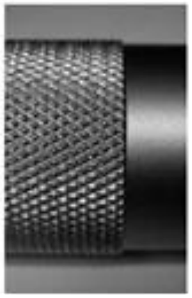
Compound rest:
This is called as tool rest, on cross slide and carries graduated circular base swivel plate to swivel tool rest to any angle, which is moved by a compound rest feed screw.
Tool post: Holds the tool

Feed Mechanism:
Provides power feed to the carriage.

Legs:
They are the supports which take the entire load of the machine over them.

TURNING OPERATIONS
The turning processes are typically carried out on a lathe, considered to be the oldest machine tools, and can be of four different types such as straight turning, taper turning, profiling or external grooving. Those types of turning processes can produce various shapes of materials such as straight, conical, curved, or grooved work piece. In general, turning uses simple single-point cutting tools. Each group of work piece materials has an optimum set of tools angles which have been developed through the years.





1)**Turning** is a machining process of generating external surfaces of revolution on a rotating work piece employing a traversing cutting tool. Or the process whereby a Centre lathes is used to produce "solids of revolution". It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer controlled and automated lathe which does not.

A.**Straight Turning**: The work is turned straight when it is made to rotate about the lathe axis, and the tool is fed parallel to the lathe axis.

B. **Taper Turning**: To produce a conical surface by gradual reduction in diameter from the cylindrical work piece.

2)**Eccentric Turning**: If cylindrical workpiece has two separate axis of rotation one being out of center to the other, the workpiece is known as eccentric turning.

3**) Facing** is part of the turning process.

Facing is the operation of machining the ends of piece of work to produce flat surface with the axis. It involves moving the cutting tool across the face (or end) of the work piece and is performed by the operation of the cross-slide. The feed is in the perpendicular direction of the axis of revolution. It is frequently the first operation performed in the production of the work piece, and often the last- hence the phrase "ending up".

4) **Knurling** is a manufacturing process, typically conducted on a lathe, whereby a visually-attractive diamond-shaped (crisscross) pattern is cut or rolled into metal. This pattern allows hands or fingers to get a better grip on the knurled object than would be provided by the originally-smooth metal surface. Occasionally, the knurled pattern is a series of straight ridges or a helix of "straight" ridges rather than the more-usual crisscross pattern.

Knurling tool having requisite serrations is forced on to the work piece, thus forming the top layer as shown in the figure.

5)**Parting or grooving**: In this a flat nosed tool plunge cuts the work piece with a feed in direction perpendicular to the axis of rotation.

6**) Drilling**: Making cylindrical holes in work piece by using a twist drill in the tailstock. Even same operation is used for Boring, counter boring, Reaming, counter sinking. This operation is limited to holes through the axis of rotation of the work piece and from any of the ends.

7)**Thread cutting**: Helical groove on a cylindrical or conical surface can be done by feeding the tool longitudinally when job is revolved between the centers, by operating the lead screw.

8)**Milling**: Milling is the operation of removing metal by feeding the work against a rotating cutter having multiple cutting edges.

9)**Grinding**: Grinding is the operation of removing metal in the form of multiple minute chips by feeding the work against the rotating grinding wheel.

10)**Grooving**: Is the processes of reducing diameter of a work piece over a narrow surface.

11)**Spinning**: Spinning is the process of forming a thin sheet of metal piece by revolving the job at high speed and pressing it against a former attached to the head stock spindle.

12)**Forming**: Forming is the process of turning of a convex, concave or of any irregular shape.

TURNING FORCES

The forces acting on a cutting in turning are important in the design of machine tools. The machine tool and its components must be able to withstand these forces without causing significant deflections, vibrations, or chatter during the operation. There are three principal forces during a turning process: cutting force, thrust force and radial force.

•The cutting force acts downward on the tool tip allowing deflection of the work piece upward. It supplies the energy required for the cutting operation.

•The thrust force acts in the longitudinal direction. It is also called the feed force because it is in the feed direction of the tool. This force tends to push the tool away from the chuck.

•The radial force acts in the radial direction and tends to push the tool away from the work piece.

MATERIAL REMOVAL RATE

The material removal rate (MRR) in turning is the volume of material removed per unit time in mm3/min. For each revolution of the work piece, a ring-shaped layer of material is removed.

$$\mathbf{MRR = pi \times D_{avg} \times d \times f \times N}$$

Where

D_{avg}: Average diameter

N: Rotational speed of the work piece

F: Feed

D: Depth of cut

Drilling is the process of using a drill bit in a drill to produce cylindrical holes in solid materials.

Drilling operations are operations in which holes are produced or refined by bringing a rotating cutter with cutting edges at the lower extremity into contact with the work piece. Drilling operations are done primarily in drill presses but not uncommon on the lathes or mills. The tool is fed in a direction parallel to its axis of rotation into the work part to form the round hole.

Drilling in metal

Under normal usage, swarf is carried up and away from the tip of the drill bit by the fluting. The continued production of chips from the cutting edges produces more chips which continue the movement of the chips outwards from the hole. This continues until the chips pack too tightly, either because of deeper than normal holes or insufficient backing off (removing the drill slightly or totally from the hole while drilling). Lubricants and coolants (i.e. cutting fluid) are sometimes used to ease this problem and to prolong the tools life by cooling and lubricating the tip and chip flow. Coolant is introduced via holes through the drill shank (see gun drill).

Straight fluting is used for copper or brass, as this exhibits less tendency to "dig in" or grab the material. If a helical drill (twist drill) is used then the same effect can be achieved by stoning a small flat parallel with the axis of the drill bit.

For heavy feeds and comparatively deep holes oil-hole drills can be used, with a lubricant pumped to the drill head through a small hole in the bit and flowing out along the fluting. A conventional drill press arrangement can be used in oil-hole drilling, but it is more commonly seen in automatic drilling machinery in which it is the work piece that rotates rather than the drill bit.

Drilling in wood

Wood being softer than most metals, drilling in wood is considerably easier and faster than drilling in metal. Cutting fluids are not used or needed. The main issue in drilling wood is assuring clean entry and exit holes and preventing burning. Avoiding burning is a question of using sharp bits and the appropriate cutting speed. Drill bits can tear out chips of wood around the top and bottom of the hole and this is undesirable in fine woodworking applications.

Drilling machine construction

In order to carry out the drilling operation, the motions required are the rotation of the drill while it is fed linearly into the work piece. Drilling machines come in a variety of shapes and sizes.

Drill press:

A typical drill press is shown in. The cutting tool in this case is the spindle either with the help of the drill chuck for small size drills that are straight shank type or by means of the spindle taper. The spindle is located inside a quill, which can reciprocate by means of manual

Operation or by means of power feed. The work piece is normally placed on the table and clamped using a suitable work holding device. These are relatively simple and less expensive in operation. However, these are not suitable for mass production.

Redial drilling: The redial drilling machine is more versatile than the drill press as described earlier. The schematic diagram of a radials drilling machine showing the principal parts and motions is shown in. the drill head can move along the radial arm to any position while the radial arm itself can rotate on the column, thus allowing for reaching any position in the radial range of machine. They are more convenient for large work piece which cannot be moved easily because of their weight, such that the drill head itself is moved to the actual location on the work piece, before carrying the drilling operations. In addition to the twist drills other hole making tools are also used.

Multiple spindle drilling: For production operations a large number of operations are carried out simultaneously which can be done through the multiple-spindle drilling machines. In the drilling heads of these machines more than one drill can be located with each of them getting the power from the same spindle motor. The use of these machines becomes more economical for large volume production of identical parts. These machines are capable of producing a large number of holes in a short time. Some machines have a fixed number of spindles in fixed locations while the others have the number fixed but their locations can be changed to suit the work piece geometry. The latter type areore versatile.

Gang drilling: Gang drilling machines are the equivalent of the progressive action type multiple spindle lathes. These consist of a number of spindles (often equal to four) laid out in parallel. Each of the spindle can have different drills or other hole making operation tools foxed in sequence. The work piece will move from one station to the other, with each completing the designated hole making operation. These are used for volume production with the work piece located in a jig with a reasonable size to allow the operator to move the part with the jig to the next station, generally on a roller conveyor.

Work holding: Work holding in drilling machines is similar to milling. Most of the small components are held in vices for drilling in job shops. However, for production operations, it is not only necessary to locate and clamp the work piece properly, but also to locate and guide the drill. Hence jigs are used to serve this function.

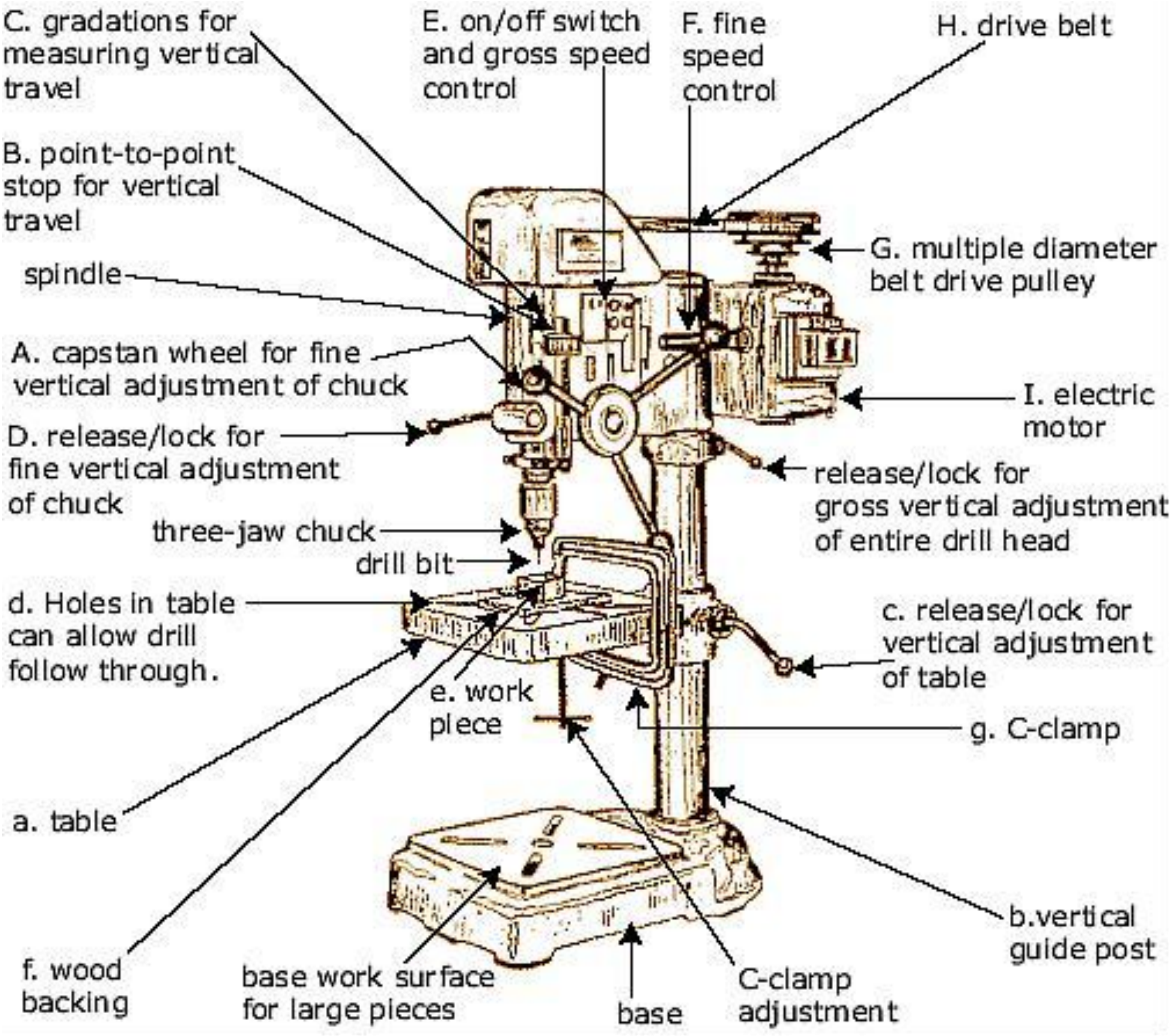
Main parts of drill press are:

