Review of Manufacturing Processes

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Instructional objectives

By the end of this lecture, the student will learn what are the different types of manufacturing processes and manufacturability of engineering materials.

Manufacturing Processes and Classification

Manufacturing processes are the steps through which raw materials are transformed into a product. The manufacturing processes can be broadly classified into three categories viz. shaping, joining and finishing processes as shown schematically in Fig 1. The selection of a particular process from a wide range of choices for a given application requires a hierarchical classification of the processes. For example, Fig 2 depicts how the shaping family can be expanded in different classes such as casting, deformation, moulding, composite and powder processing, and prototyping. Next, moulding as a class can be enlarged into a number of member processes such as compression, rotational, transfer, injection moulding, etc. Lastly, each member process can be identified with a number of attributes, which would facilitate the selection of a member process for a given material, dimension, level of requisite tolerances and so on. Similarly, Fig 3 depicts how the joining and machining family can be expanded in different classes and actual processes. A brief description of the three broad categories of the manufacturing processes and the corresponding classifications are outlined in the following: [1] and [2].

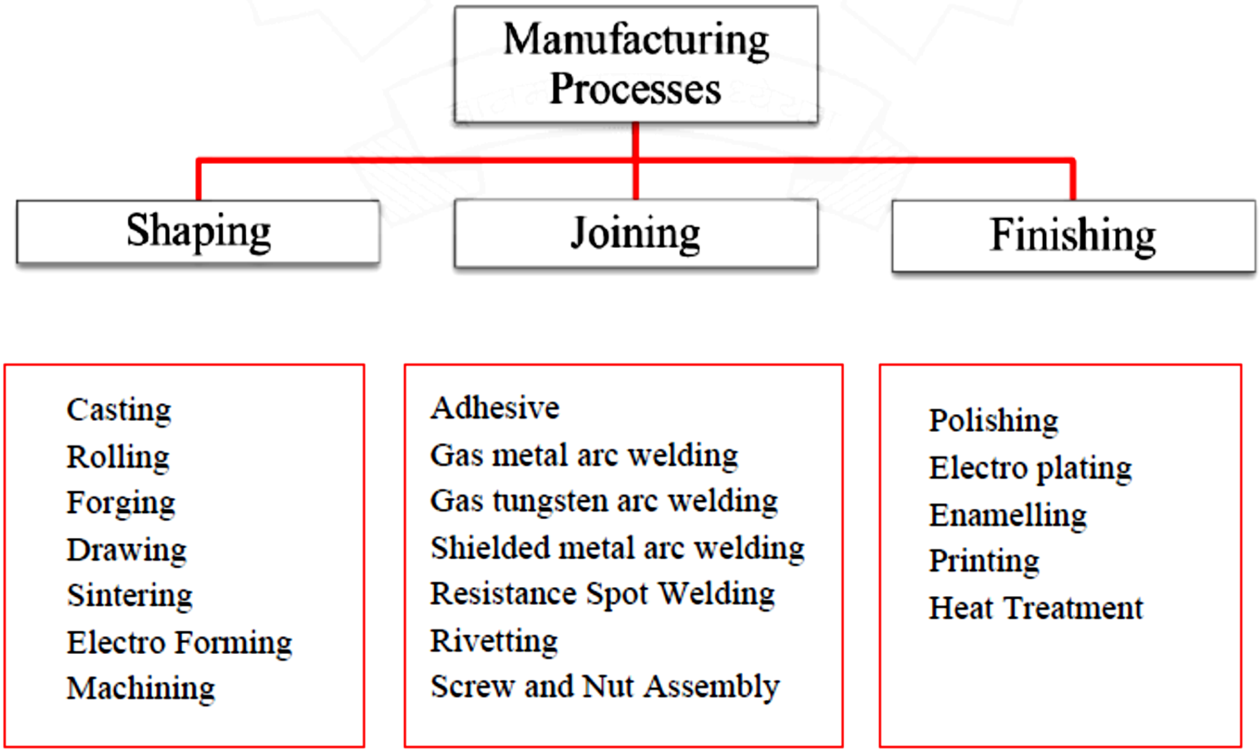


Fig 1 Different Classes of Manufacturing Processes

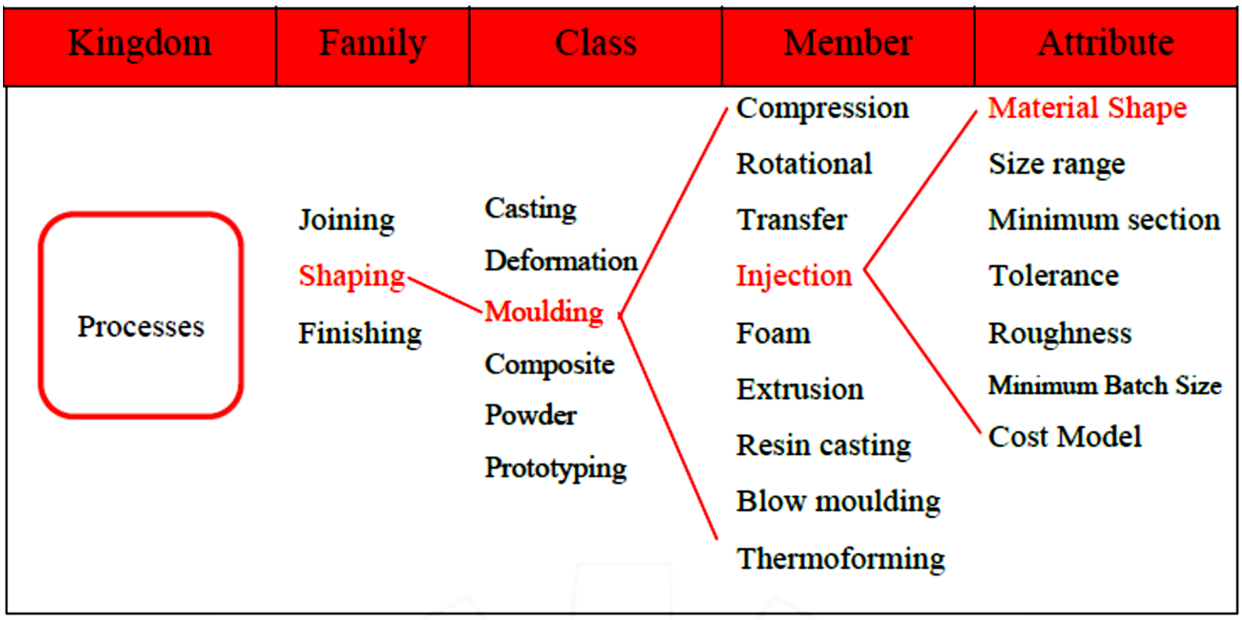


Fig 2 Taxonomy of Process with Part of the Shaping Family

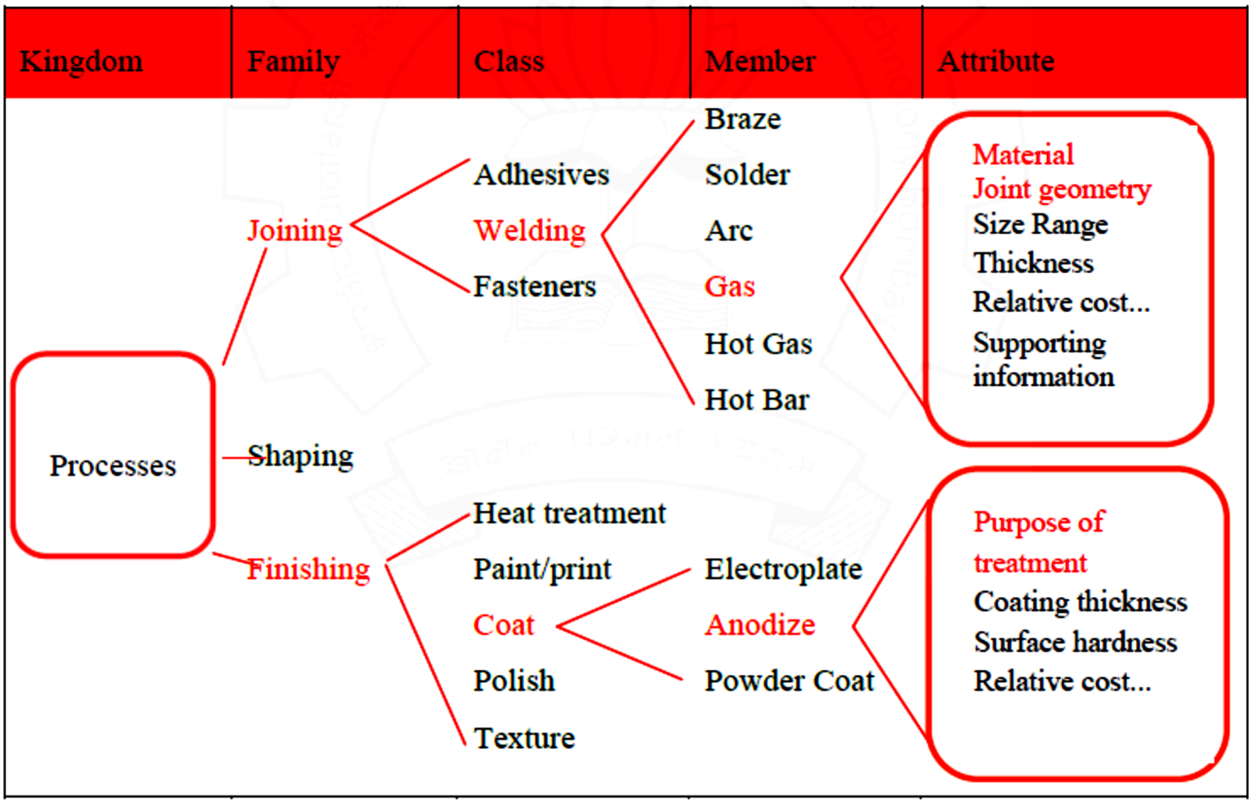


Fig 3 Taxonomy of Processes with Part of the Joining and Finishing Family

Shaping Processes

The shaping processes are referred to those that use a certain raw material and shape it to a final part. Casting, moulding, powder material processing, primary and secondary material forming, machining are typical example of shaping processes. A short exposure of different shaping processes is enlisted below.

Casting Processes

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

- liquefying of metallic material by properly heating it in a suitable furnace,