Base: The base is that portion of the machine on which the vertical column is mounted. In a belt driven machine the counter shaft consisting of a fast and loose pulley and the cone pulley is fitted to the base of the machine. The top of the base in round column drilling machine is accurately machined and has T-slots on it so that large work piece may be set.

Column: The column is the vertical component of the machine, which supports the table and the head containing the driving mechanism. The column should be sufficiently rigid so that it can take up the entire cutting pressure of the drill. The column may be made of box section or round column. The box type is more rigid. In some of the round column machines rack teeth are cut on the column for vertical movement of the ram and the table. In box column type machines, the front face of the column is accurately machined to form guide ways for the movement of the table.

Table: The table is mounted on the column and is provided with T slots for clamping the work directly on its face. The table may be round or rectangular in shape. For centering the work below the spindle, the table may have three types of adjustments: vertical, radial about the column and circular adjustment about its own axis. After the required adjustment has been made the table and the arm are clamped in position.

Head: The drill head is mounted on the top of the column and houses the driving and feeding mechanism for the spindle. In some of the machines the drill may be adjusted up or down forAccommodating different heights of work in addition to the table adjustment. In lighter machines, the driving motor is mounted at the rear end of the head counterbalancing the weight of the drill spindle.



Hole making operations:

Introduction; machining round holes in metal stock is one of the most common operations in the manufacturing industry. It is estimated that of all the machining operations carried out, there are about 20% hole making operations. Literally no work piece leaves the machine shop without having a hole made in it. The various types of holes are shown in.

The types of hole making operations performed on the holes are:

i. Drilling
ii. Boring
iii. Reaming
iv. Counter sinking
v. Counter boring
vi. Tapping

A large variety of drills are development in addition to the standard twist drill as detailed above for specific applications.

Oils hole drills: These drills are most useful for deep hole drilling. These are provided with two internal holes extending through the length of the drill through which the cutting fluid can be pumped under pressure. This keeps the cutting edge cool while flushing away the chips as well.

Step drills: A variety of step drills are development to suit for combination machining of operations such as multiple hole drilling, counter boring and counter sinking.

Core drills: These are special holes meant for enlarging already existing holes such as those in castings. These are either of the three-flute or four-flute type. The four flute type is used for enlarging the drilled holes while the three-flute type is used for punched or cored holes. The three-flute type keeps the chatter to minimum due to the fact that the cutting lips are not diametrically opposite.

Shell core drill: these are similar to the core drills, but do not have a normal shank for the purpose of holding and are for the large diameters. This needs it be mounted using a stub arbor similar to the shell end mills with the help of the central hole present.

Spade drills: Spade drills are used to make smaller diameter holes with low cutting speeds and high feed rates. These have long supporting bars with the cutting blade attached at the end. These are less expensive since the support structure can be made more rigid using ordinary steel with no spiral flutes. Spade drill are also used to machine small conical shapes for subsequent drilling or making a bevel (similar to counter sinking) on the existing holes to facilitate the subsequent tapping and assembling operations.

Carbide tipped drills: Most of the drills are made of high speed steel. However, for machining hard material as well as for large volume production, tungsten carbide tipped drills are available as shown in. the tungsten carbide tips of suitable geometry are clamped to the end of the tool to act as the cutting edges. As explained earlier in coatings provide a better alternative in improving the cutting tool life. This is more so in the case of a high speed steel drill. The titanium nitride (Tin) coating on the drills improves the drill tool life on an average by two to ten times while drilling steel.

Terminology of twist drill:

Twist drill is made out of high speed steel. They may be parallel shank or tapered shank.

Body: It is the part of the drill which carries flutes and extends from the dead center up to almost the start of the neck. This part is always relieved.

Axis: The longitudinal center line of the drill along which the whole body, neck and shank are concentric.

Chisel edge or dead center: The short edge formed at extreme tip end of the drill, due to intersection of the flanks.

Shank: The portion of drill beyond neck which is gripped in the holding device.

Point: The cone shaped surface at the end of the flutes, formed by grinding, and containing the dead center, lips and flanks, etc.

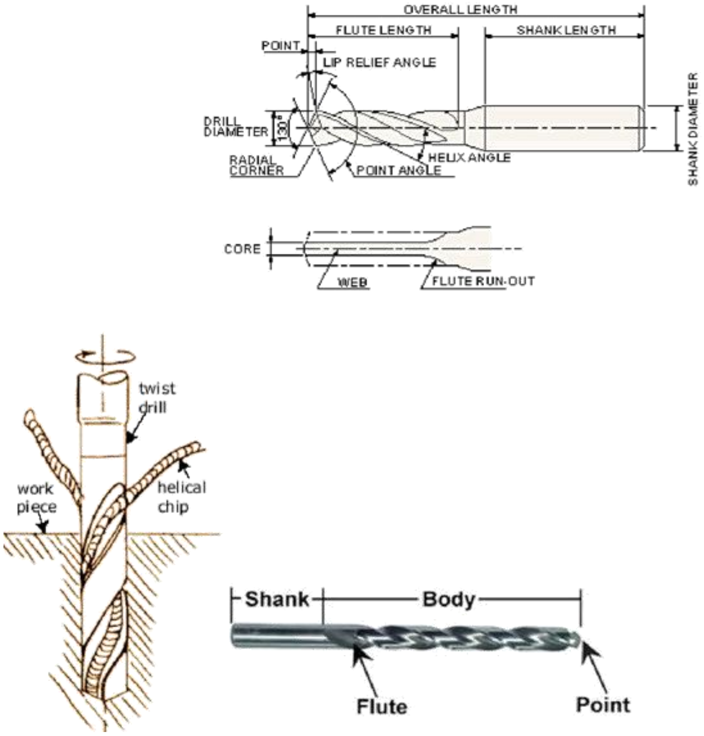


FIGURE – TWIST DRILL

Lip or cutting edge: it is the main cutting part formed by the intersection of each flank and face. Body clearance: A small reduction in the diameter of the body adjacent to the land.

Land or margin: Narrow flat surface which runs all along the flutes of the drill on its leading edge. Lip clearance: the part of the conical surface of point, which is ground to relief near the cutting edge.

Face: the curved surface of the flute near the lip is called face. The chips cut the material slide upward along the surface

Flutes: the helical grooves in the body of the drill are known as flutes. Commonly used drills carry two flutes, while special drills may carry four. These flutes make the chips curl and provide passage for their exit. Also, cutting edges are formed on the point due to machining of these flutes and the cutting fluid reaches the cutting area through these flutes only.

Flank: It is the curved surface, on either side of the dead Centre, which is confined between the cutting edge on its one side and the face of the other flute on the other side.

Web: The central metal column of the drill body, that separates the flutes from one another, is known as web. Its thickness gradually increases from the tip side towards shank side, where it is maximum.

It is this part of the drill which is largely responsible for providing strength and rigidity to the drill.

Chisel Edge Corner: The point of intersection of the chisel edge and the lip is known as chisel edge corner.

Outer Corner: That extreme of the dead Centre, where the face and flank intersect to form a corner, is called outer corner

Neck: the smaller diameter cylindrical portion which separates the body and shank

Tang: the flat portion of rectangular cross-section provided at the end of the tapered shank, which fits into the sleeve or spindle.

Heel: an edge formed where the body clearance and flute intersect.

Rake angle: also called as helix angle formed between plane containing the drill axis and the leading edge of land.

Positive for left hand flute Negative for right hand flute Zero for parallel flute

Drilling Time Estimation

$$V= \pi D N/ 1000$$

Where
V= Cutting speed (surface), m/min
D= Diameter of the twist drill, mm
N= rotational speed of the drill, rev/min.

Material Removal Rate (MRR)

$$MRR= \pi D2 f/ N 4$$

MILLING PROCESS

A milling machine is a machine tool used for the shaping of metal and other solid materials. Its basic form is that of a rotating cutter which rotates about the spindle axis (similar to a drill), and a table to which the work piece is affixed. The cutter and work piece move relative to each other, generating a tool path along which material is removed. The movement is precisely controlled, usually with slides and leadscrews or analogous technology. Often the movement is achieved by moving the table while the cutter rotates in one place, but regardless of how the parts of the machine slide; the result that matters is the relative motion between cutter and work piece. Milling machines may be operated manually or by CNC (computer numerical control).

Milling machines can perform a vast number of operations, some of them with quite complex tool paths, such as slot cutting, planning, drilling; die sinking, rebating, routing, etc.

Cutting fluid is often pumped to the cutting site to cool and lubricate the cut, and to sluice away the resulting swarf.