- pouring of hot molten metal into a previously made colder mould cavity,

- extraction of the solidified cast from the mould cavity

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

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

Classification of casting processes

The casting processes can be classified into two broad categories – *expendable mold casting processes* and *permanent mold casting processes*. In *expendable mold casting processes,* the mold is usually broken to free the solidified cast whereas the mold can be reused in case of *permanent mold casting*. The pattern used to prepare the molds can also be *permanent* and *expendable*, and subsequently, the *expendable mold* casting processes are further categorized as *expendable-pattern-expendable-mold* and *permanent-pattern-expendable-mold* processes. *Fig 4* depicts a detailed classification of the casting processes [3] and [4].

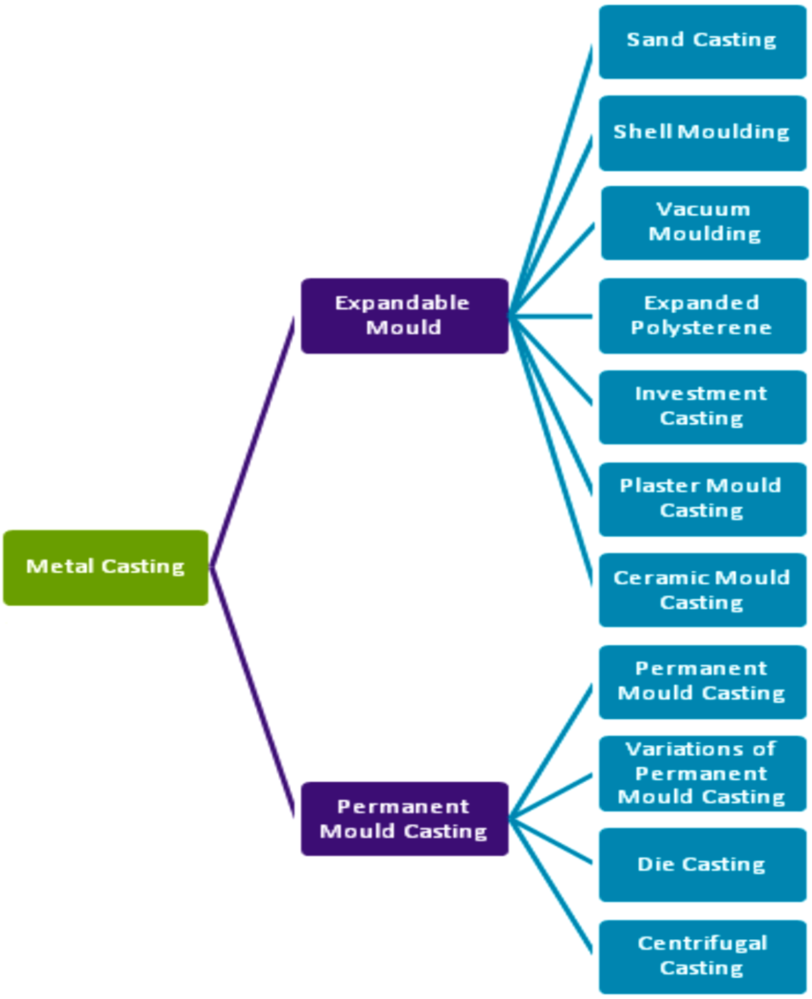


Fig 4 Classification of casting processes

Fig 5 shows a typical mold arrangement for sand casting. Further details of different casting process are discussed in the subsequent lectures.

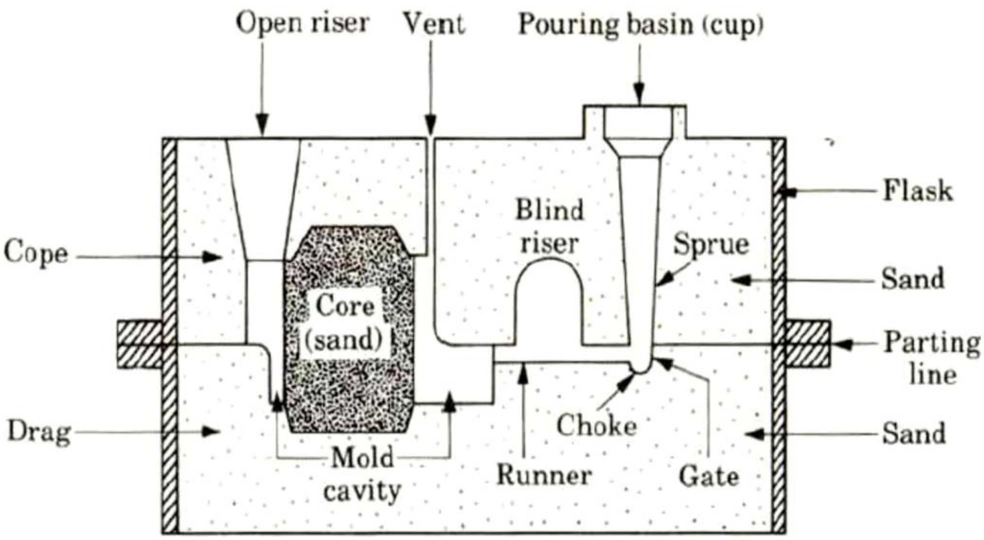
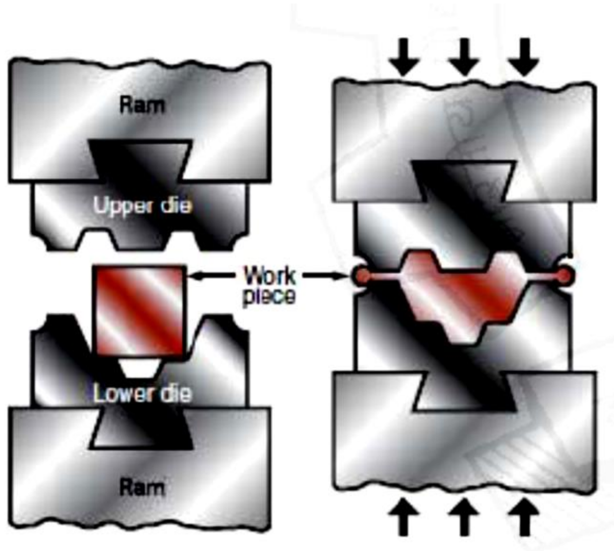


Fig 5 Typical mold setup for sand casting process

Bulk Deformation Processes

The deformation processes shape a final part by plastic deformation with the application of pressure and with or without the assistance of heat. The deformation processes are also referred to as metal forming processes. The metal forming processes that induce a significant shape change starting with a *bulk shape* rather than sheet are categorized under the bulk deformation processes. In most of the cases cylindrical bars and billets, rectangular billets and slabs, and similar shapes are processed by stressing metal sufficiently in cold, warm or hot condition to cause plastic flow into desired shape. Complex shapes with good mechanical properties can be produced easily and expensively using these processes. *Forging, rolling, extrusion* and *drawing* are the common example of bulk deformation process. Depending on the temperature at which the deformation is carried out, these processes can be classified in to *hot working* and *cold working* processes. When the plastic deformation is carried out above the recrystallization temperature of the material, the corresponding operation is referred to as *hot working*. Similarly, when the plastic deformation is induced below the recrystallization temperature of the material, the processes are referred to as *cold working*. *Fig 6* depicts some of the *bulk deformation processes* in a schematic manner [2].