Types of milling machines: To satisfy various requirements they come in different shapes and sizes. In view to large material removal rates milling machines come with a very rigid spindle and large power. They can be broadly classified as –

Knee and column type milling machines Fixed bed type milling machines

Planer type milling machines Production milling machines
Special purpose milling machines

Further they are classified as

Knee and column type milling machines: These are general purpose machines and have single spindle only. They are so called because their two main structural elements – a column shaped frame and a knee shaped projection. Where the work table is supported on the knee and which can slide in vertical direction along the vertical column. These machines depending upon the spindle position are classified as:

1. Hand milling machine
2. Plain or horizontal milling machine
3. Vertical milling machines
4. Universal milling machine

5. Omniversal milling machines

Fixed bed type or manufacturing type milling machines: These machines, in comparison to the column type are more sturdy and rigid, heavier in weight and larger in size. They are not suitable for tool room work. Most these are either automatic or semi-automatic in operation. They may carry either single spindle or multiple spindles. They perform operations like slot cutting, grooving, gang milling and facing. Also they facilitate machining of various jobs together, called multiple piece milling. They are classified as:

1. Plain milling machine (having single horizontal spindle)
2. Duplex head milling machine (having double horizontal spindles)
3. Triplex head milling machines (having two horizontal and 1 vertical spindles)
4. Rise and fall milling machine (for profile milling)

Planer type milling machines:

They are used for heavy work. Up to a maximum of four tool heads can be mounted over it, which can be adjusted vertically and transverse directions. It has a robust and massive construction like a planer.

Production milling machines:

They are also manufacturing machines but don’t have fixed bed. They are classified as:

1. Rotary type or continuous type
2. Drum type
3. Tracer controlled

Special purpose milling machines:

These machines are designed to perform a specific type of operation only. They include:

1. Thread milling machine
2. Profile milling machine
3. Gear milling machine
4. Cam milling machine
5. Planetary milling machine
6. Double end milling machine
7. Skin milling machine
8. Spar milling machine

From all types of milling machines knee type milling machines are used commonly in tool rooms and machine shops. The principal parts of all knee type are similar although the movements of the moving parts differ they are:

1.**Base**: It is a heavy casting provided at the bottom of the machine. It is accurately machined on both the top and bottom surfaces. It actually acts as load bearing member for all parts. Column of the machine is secured to it. Also it carries the screw jack which supports and moves the knee. In addition it serves as a reservoir for the coolant.

2.**Column**: It is a very prominent part of milling machine and is produced with enough care. To this, are fitted all various parts and controls. On the front face vertical parallel ways are made in which the knee slides up and down. And its rear end carries the enclosed motor drive. Top of the column carries a dovetail horizontal ways for the over arm.

3.**Knee**: It is a rigid casting, which is capable of sliding up and down along the vertical ways on the front face of the column. This enables the adjustment of the table height or in other words the distance between the cutter and the job mounted on the table. The adjustment is provided by operating elevating jack, provided below the knee, means of hand or application of power feed.

4. Saddle: It is the intermediate part between the knee and the table and acts as support to the table. It can be adjusted along the ways provided on the top surface of the knee, to provide cross feed to the table. As it carries horizontal ways, along this moves the table during longitudinal traverse.

5. Table: it acts as a support for the work. Work piece is mounted on it either directly or held in a driving head. It is made of cast iron, accurately machined on the top surface. It carries T- slots to accommodate the clamping bolts for fixing the work or securing the fixtures. Cross feed is provided by moving the saddle and vertical feed is given by raising or lowering the knee. Both hand and power feed can be employed for this purpose.

6. Over arm: it is a heavy support provided on the top of the both plain and universal milling machines. It can slide horizontally, along the ways provided on the top of the column and adjusted to a desired position in order to support to the projection arbor by accommodating its free end in the yoke.

MILING CUTTERS

There are a large variety of milling cutters available to suit specific requirements. The versatility of the milling machine is contributed to a great extent by the variety of milling cutters that are available.

Milling cutters are classified into various types based on a variety of methods.
1) Based on constructions:
(A) Solid
(b) Inserted tooth type

2) Based on mounting:
(a) Arbor mounted
(b) Shank mounted
(c) Nose mounted

3) Based on rotation:
(a)Right hand rotation (counter clockwise)
(b)Left hand rotation (clockwise)

4) Based on helix:
(a)Right hand helix
(B) left hand helix

Milling cutters are generally made of high speed steel or cemented carbides. The cemented carbide cutters can be of a brazed tip variety or with index able tips. The index able variety is more common since it is normally less expensive to replace the worn out cutting edges than to regrind them.

Plain milling cutters:

These are also called slab milling cutters and are basically cylindrical with the cutting teeth on the periphery as shown. These are generally used for machining flat surface.

Side and face milling cutters:

These have the cutting edges not only on the face like the slab milling cutters, but also on both the sides. As a result, these cutters become more versatile since they can be used for side milling as well-as for slot milling.

Staggered tooth side milling cutters are a variation where the teeth are arranged in an alternate helix pattern. This type is generally used for milling deep slots, since the staggering of teeth provides for greater chip space.

Sitting saw:

The other common form of milling cutters in the arbor mounted category is the slitting saw. This is very similar to a saw blade in appearance as well as function. Most of these have teeth around the circumference while some have side teeth as well. The thickness of these cutters is generally very small and is used for cutting off operations or for deep slots.

Special form cutters:

In addition to the general type of milling cutters described above, there are a large number of special form milling cutters available which are used for machining specific profiles. Angular milling cutters are made in single or double angle cutters for milling any angle such as 30, 45 or 600. Form relieved cutters are made of various shapes such as circular, corner rounding, convex or concave shapes.

T-slot milling cutters are used for milling T-slots such as those in the milling machine table. The central slot is to be milled first using an end mill before using the T-slot milling cutter. Woodruff key seat milling cutters are used for milling as the name suggests woodruff key seats.

Some other special form cutters are dovetail milling cutters and gear milling cutters.

End mills:

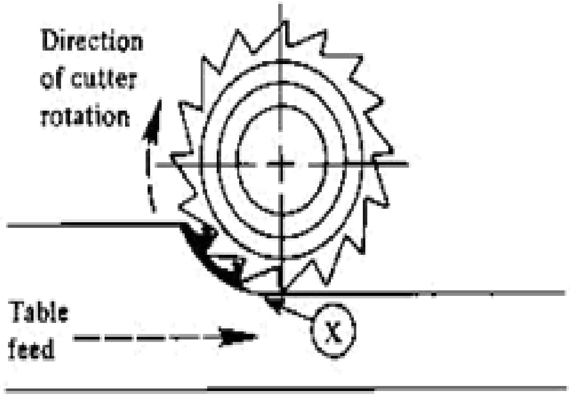
These are shank mounted as shown and are generally used in vertical axis milling machines. They are used for milling slots, key ways and pockets where other type of milling cutters cannot be used. A depth of cut of an almost half the diameter can be taken with the end mills.

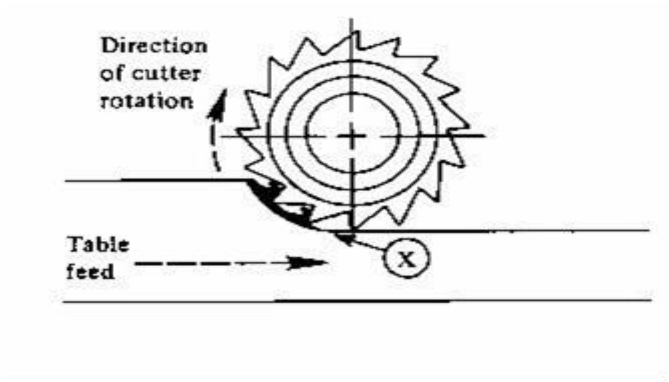
The end mills have the cutting edge running through the length of the cutting portion as well as on the face radically up to a certain length. The helix angle of the cutting edge promotes smooth and efficient cutting even at high cutting speeds and feed rates. High cutting speeds are generally recommended for this type of milling cutters.

Up and down milling:

Based on the directions of the movement of the milling cutter and the feeding direction of the work piece, there are two possible types of milling:

(i) Up milling (conventional milling)
(j) Down milling (climb milling)





Up milling:

In up milling the cutting tool rotates in the opposite direction to the table movement. In the conventional or up milling, the chip starts as zero thickness and gradually increases to the maximum size as shown. This tends to lift the work piece from the table. There is a possibility that the cutting tool will rub the work piece before starting the removal. However, this process is inherently safe.

The initial rubbing of the cutting edge during the start of the cut in up milling tends to dull the cutting edge and consequently have a lower tool life. Also since the cutter tends to cut and slide alternatively, the surface generated is left with the machining marks.

Down milling (climb milling)

In down milling the cutting tool rotates in the same directions as that of the table movement. In climb or down milling, the chip starts as maximum thickness and goes to zero thickness gradually as shown. This is suitable for obtaining fine finish on the work piece. The cutting force acts downwards and as such keeps the work piece firmly in the work holding device. This is good for thin and frail work pieces. In this case the cutting force direction as well as the lead screw motion being in the same direction, there is a possibility that the backlash present in the table lead screw will interfere with the actual motion of the table making it jerky. Sometimes the work may be pulled into the cutter, which may result in a broken milling cutter or damaged work piece. This may sometimes be dangerous to the machine tool as well. The chip starts with maximum thickness and this gives a large force, which will have to be taken care of by a rigid lead screw for table feeding.

In down milling, though the cut starts with a full chip thickness, it gradually reduces to zero. This helps in eliminating the feed marks present in the case of up milling and consequently a better surface finish. Climb milling also allows greater feeds per tooth and longer cutting life between regrinds than conventional milling.

Advantages:

1. Suited to machine thin and hard-to-hold parts since the work piece is forced against the table or holding device by the cutter.
2. Work need not be clamped as tightly.
3. Consistent parallelism and size can be maintained, particularly on thin parts.
4. It can be used where breakouts at the edge of the workpeice cannot be tolerated.
5. It requires up to 20% less power to cut by this method.
6. It can be used when cutting off stock or when milling deep, thin slots.

Disadvantages:-

1. It can be used unless the machine has a backlash eliminator and the table jibs have been tightened.
2. It cannot be used for machining castings or hot rolled steel, since the hard outer scale will damage the cutter.

Dividing head:

A dividing head is one of the most important attachments of the milling machine and is almost indispensable. A typical construction of the dividing head is shown. The main spindle of the dividing head drives the work piece by means of a 3- jaw universal chuck or a dog and live center similar to a lathe.

The index plate of a dividing head consists of a number of holes with a crank and pin. The index crank drives the spindle and the live center through a worm gear, which generally has 40 teeth as shown. As a result, a full rotation of the work piece is produced by 40 full revolutions of the index crank. Further indexing is made possible by having the index plates with equi-spaced holes around various circles. This would aloe for indexing the periphery of the work piece to any convenient number of divisions.