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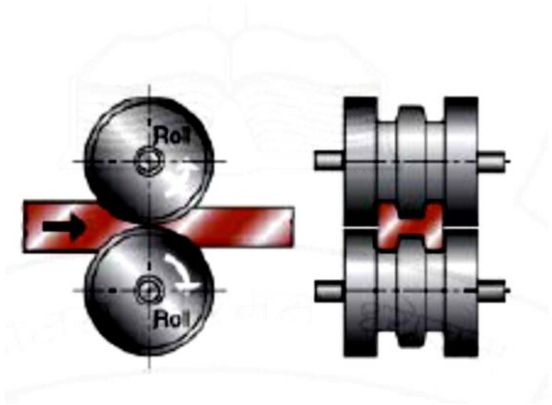

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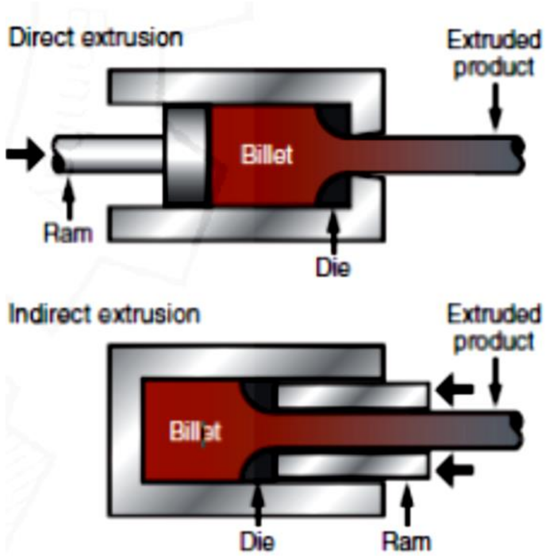

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Fig 6 Schematic picture of (a) forging, (b) rolling, and (c) rolling processes

Machining

Machining is a form of subtractive manufacturing in which a sharp cutting tool is used to physically remove material to achieve a desired geometry. Most of the engineering components such as gears, bolts, screws, nuts need dimensional and form accuracy for IIT Bombay serving their purpose, which cannot be obtained through casting or deformation process like forging, rolling, etc. *Fig 7* schematically illustrates the basic principle of machining [4].

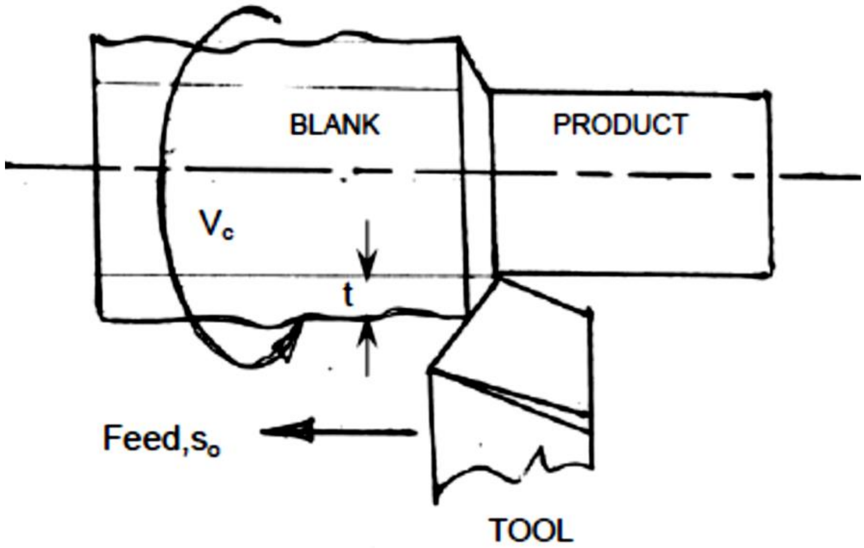


Fig 7 Schematic illustration of machining process

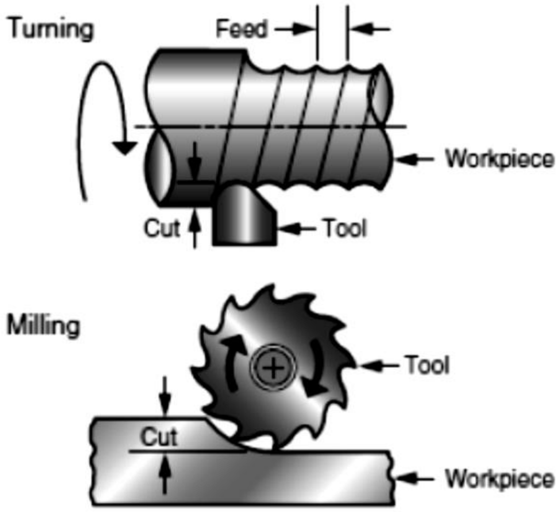
A wide variety of machining processes are available today that can broadly be classified in three main categories – conventional machining processes that are used for all kinds of bulk material removal operations, grinding processes that are primarily employed to obtain a desired surface finish, non-conventional or advanced machining processes that are used for special kind of material removal operations. As per the name suggests, non-conventional machining processes do not follow the principle of relative hardness as conventional machining, where the tool material must be harder than the work material for proper removal of material. The processes that remove material by melting, evaporation, chemical and / or electrochemical action etc. are generally referred to as non-conventional machining processes. Electro-discharge machining, electrochemical machining, laser and electron beam machining are some of the common examples of non-conventional machining processes [2].

Fig 8 depicts schematic presentation of various machining operations. The advantages of machining process are manifold. Some of these broad merits of machining processes are listed below.

1) The machining processes can produce a wide variety of dimensions with fine form accuracy.
2) Almost all kind of engineering materials and plastics can be machined,

3) The machining processes can be easily automated to achieve an excellent productivity,

4) The role of the process parameters and their control to obtain a desired part with good dimensional accuracy are well established in most of the machining processes.



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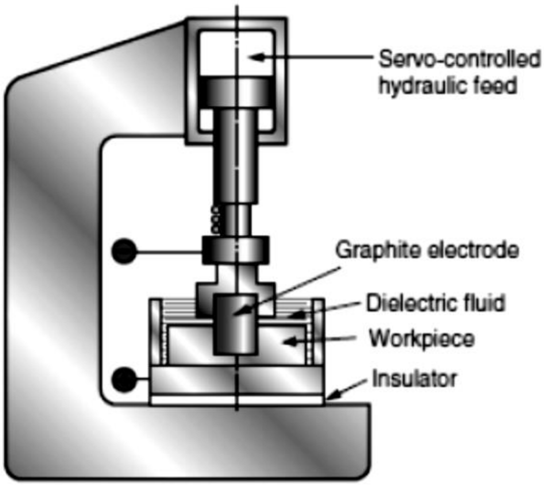

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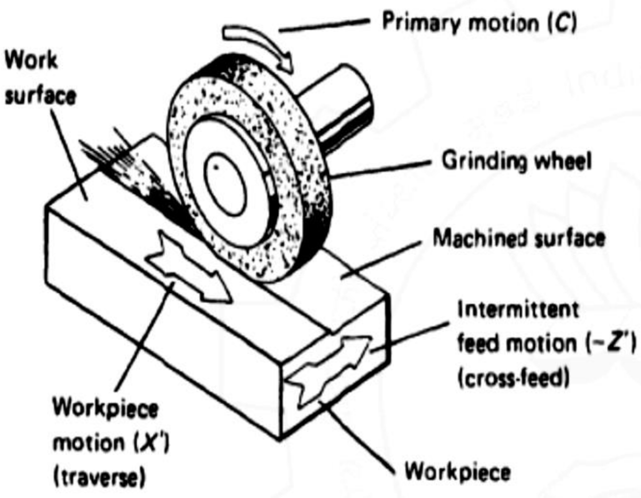

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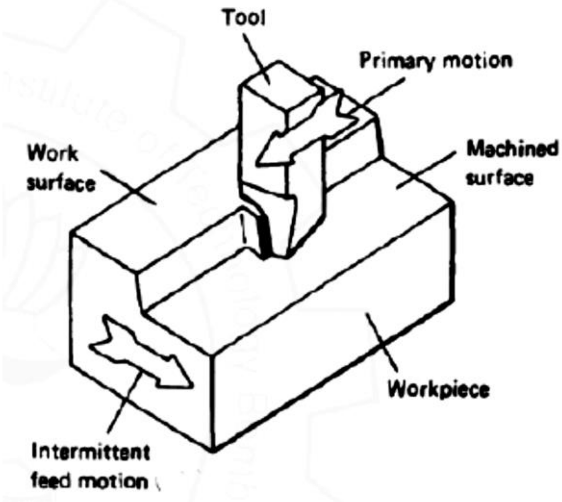