Simple or plain indexing:-

Plain indexing is the name given to the indexing method which is carried out using any of the indexing plates in conjunction with the worm. With this it is possible to obtain relatively simple divisions. To understand this procedure let us assume that a gear is to be divided equally into 20 divisions. Since 40 revolutions of the index crank produces one full revolution of the work piece, we need to rotate the index crank for two full turns for cutting each tooth of the gear.

Let us assume that we want six equal divisions to be made. The rotation of the index crank=40/6=6*2/3=turns.

This means that the index crank should be rotated for six full turns followed by two thirds of a rotation. The fraction of a rotation required is to be obtained with the help of the index plates as given above. This can be done as follows using any of the Brown & Sharpe plates.

Compound Indexing:

Using the simple indexing method a majority of the indexing jobs can be completed. However when the available capacity of the index plates is not sufficient to do a given indexing job, the compound indexing method can be used. In order to obtain more complex indexing the following method is used. First, the crank is moved in the usual fashion in the forward direction. Then a further motion is added or subtracted by rotating the index plate after locking the plate with the plunger. This is termed as compound indexing.

For example, if the indexing is done by moving the crank by 5 holes in the 20 hole circle and then the index plate together with the crank is indexed back by a hole with the locking plunger registering in a 15 hole circle as shown. Then this is compound indexing.

The total indexing done is then

5/20-1/15=11/60

i.e. 19holes in a 60 hole circle. Unfortunately the 60 hole circle is not available in the brown and Sharpe range of index plates. Similarly it is possible to have the two motions in the same direction as

5/20+1/15=19/60

i.e., 19 holes in a 60 hole circle.

Therefore by following this method any other indexing can also be done.

Angular Indexing:

Sometimes it is desirable to carry out indexing using the actual angles rather than equal numbers along the periphery. Here, angular indexing would be useful. The producer remains the same as in the previous cases. Except that the angle will have to be first converted to equivalent divisions. Since 40 revolutions of the crank equals to a full rotation of the work piece, which means 3600, one revolution of the crank is equivalent to 90.

Differential Indexing:

Though compound index is a convenient way to get any indexing required, it is fairly cumbersome to use in practice. Hence differential indexing is used for that purpose which is an automatic way to carry out the compound index method. The arrangement for differential indexing is shown.

In differential indexing, the index plate is made free to rotate. A gear is connected to the back end of the dividing head spindle while another gear is mounted on a shaft and connected to the shaft of the index plate through bevel gear as shown. When the index crank is rotated, the motion is through the intermediate gearing as explained above, the index plate will also start rotating. If the chosen indexing is less than the required one, then the index plate will have to be moved in the same direction as the movement of the crank to add the additional motion. If the chosen indexing is more, then the plate should move in the opposite direction to subtract the additional motion.

The direction of the movement of the index plate depends upon the gear train employed. If an idle gear is added between the spindle gear and the shaft gear in case of a simple gear train, then the index plate will move in the same direction to that of the indexing crank movement. In the case of a compound gear train an idler is used when the index plate is to move in the opposite direction. The procedure of calculation is explained with the following example.
The change gear set available is 24, 24, 28, 32, 40, 44, 48, 56, 64, 72, 86 and 100.

Shaping Machine:

Shaper is a versatile machine which is primarily intended for producing flat surfaces. These flat surfaces may be horizontal, vertical or inclined. This machine involves the use of a single point tool held in a properly designed tool box mounted on a reciprocating ram. The main significance of this machine lies in:

- It has Greater flexibility.
- Ease in work holding
- Quick adjustment of the work
- Tools used have relatively simple design.

Principle:

The job is held in a device like vice or clamped directly on the machine table. The tool is held in the tool post mounted on the ram. This ram reciprocates to and fro and, in doing so makes the tool to cut the material in the forward stroke. No cutting of material takes place during the return stroke of the ram. Hence it is termed as idle stroke.

There are different types of shaping machine

1. Standard shaper
2. Draw-cut shaper
3. Horizontal shaper
4. Vertical shaper
5. Geared shaper
6. Crank shaper
7. Hydraulic shaper
8. Contour shaper
9. Traveling head shaper
10. Universal shaper

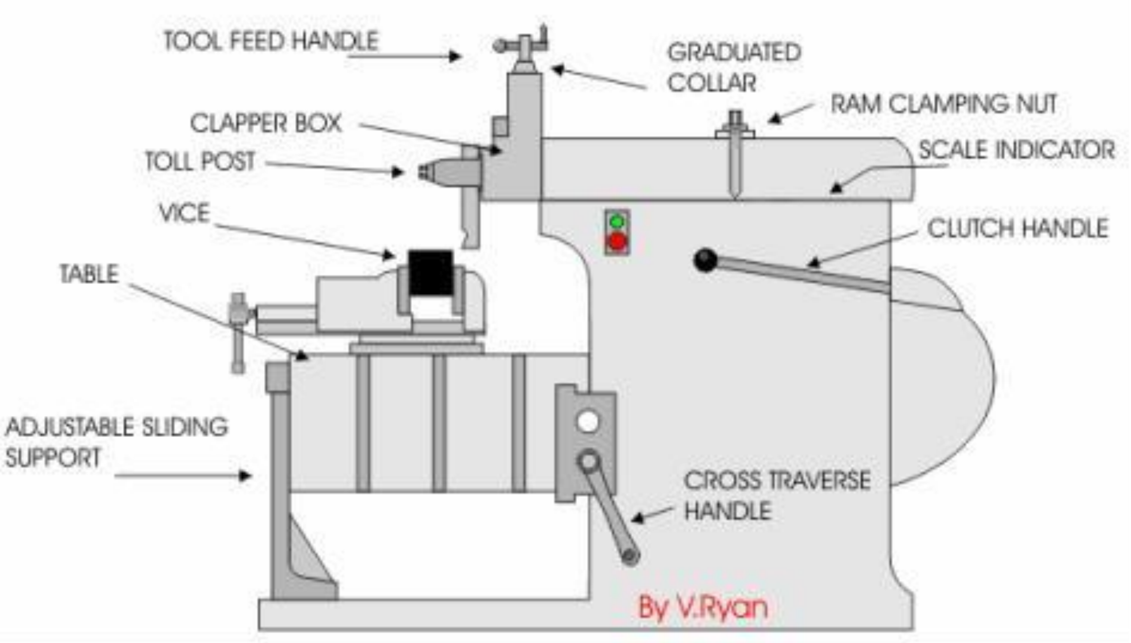


Figure: Shaping machine

Main parts of shaper:

Base:

It is a heavy robust cast iron body which acts as a support for all the other parts of the machine which are mounted over it.

Column:

It is a box type cast iron body, mounted on the base and acts as housing for operating mechanism of the machine and the electrical. It also acts as a support for other parts such as cross rail, ram, etc.

Cross-rail:

It is a heavy cast iron construction, attached to the column at its front vertical guide ways. It carries two mechanisms- one for elevating the table & second for cross traverse of the table.

It carries accurately machined and scraped horizontal guide ways at its front. An apron to which is bolted the machine table, slides along these ways to provide cross traverse to the table and hence the job. The apron is moved by rotating a lead screw provided inside the cross rail. Up and down vertical motion to the table is provided by means of a vertical lead screw which is operated by rotating a table traverse screw. The table carries T-slot on its top side faces for clamping the work or a vice is provided. Automatic feed is provided by means of an eccentric driven ratchet and pawl operated mechanism. For the drive, an electric motor, fitted at the back of the machine, is used from which the drive is transferred to gear box through V-belts. Quick return motion of the ram is controlled by an eccentric pin sliding in rocker arm.

Table:

It is made of cast iron and has a box type construction. It holds and supports the work during the operation and slides along the cross rail to provide feed to the work. T-slots are provided on its top and sides for securing the work to it.

Ram:

It is also a cast iron casting, semicircular in shape and provided with ribbon construction inside for rigidity and strength. It carries the tool head and travels in dove tail guide ways to provide straight line motion to the tool. It carries the mechanism for adjustment of ram position inside it.

Tool Head:

It is the device in which tool is held. It can slide up and down and swung to a desired direction or angle to set the tool at a desired position for the operation.

Vice:

It is the job holding device and is mounted on the table. It holds and supports the work during operation.

Types of operations performed on shaper

- Machining Horizontal surfaces Machining Vertical surfaces
- Machining angular surfaces and machining irregular surfaces
- Machining Splines or Cutting gears
- Cutting slots, grooves and keyway

GRINDING OPERATION

Grinding is the processes of removing material by the abrasive action of a revolving wheel on the surface of a work piece in order to bring it to required shape and size. The wheel used for performing the grinding operation is known as grinding wheel. It consists of sharp crystals called abrasives, held together by a bond material. The wheel may be a single piece or solid type composed of several segments of abrasive blocks joined together. It is basically a finishing operation used to remove a very small amount of material. This is used for the following purposes:

1. Machining materials which are too hard for other materials such as tool and die steels and hardened steel materials.

2.For close dimensional accuracy of 0.3 to 0.5 Zm

3. High degree of surface finish or smoothness Ra = 0.15 to 1.25 Zm

Grinding wheel designation and selection:

Grinding wheels are produced by mixing the appropriate grain size of the abrasive with the required bond and pressed into the shape. The characteristics depend upon following parameters:

- Abrasive material used
- Bonding material used
- Grade
- Grain

Abrasive material:

These are hard materials with adequate toughness. They are classified as:

1. Natural abrasives: they are obtained directly from mines like stone, emery, corundum and diamond. Except diamond others are not used now as they have impurities.

2. Artificial abrasives: they are manufactured under controlled conditions in closed electric furnace to avoid impurities and achieve necessary temperature for chemical reaction to take place. Examples are:

(a) Silicon carbide:

Silicon dioxide is mixed with coke, saw dust, salt and piled up around a carbon electric conductor of resistance type furnace. A heavy current is switched on and

A temperature of about 2600C is generated to form silicon carbide.

$Sio_2 + 3C = SiC + 2 CO$

Where silicon combines with coke to form silicon carbide and salt vaporizes to form carbides with the metallic impurities present and removes them. The saw dust burns and provides porosity to the mass for escaping gases.

(b) Carborundum, crystolon and electrolon.

(c) Aluminum oxide (Al203):

Bauxite is fused in to the furnace and current is passed where aluminum oxide block is formed along with iron scraps acts as flux to collect impurities. Common trade names are Aloxite and borolon.

(d)Artificial diamonds: artificially manufactured
Bond materials: To have effective and continuous cutting action, it is necessary that the grains of abrasive material should be held firmly together to form a series of cutting edge. The material used to for holding the grains together with the wheel is called as bonds. They are different types like

OVirtified'V': Clay mixed with fluxes like feldspar which hardens to a glass like substance on firing to a temperature of 1250C.this has good strength, rigid, and porous and not affected by fluids. But is brittle and is sensitive to impacts and also called as ceramic bond.

OSilicate'S': This is NaSio sodium silicate or water glass and hardened when heated. It is not strong as 'V' and used at less generation of heat. It is affected by dampness and less sensitive to shocks.

ORubber'R': Of all this is the flexible bond and is made up of natural or synthetic rubber. The strength is developed by vulcanization. This has high strength and is less porous. This is affected by dampness and alkaline solutions. It is generally used for cutting off wheels, regulating wheels in Centre less grinding and for polishing.

OResiniod 'B': These are thermosetting plastics such as phenol formaldehyde. This has good strength and is more elastic than 'V'. It is not heat and chemical resistant. Used for rough grinding, parting off and high speed grinding and for fine finishing of roll grinding.

OShellac'S': This is relatively less used bond. Generally used for getting a very high surface finish. Typical applications are rolls, cutlery, and cam shaft finishing's.

Grain size:
The term grain or grit denotes the approximate size of the abrasive particles and givesan idea of the coarseness or fineness of the grinding wheel. Compared to a normal cutting tool, the abrasives used in grinding wheel are relatively small. The size of an abrasive grain more generally called grit is identified by a number which is based on the sieve size used. These vary coarse size of 6 or 8 to a super fine size of 500 or 600. The sieve number is specified in terms of the number of openings per square inch. Thus larger the grain number finer is the grain size.

The surface finish generated depends upon the grain size used as shown. Fine grains take a very small depth of cut and hence provide a better surface finish. Also fine grains generate les heat and are good for faster material removal. Though each grain cuts less, there are more grains per unit surface area of the wheel in case of fine grain size. Fine grains are also used for making from grinding wheels.

Grade: It is number representing the number of meshes per inch of the screen through whichgrains of crushed abrasives are passed for grading. The coarser grit wheels are used for grinding soft and ductile materials whereas hard and brittle materials are grinded by soft grit wheels. This designates the force holding the grains. The grade of the wheel depends on the kind of bond, structure and amount of abrasive grains. Greater the bond content and a strong bond results in a harder grinding wheel.

Soft wheels are generally used for hard materials and hard wheel for soft materials.

Different wheel grades are represented by alphabets from A to Z, A being the softest and Z the hardest.

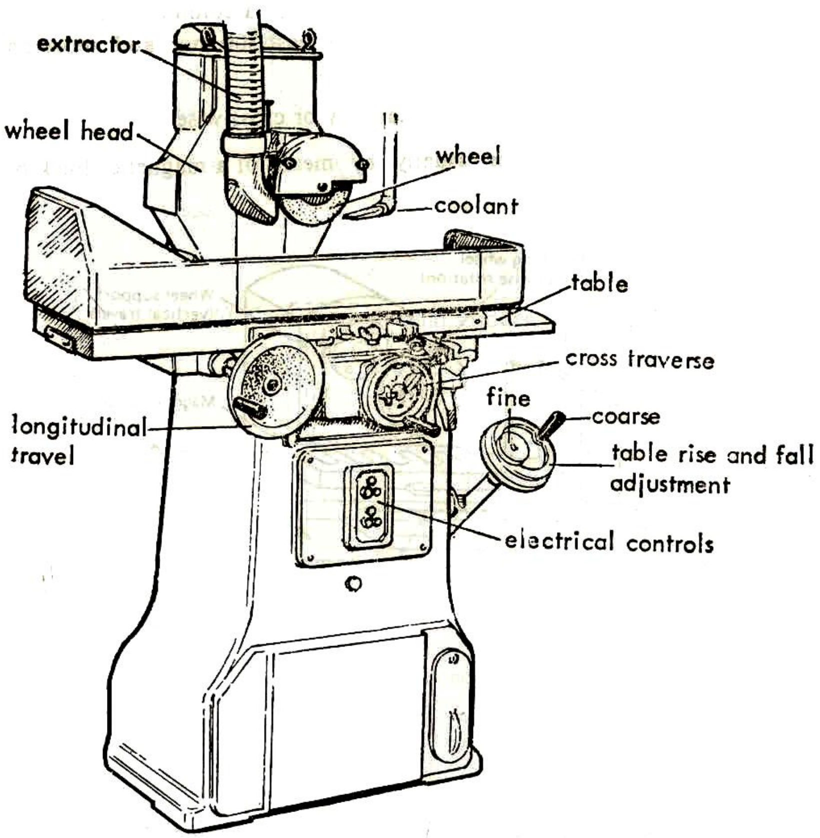
Soft	A B C D E F G H
Medium	I J K L M N O P
Hard	Q R S T U V W X Y Z

Structure: This term denotes the spacing between the abrasive grains, or in other words thedensity. It is also called as the hardness of the grinding wheel. The proportion of the bond in certain volume of the wheel effects the structure. A higher proportion will render an open structure and a lower proportion will lead to closer structure. If two wheels of same grit and grade are used on same material, one having an open structure and the other close structure, the former will be found to cut faster and more freely in comparison to the latter and also will have more life as compared to it.

Types of grinding machines:

There are three types of grinding machines

1. Cylindrical grinding machine
2. Surface grinding machine
3. Centre less grinding machine



Grinding is the process of removing metal by the application of abrasives which are bonded to form a rotating wheel. When the moving abrasive particles contact the workpiece, they act as tiny cutting tools, each particle cutting a tiny chip from the work piece. It is a common error to believe that grinding abrasive wheels remove material by a rubbing action; actually, the process is as much a cutting action as drilling, milling, and lathe turning.

The grinding machine supports and rotates the grinding abrasive wheel and often supports and positions the work piece in proper relation to the wheel.

The grinding machine is used for roughing and finishing flat, cylindrical, and conical surfaces; finishing internal cylinders or bores; forming and sharpening cutting tools; snagging or removing rough projections from castings and stampings; and cleaning, polishing, and buffing surfaces. Once strictly a finishing machine, modem production grinding machines are used for complete roughing and finishing of certain classes of work.

CNC MACHINING

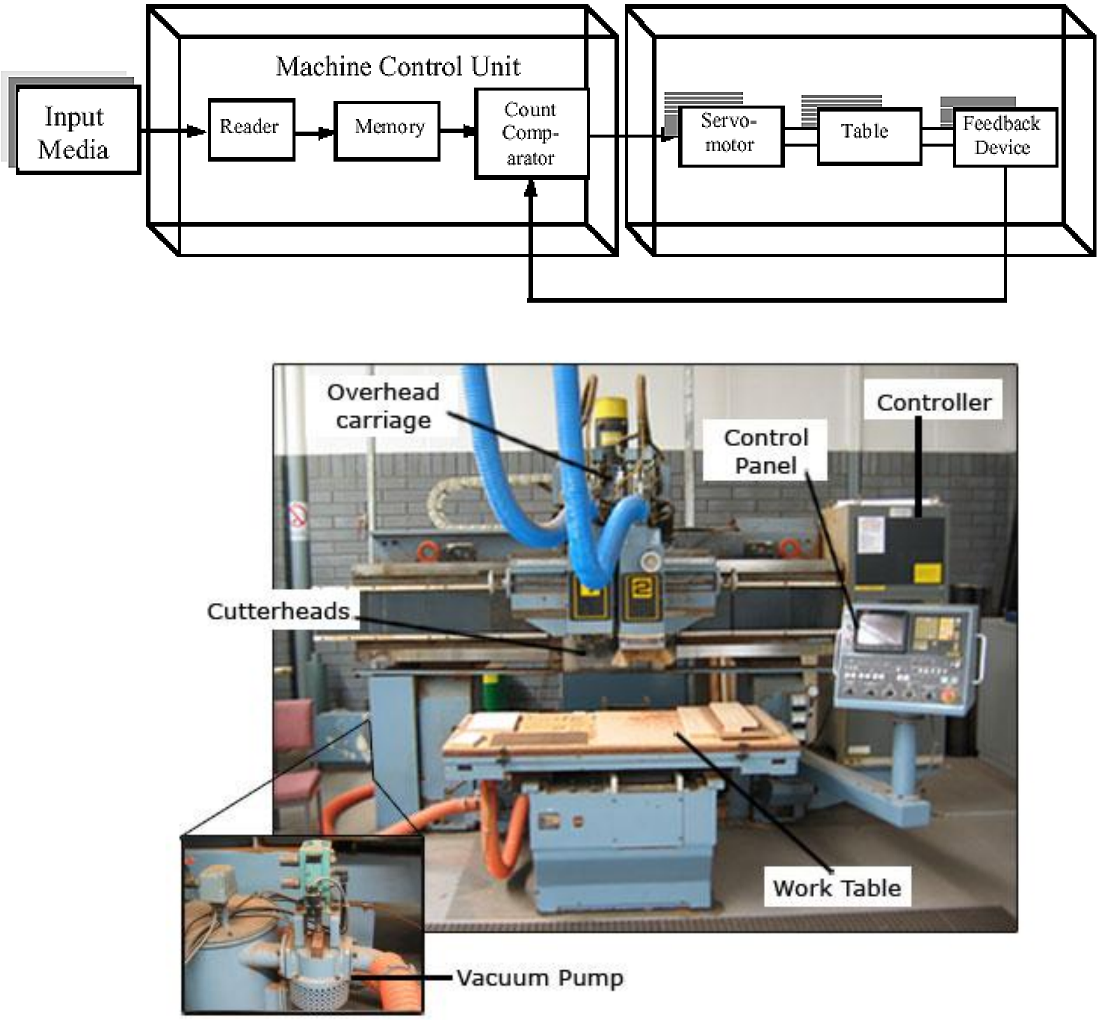


FIGURE – CNC Machine and process

BASIC PRINCIPLES OF CNC OPERATION

The basic principles of CNC operation include the following:

- Tooling
- Function keys
- Operational keys
- Movements
- Vacuum pump.

Tooling

Tooling consists of vertical mounted tooling that can operate independently or in conjunction with each other under computer or manual control and move laterally across the machine axis.

Function keys

The computer numerical control consists of address/data/programming function keys.

Operational keys

The operator control panel consists of operational keys to start the machine cycle in memory, manual or tape mode.

Movements

The machine consists of three lateral axial movements which operate in conjunction with each other, or independently. These consist of:

- X axis, horizontal longitudinal head carriage movement (usually left/right).
- Y axis, horizontal, lateral table movement (usually front/back at 90° to X axis).
- Z axis, vertical lateral cutting head movement (up/down).
- Further axes can define head tilt, helicoidally revolution, etc.