(d)

Fig 8 Schematic presentations of four machining processes – (a) Turning and milling, b) electro discharge machining, c) surface grinding, d) shaping

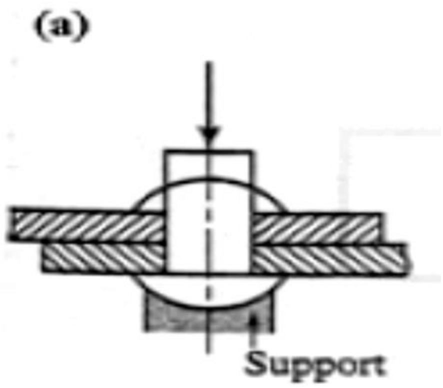
Joining Processes and Surface Treatment Methods

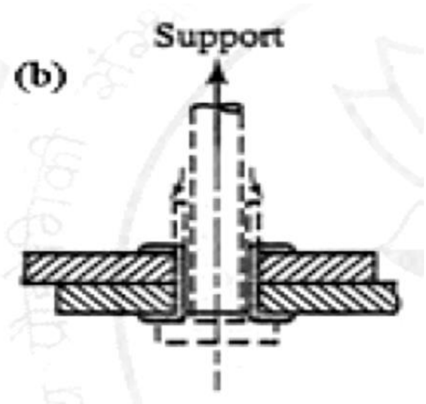
Though shaping is one of the most important processes and can produce a wide range of components, it is often deficient in making a complete product due the complexity associated with the shape and functions. So, joining of simple pre-shaped parts into a fully functional structure is necessary. Welding, brazing and soldering, fastening, and adhesive bonding are the most commonly use process in joining. Even after joining, further processing may be required to enhance the mechanical properties and aesthetics of the final assembled part or component to meet specific operational condition.

The joining processes can be broadly classified into two groups – one that produces *non-permanent joints* and the other that constructs *permanent joints*. The first group includes some of the common mechanical joining processes such as *screws and bolts*, *snap fits*, *shrink fits* etc. The *permanent joining* processes can be classified into four groups including *mechanical*, *solid state*, *liquid state*, and *liquid-solid state*. The *mechanical joining* processes, which are *permanent* in nature, include *rivet*, *stitch*, *staple*, and *lap-seam*. In principle, these joints are heterogeneous in nature since no atomic bonding takes place along the original joint interface [1].

Mechanical Joining Processes

The *permanent joining* processes, which are mechanical in nature, are, in principle, derivatives of the basic metal working processes. These are often referred to *fasteners*. The most common *mechanical joining* methods are rivet, nut and bolts, staple, seam joint etc. *Fig 9* schematically depicts a number of mechanical joints.





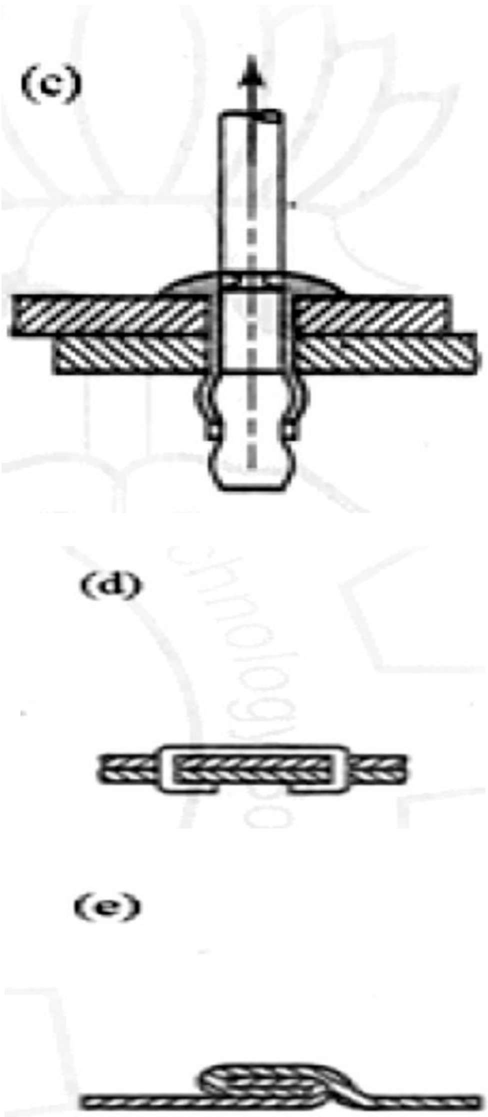


Fig 9 Schematic presentation of five mechanical joints: (a) rivet, (b) tubular rivet (c) blind rivet, (d) staple, (e) seam