Vacuum pump

The work piece is held in place by suction from a vacuum pump located at the side of the machine.

The Unconventional or Non-traditional Machining methods

Conventional machining processes utilize the ability of the cutting tool to stress the material beyond the yield point to start the material removal processes so they require harder cutting tool than the work piece.

Development of newer methods has always been the endeavor of engineering personnel and scientist. The main idea behind such endeavors have generally been the economic considerations, replacement of exciting manufacturing methods by more efficient and quicker ones, achievement of higher accuracies and quality of surface finish, adaptability of cheaper materials in place of costlier ones and developing methods of machining such materials which cannot be easily machined through conventional methods, etc. of all these reasons, the last one has contributed considerably to the post-war development in machining methods, particularly because of the use of a large number of hard to machine materials in the modern industry. A few of such materials are tungsten, hardened and stainless steel, tantalum, Inconel, uranium, beryllium and some high-strength steel alloys. The increasing utility of such materials in the modern industry has forced the research engineers to develop newer machining methods, so as to have full advantage of these costly materials.

The use of such hard to machine materials is quite common in aircraft industries, space research equipment, nuclear power plants, missile technology, sophisticated armament, etc. To meet the needs of such industries, whereas on one hand newer materials have been developed at the same time newer machining methods have evolved called as Unconventional or Non-traditional Machining methods.

Classification of Unconventional or Non-traditional Machining methods:
They are broadly classified on the basis of the following criteria:

Type of energy used:
Mechanical, chemical, electro-chemical or electro-thermal

Media for energy transfer
High velocity particles, physical contact, reactive atmosphere, electrolyte, hot gases, electrons, radiation.

Mechanism of metal removal:
Erosion, shear, chemical ablation, ionic dissolution, vaporization, spark, erosion.

Source of energy:
Pneumatic, hydraulic, mechanical, corrosive agent, high current, high voltage, ionized gases.

Thermal and electro thermal methods are:

- EDM
- LBM
- PAM
- EBM
- IBM

Chemical and Electro Chemical Are

- ECM
- ECG
- ECH
- ECD

Mechanical Are

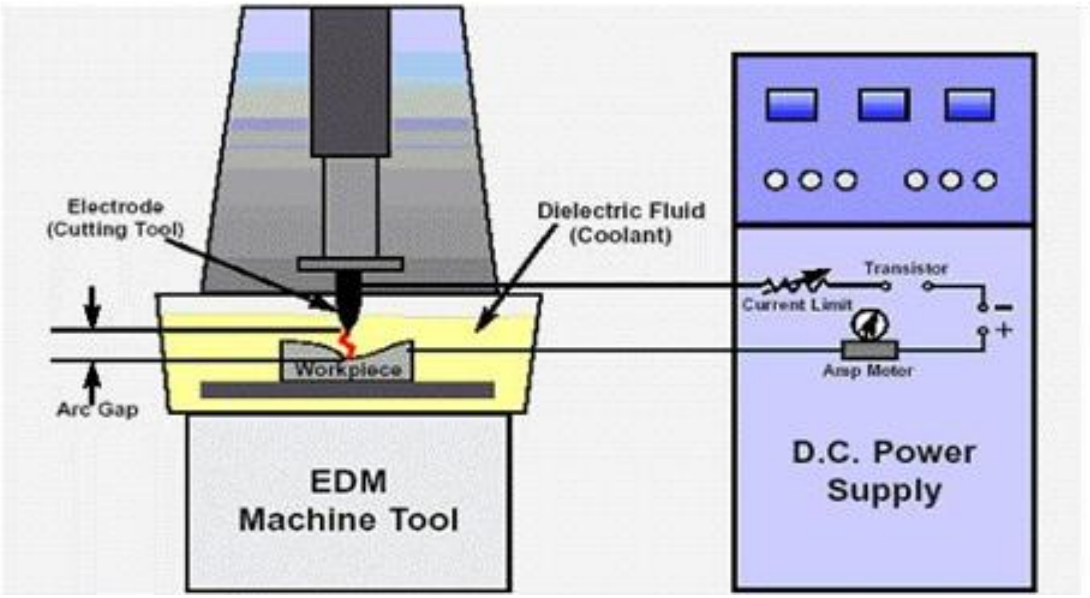
- USM
- AJM
- WJM

Electrical Discharge Machining:

It is also known as spark-over-initiated discharge machining or spark erosion machining or simply spark machining. It is probably the versatile of all methods. The metal removal takes place due to erosion caused by the electric spark. These processes may be used for machining any material, irrespective of its hardness, which is an electric conductor. The rate of metal removal and the resulting surface can be controlled by proper variation in the energy and the duration of spark discharge. A liquid dielectric is used, in some cases gaseous dielectrics are also used.

Setup:

- The main elements of this setup include
- Power supply
- Dielectric medium Work piece
- Tool servo control
- Speed reduction gear box
- Rack and pinion mechanism or any other mechanism Electric circuit to generate discharge



Both tool and work piece are connected to the D.C Electric supply source. As shown in figure the work piece is connected to the positive terminal and the tool to the negative terminal of the power supply. Consequently, the work piece becomes Anode and tool cathode

Principle:
The principle involved in the process is that the work piece and the electrode are separated by a gap, called spark gap. This gap is filled up by a dielectric, which breaks down when a proper voltage is applied between these two. The spark usually varies from 0.0005 to 0.05 mm. when a circuit voltage of 50v to 450v is applied, electrons start flowing from cathode to anode, due to the electrostatic field, and the gap is ionized. The consequent drop in resistance and discharge of electric energy results in an electrical breakdown. The electric spark so caused directly impinges on the surface of the work piece. It takes only a micro-second to complete the cycle and the spark discharges hit the anode with considerable force and velocity, resulting in the development of a very high temperature (around 10,000°C) on the spot hit by the discharges. This forces the metal to melt, and a portion of it may be vaporized even. These vaporized are melted particles are thrown into the gap by electrostatic and electromagnetic forces, from where they are driven away by the flowing liquid dielectric. The maximum effect of the arc impingement is on the elevated spots on the work surface. So they are first to get removed. It is because they are nearest to the tool tip.

The gap control is affected through a servo system. This system correctly locates the tool in relation to the work piece surface and maintains constant gap throughout the operation and senses changes in gap conditions, if any. Also it immediately corrects the deviations caused due to these changes. The servo system used may be electrical or hydraulic.
Remember that erosion takes place on both tool and piece, but tool is eroded less because of its tip subjected to compressive forces due to electric and magnetic fields, resulting smaller erosion.

And other important point to be noted is that unlike conventional method the machining speed cannot be increased by simply using multiple tools because it is confined to particular spot. If more tools are used separate servomechanisms are required.

Dielectric fluid:
Dielectric fluid called as a spark conductor, coolant and also flushing medium. The requirements are as follows:

a. It should have sufficient and stable dielectric strength to serve as an insulating between the tool and work till the breakdown voltage is reached.
b. It should de-ionize rapidly after the spark discharge has taken place.

c. It should have low viscosity and good wetting capacity to provide an efficient cooling mechanism and remove the swarf particles from the machining gap.
d. It should be chemically neutral so as to attack the electrode, work piece, the table or the tank.
e. Its flash point should be high so that there no fire hazards.

f. It should not emit any toxic vapors or unpleasant odurs.

g. It should be economical and easily available.

Examples: Hydrocarbon fluids, silicone-based oils and de-ionized water. Kerosene and water with glycol are also used.
Electrodes:
In the EDM process the shape of the electrode is impressed on the work piece in its complimentary form and as such the shape and accuracy of the electrode plays a very important role in the final accuracy of the work piece machined.

The electrode material should have the following characteristics serve as a good tool.

- It should be a good conductor of electricity and heat.
- It should be easily Machin able to any shape at reasonable cost
- It should produce efficient material removal rates from work pieces. It should resist the deformation during erosion process.
- It should exhibit low electrode wear rates. It should be available in a variety shapes.

Process Characteristics:

The metal removal rates in EDM depend upon the following parameters:

1. Current in spark
2. Frequency of the discharge
3. Electrode material
4. Work piece
5. Dielectric flushing condition

Advantages:

•There is no physical contact between the tool and the work piece and hence no cutting forces
•Enable high accuracy on tools and dies, because they can be machined in ‘as hard’ condition.
•Even highly delicate section and week materials can be machined without any fear of distortion because there is no direct contact between the tool and the Work piece.
•Irrespective of its hardness or strength, any material, which is an electrical conductor, can be machined.
•Any shape that can be imparted to the tool can be reproduced on the work
•Fine holes can be easily drilled.
•It is a quicker process. Even harder materials can be machined at a much faster rate than conventional machining.

Disadvantages:

This process has some distinct disadvantages as well, such as capacity to machine small Work pieces only, unsuitability for machining of electrical non-conductors, thermal distortion, inability to produce sharp corners etc.

Applications:

•There is no physical contact between the work and the tool hence no cutting forces act on the work. Even fragile pieces can be machined.

•Any complex shapes required in dies can be easily produced with required degree of accuracy and finish.

•Process not affected by the work piece hardness.

•High aspect ratio surfaces can be machined.

•Process is mostly automated. With very little operator skill.

•Even spark are produced there is no thermal damage of the material.

ELECTRON BEAM MACHINING

Definition:

It is a process of machining materials with the use of a high velocity beam of electrons. The work piece is held in a vacuum chamber and the electron beam focused on to it magnetically. As the electrons strike the work piece, their kinetic energy is converted into heat. This concentrated heat raises the temperature of work piece materials and vaporizes a small amount of it, resulting in removal of metal from the work piece. The reason for using a vacuum chamber is that, if otherwise, the beam electrons will collide with gas molecules and will scatter.

The main elements of Electron Beam Machining setup are shown in.

The setup is enclosed in a vacuum chamber, which carries vacuum of the order of 10-5 mm of mercury. This chamber carries a door, through which the work piece is placed over the table. The door is than closed and sealed.

The Electron gun:

Which is mainly responsible for emission of electrons, consists of three main parts

1. A tungsten filament (acts as cathode)
2. The grid cup
3. and the anode.
4. Electromagnetic lens
5. Deflector coil

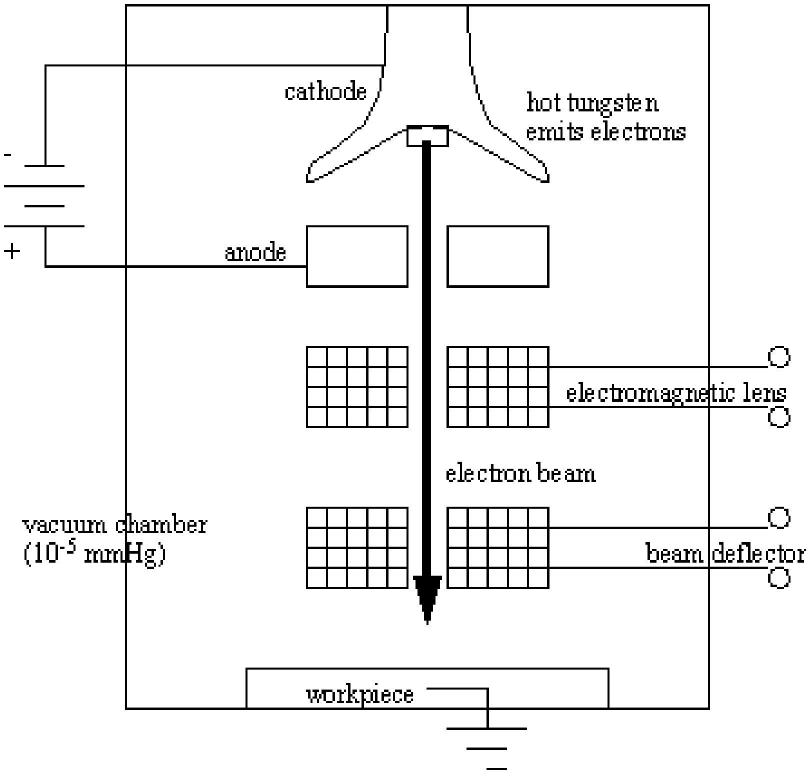


FIGURE- EBM

Procedure:

- The filament is connected to the –ve terminal of the D.C power supply, to act as cathode, and the anode to the +ve terminal, as shown.
- When DC supply is put on the filament wire is heated up to a temperature of about 25000C in the vacuum, which results in a cloud of electrons which emit from the grid cup to travel downwards. As the electrons are attracted by the anode, they pass through its aperture in the form of a controlled beam without colliding with it.
- A potential difference of 50 to 150 KV is maintained between the filament and the anode. As such, the electrons passing out of anode, is maintained by them till such time as they strike the Work piece. It becomes possible because the electrons travel through the vacuum.
- This high velocity electron stream, after leaving the anode, passes through the tungsten diaphragm and then through the electromagnetic focusing coils (or focusing lens). By then, the stream is quite aligned and the focusing lens manages to focus it precisely on to the desired spot on the Work piece.
- The electromagnetic deflector coil then deflects this aligned stream (beam) on to the work, through which the path of cut can be controlled.
- Further, the table, on which the Work piece is loaded, can also be traversed to feed the Work piece as needed.

- This velocity beam of electrons impinges on the Work piece, where its kinetic energy is released and gets converted into heat energy. The high intensity heat, so produced, melts and vaporizes the work material at the spot of beam impingement. By alternately focusing and turning off the cutting process can be continued as long as it is needed.

- Melting and vaporizing of the metal takes only a small fraction of a second and turning off the beam is necessary to conduct away the heat from the Work piece. A suitable viewing device is always incorporated so as to enable the operator to observe the progress of machining operation

- Adequate vacuum is required to be maintained inside the chamber so that the electrons can travel from cathode to anode without any hindrance, there is no arc discharge between the electrons, there is no loss of heat from cathode, there is no contamination of cathode and the high velocity attained by the electron beam while leaving anode is maintained up to the event of its impingement on the work.

Advantages

1. Any material can be machined
2. Work piece is not subjected to any physical or metallurgical damage.
3. Problem of tool wear is non-existent. So, close dimensional tolerances can be achieved.
4. Heat can be concentrated on a particular spot.
5. An excellent technique for micro machining
6. There is no contact between the work and tool

Disadvantages

1. High initial investment needed.
2. Highly skilled operator required to perform the operation.
3. Not suitable for producing perfectly cylindrical deep holes.
4. Suits for small and fine cuts only.
5. Work piece size is limited due to requirement of vacuum in the chamber.
6. Low rate of metal removal
7. High power consumption
8. Difficult to produce slots and holes of uniform shapes and dimensions.

Applications

1. Very effective for machining of materials of low heat conductivity and high melting point.
2. Micro-machining operations on Work piece of thin sections.
3. Micro-drilling operations (up to 0.002 mm) for thin orifices, dies for wire drawing, parts of electron microscopes, fiber spinners, injector nozzles for diesel engines, etc.

LASER BEAM MACHINING (LBM)

Laser is the term used for the phenomenon of ‘amplification of light by stimulated emission of radiation’. The setup consists of a stimulating light source (like xenon flash lamp) and a laser rod (laser tube), from where it is reflected and accelerated in the path. This light is emitted in the form of a slightly divergent beam. A lens is incorporated suitable in the path of this beam of light which converges and focuses the light beam on to the Work piece melts the work material and vaporizes it. It is of laser beam on the Work piece melts the work material and vaporizes it. It is a very costly method and can be employed only when it is not feasible to machine a Work piece through other methods.

The setup for laser beam machining, together with its circuit. It mainly consists of a laser tube or rod, a pair of mirror- one at each end of the tube, a flash tube or lamp (energy source), an amplifying source (laser), a power supply source, a cooling system and lens (focusing source). The main setup is setup is fitted inside an enclosure, which carries a highly reflective surface inside.

In operation, the optical energy (light) is thrown by flash lamp on to the laser tube (Ruby rod). This excites the atoms of the inside media, which absorb the radiation of incoming light energy. This results in the to and fro travel of light between the two reflecting mirrors. But, the partial reflecting mirror does not reflect the total light back and a part of it goes out in the form of a coherent stream of monochromatic light. This highly amplified stream of light is focused through a lens, which converges it to a chosen point on the Work piece. This high intensity converged laser beam, when falls on the Work piece, melts the Work piece material, vaporizes it almost instantaneously and penetrates into it. Thus, it can be called a type of thermal cutting process.

Operation:

1. Ruby crystal is obtained by aluminum oxide dispersed with chromium through it. And two ends are silvered to form mirrors internally; the front mirror has a small aperture for the laser beam to emerge out.
2. A cylindrical ruby crystal is taken over which xenon flash tube is coiled or surrounded. Xenon tube is connected to the capacitor bank which in turn connected to DC supply.
3. So when power is switch on the capacitor bank supply a high voltage current to the xenon. Which causes a white light to emerge and the white light hits the ruby crystal where the chromium ions are ionized and pumped out with high energy levels and drop to intermediate level with release of energy and heat and after bombarding with other atom of chromium or with the mirrors reach to higher energy levels to form a fluorescent red light. Finally this light reaches a threshold frequency and escapes through the small aperture in the front mirror.
4. And this light is focused on to the lens and from there on to the work piece.

The lasing medium or laser used in the process can be of solid or gaseous type. The former type is special glass rods carrying reflective coatings at their end faces. They can provide short duration laser beams only. Against these, the letter type, produce continuous laser beam and are, therefore, very suitable for welding and cutting operations.

Advantages:

1. Any material can be easily machined irrespective of its structure and physical and mechanical properties.
2. Unlike conventional machining, there is no direct contact between the tool and the Work piece and no involvement of large scale cutting forces.
3. Tool wear is non-existent.
4. Can be effectively used for welding of dissimilar metals as well.
5. Small heat effected zone around the machined surface.
6. Very small holes and cuts can be made with fairly high degree of accuracy.

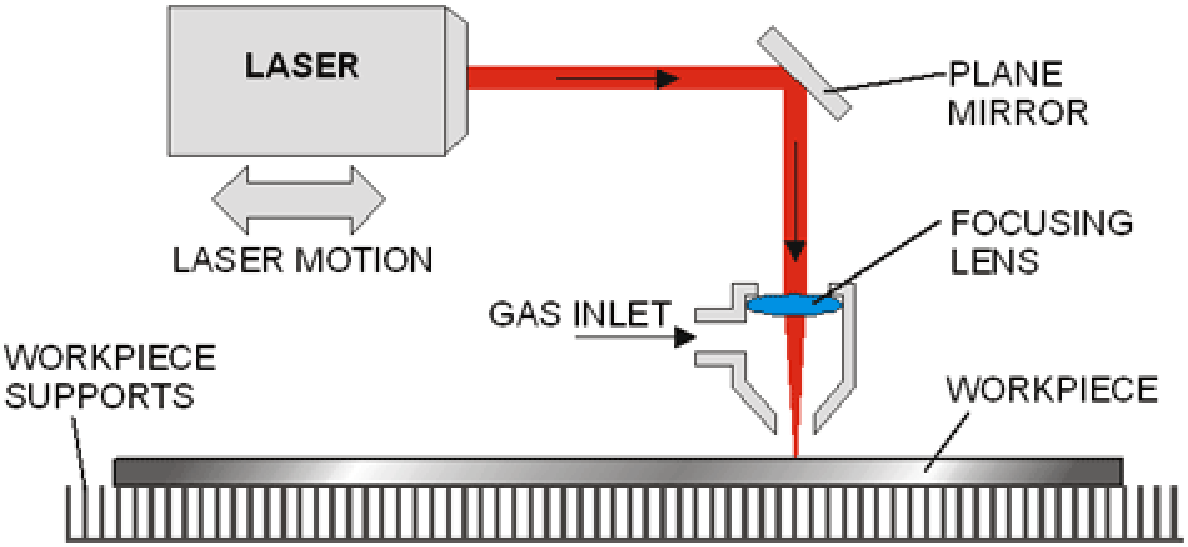


FIGURE: Laser beam machining process

Disadvantages

1. High capital investment needed.
2. Operating cost is also quite high
3. Highly skilled operators are needed.
4. Production rate is low.
5. Its application is limited to only thin sections and where a very small amount of metal removal is involved.
6. Cannot be effectively used to machine highly heat conductive and reflective materials.

Applications

1. Trimming of carbon resistors.
2. Drilling small, holes in hard materials like tungsten and ceramics.
3. Cutting complex profiles on thin and hard materials, viz., thin films for making ICs.
4. Cutting or engraving patterns on thin films.
5. Dynamic balancing of precision rotating components, such as of watches.
6. Trimming of sheet metal and plastic parts

UNIT V

AIRCRAFT COMPOSITE

What is a composite? A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite systems include concrete reinforced with steel and epoxy reinforced with graphite fibers, etc. Give some examples of naturally found composites. Examples include wood, where the lignin matrix is reinforced with cellulose fibers and bones in which the bone-salt plates made of calcium and phosphate ions reinforce soft collagen.

What are advanced composites? Advanced composites are composite materials that are traditionally used in the aerospace industries. These composites have high performance reinforcements of a thin diameter in a matrix material such as epoxy and aluminum. Examples are graphite/epoxy, Kevlar R†/epoxy, and boron/ aluminum composites. These materials have now found applications in commercial industries as well.

Drawbacks and limitations in use of composites include:

1. High cost of fabrication of composites is a critical issue
2. Mechanical characterization of a composite structure is more complex than that of a metal structure. Unlike metals, composite materials are not isotropic, that is, their properties are not the same in all directions.
3. Repair of composites is not a simple process compared to that for metals. Sometimes critical flaws and cracks in composite structures may go undetected.
4. Composites do not have a high combination of strength and fracture toughness

* compared to metals. Composites do not necessarily give higher performance in all the properties used for material selection. What fiber factors contribute to the mechanical performance of a composite?
Four fiber factors contribute to the mechanical performance of a composite:
• Length: The fibers can be long or short. Long, continuous fibers are easy to orient and process, but short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers. These include impact resistance, low shrinkage, improved surface finish, and dimensional stability. However, short fibers provide low cost, are easy to work with, and have fast cycle time fabrication procedures. Short fibers have fewer flaws and therefore have higher strength.
• Orientation: Fibers oriented in one direction give very high stiffness and strength in that direction. If the fibers are oriented in more than one direction, such as in a mat, there will be high stiffness and strength in the directions of the fiber orientations. However, for the same volume of fibers per unit volume of the composite, it cannot match the stiffness and strength of

unidirectional composites.

- Shape: The most common shape of fibers is circular because handling and manufacturing them is easy. Hexagon and squareshaped fibers are possible, but their advantages of strength and high packing factors do not outweigh the difficulty in handling and processing.
- Material: The material of the fiber directly influences the mechanical performance of a composite. Fibers are generally expected to have high elastic moduli and strengths. This expectation and cost have been key factors in the graphite, aramids, and glass dominating the fiber market for composites.

What are the matrix factors that contribute to the mechanical performance of composites? Use of fibers by themselves is limited, with the exceptions of ropes and cables. Therefore, fibers are used as reinforcement to matrices. The matrix functions include binding the fibers together, protecting fibers from the environment, shielding from damage due to handling, and distributing the load to fibers. Although matrices by themselves generally have low mechanical properties compared to those of fibers, the matrix influences many mechanical properties of the composite. These properties include transverse modulus and strength, shear modulus and strength, compressive strength, interlaminar shear strength, thermal expansion coefficient, thermal resistance, and fatigue strength. Other than the fiber and the matrix, what other factors influence the mechanical performance of a composite? Other factors include the fiber–matrix interface. It determines how well the matrix transfers the load to the fibers. Chemical, mechanical, and reaction bonding may form the interface.

In most cases, more than one type of bonding occurs.

- Chemical bonding is formed between the fiber surface and the matrix. Some fibers bond naturally to the matrix and others do not. Coupling agents* are often added to form a chemical bond.
- The natural roughness or etching of the fiber surface causing interlocking may form a mechanical bond between the fiber and matrix.
- If the thermal expansion coefficient of the matrix is higher than that of the fiber, and the manufacturing temperatures are higher than the operating temperatures, the matrix will radially shrink more than the fiber. This causes the matrix to compress around the fiber.
- Reaction bonding occurs when atoms or molecules of the fiber and the matrix diffuse into each other at the interface. This interdiffusion often creates a distinct interfacial layer, called the interphase, with different properties from that of the fiber or the matrix. Although this thin interfacial layer helps to form a bond, it also forms micro cracks in the fiber. These micro cracks reduce the strength of the fiber and thus that of the composite. How are composites classified? Composites are classified by the geometry of the reinforcement — particulate, flake, and fibers or by the type of matrix — polymer, metal, ceramic, and carbon.
- Particulate composites consist of particles immersed in matrices such as alloys and ceramics.

They are usually isotropic because the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature, oxidation resistance, etc. Typical examples include use of aluminum particles in rubber; silicon carbide particles in aluminum; and gravel, sand, and cement to make concrete.

- Flake composites consist of flat reinforcements of matrices. Typical flake materials are glass, mica, aluminum, and silver. Flake compos ites provide advantages such as high out-of-plane flexural modulus,*higher strength, and low cost. However, flakes cannot be oriented easily and only a limited number of materials are available for use.
- Fiber composites consist of matrices reinforced by short (discontinuous) or long (continuous) fibers. Fibers are generally anisotropic†and examples include carbon and aramids. Examples of matrices are resins such as epoxy, metals such as aluminum, and ceramics such as calcium–alumino silicate. Continuous fiber composites are emphasized in this book and are further discussed in this chapter by the types of matrices: polymer, metal, ceramic, and carbon. The fundamental units of continuous fiber matrix composite are unidirectional or woven fiber laminas. Laminas are stacked on top of each other at various angles to form a multidirectional laminate.
- Nanocomposites consist of materials that are of the scale of nanometers (10–9 m). The accepted range to be classified as a nanocomposite is that one of the constituents is less than 100 nm. At this scale, the properties of materials are different from those of the bulk material. Generally, advanced composite materials have constituents on the microscale (10–6 m). By having materials at the nanometer scale, most of the properties of the resulting composite material are better than the ones at the microscale. Not all properties of nanocomposite are better; in some cases, toughness and impact strength can decrease.

Applications of nanocomposite include packaging applications for the military in which nanocomposite films show improvement in properties such as elastic modulus, and transmission rates for water vapor, heat distortion, and oxygen. Polymer Matrix Composites What are the most common advanced composites? The most common advanced composites are polymer matrix composites (PMCs) consisting of a polymer (e.g., epoxy, polyester, urethane) reinforced by thin diameter fibers (e.g., graphite, aramids, boron). For example, graphite/epoxy composites are approximately five times stronger than steel on a weight for-weight basis. The reasons why they are the most common composites include their low cost, high strength, and simple manufacturing principles.

What are the drawbacks of polymer matrix composites? The main drawbacks of PMCs include low operating temperatures, high coefficients of thermal and moisture expansion,* and low elastic properties in certain directions. Give names of various polymers used in advanced polymer composites. These polymers include epoxy, phenolics, acrylic, urethane, and polyamide. Why are there so many resin systems in advanced polymer composites? Each polymer has its advantages and drawbacks in its use:

- Polyesters: The advantages are low cost and the ability to be made translucent; drawbacks include service temperatures below 170°F (77°C), brittleness, and high shrinkage* of as much as 8% during curing.
- Phenolics: The advantages are low cost and high mechanical strength; drawbacks include high void content. • Epoxies: The advantages are high mechanical strength and good adherence to metals and glasses; drawbacks are high cost and difficulty in processing. Mechanics Terminology How is a composite structure analyzed mechanically? A composite material consists of two or more constituents; thus, the analysis and design of such materials is different from that for conventional materials such as metals.

The approach to analyze the mechanical behavior of composite structures is as follows.

1. Find the average properties of a composite ply from the individual properties of the constituents. Properties include stiffness, strength, thermal, and moisture expansion coefficients. Note that average properties are derived by considering the ply to be homogeneous. At this level, one can optimize for the stiffness and strength requirements of a lamina. This is called the micromechanics of a lamina. Schematic of analysis of laminated composites.
2. Develop the stress–strain relationships for a unidirectional/bidirectional lamina. Loads may be applied along the principal directions of symmetry of the lamina or off-axis. Also, one develops relationships for stiffness, thermal and moisture expansion coefficients, and strengths of angle plies. Failure theories of a lamina are based on stresses in the lamina and strength properties of a lamina. This is called the macromechanics of a lamina.

A structure made of composite materials is generally a laminate structure made of various laminas stacked on each other. Knowing the macromechanics of a single lamina, one develops the macromechanics of a laminate. Stiffness, strengths, and thermal and moisture expansion coefficients can be found for the whole laminate. Laminate failure is based on stresses and application of failure theories to each ply. This knowledge of analysis of composites can then eventually form the basis for the mechanical design of structures made of composites.

Several terms are defined to develop the fundamentals of the mechanical behavior of composites. These include the following. What is an isotropic body? An isotropic material has properties that are the same in all directions. For example, the Young’s modulus of steel is the same in all directions. What is a homogeneous body? A homogeneous body has properties that are the same at all points in the body. A steel rod is an example of a homogeneous body. However, if one heats this rod at one end, the temperature at various points on the rod would be different. Because Young’s modulus of steel varies with temperature, one no longer has a homogeneous body. The body is still isotropic because the properties at a particular point are still identical in all directions.

Are composite materials isotropic and/or homogeneous? Most composite materials are neither isotropic nor homogeneous. For example, consider epoxy reinforced with long glass fibers. If one chooses a location on the glass fiber, the properties are different from a location on the epoxy matrix. This makes the composite material nonhomogeneous (not homogeneous). Also, the stiffness in the direction parallel to the fibers is higher than in the direction perpendicular to the fibers and thus the properties are not independent of the direction. This makes the composite material anisotropic (not isotropic).

What is an anisotropic material? At a point in an anisotropic material, material properties are different in all directions. What is a nonhomogeneous body? A nonhomogeneous or inhomogeneous body has material properties that are a function of the position on the body. What is a lamina? A lamina (also called a ply or layer) is a single flat layer of unidirectional fibers or woven fibers arranged in a matrix. What is a laminate? A laminate is a stack of plies of composites. Each layer can be laid at various orientations and can be made up of different material systems. What is a hybrid laminate? Hybrid composites contain more than one fiber or one matrix system in a laminate.

The main four types of hybrid laminates follow. • Interply hybrid laminates contain pliesmade of two or more different composite systems. Examples include car bumpers made of glass/epoxy layers to provide torsional rigidity and graphite/epoxy to give stiffness. The combinations also lower the cost of the bumper. • Intraply hybrid composites consist of two or more different fibers used in the same ply. Examples include golf clubs that use graphite and aramid fibers. Graphite fibers provide the torsional rigidity and the aramid fibers provide tensile strength and toughness.

• An interply–intraply hybrid consists of plies that have two or more different fibers in the same ply and distinct composite systems in more than one ply.
• Resin hybrid laminates combine two or more resins instead of combining two or more fibers in a laminate. Generally, one resin is flexible and the other one is rigid. Tests have proven that these resin hybrid laminates can increase shear and work of fracture properties by more than 50% over those of all-flexible or all-rigid resins