Solid State Joining Process

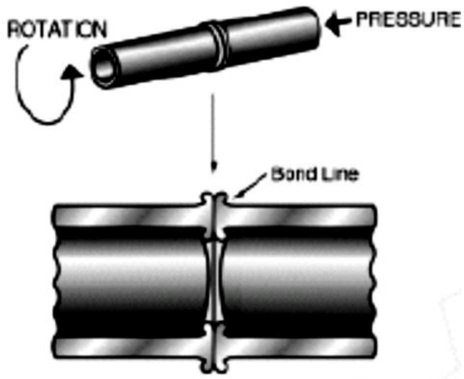
In *solid state joining processes*, the bonding between the assembled members occurs through *adhesion* and / or *diffusion* across the original joint interface. However, adhesions between the two surfaces are difficult due to the presence of surface contaminants such as oxide layers, adsorbed gas films,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

• *Relative movement* of faying surfaces under an axial force that helps to break up surface films facilitating the exposure and mating of clean surfaces,

• *Plastic deformation* of the contacting bodies leading to *growth* and *extension* of the contacting surfaces that would result in rupture of interfacial contaminants and exposure of fresh, clean surfaces, subsequently, creating a solid-state weld,

• *Softening* of contacting interfaces by localized heating, applied externally or generated in-process, to promote easy *plastic deformation* and / or *inter-atomic diffusion* creating a solid-state bond.

Various solid-state joining processes are developed following some of the principles mentioned above. *Fig 10* schematically depicts three common solid state joining processes [2].



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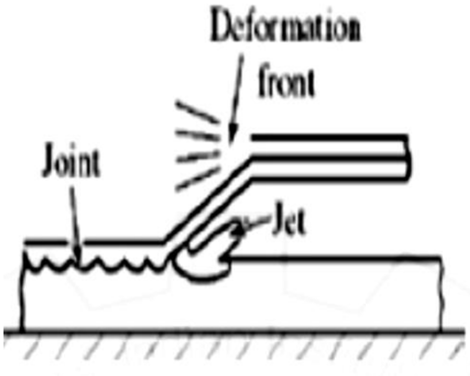

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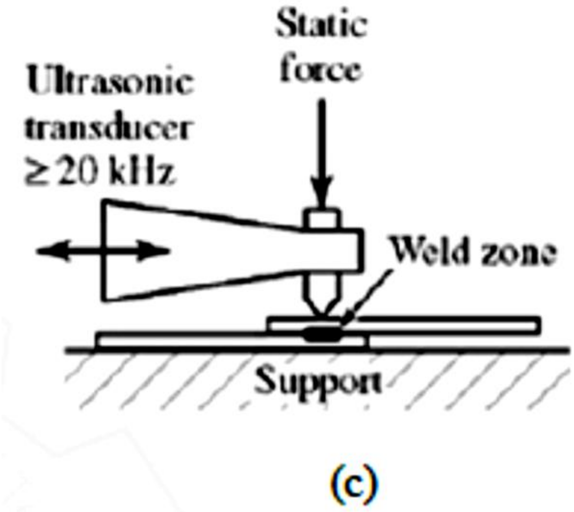

Fig 10 Three different types of solid state joining process; (a) Friction welding, (b) Explosion welding, and (c) Ultrasonic welding

Liquid State Joining Process

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

***Shielded metal arc welding process* (*SMAW*)**

Shielded Metal Arc Welding (SMAW) Process is a manual welding process where an electric arc is used for localized melting of workpiece materials. The electric arc is created between a consumable electrode and the workpiece material as shown schematically in *Fig 11*. The electrode is covered with a coating (referred to as *flux*), which is extruded on the surface of the electrode. During welding, the electrode coating decomposes and melts providing a protective atmosphere on the weld area to avoid the reaction between hot liquid metal and atmospheric gases. SMAW process is the most popular amongst all other *fusion arc welding* processes since the equipment is inexpensive and easy to use. SMAW process can be used on carbon steels, low alloy steels, stainless steels, cast irons, copper, nickel, and aluminium [5].

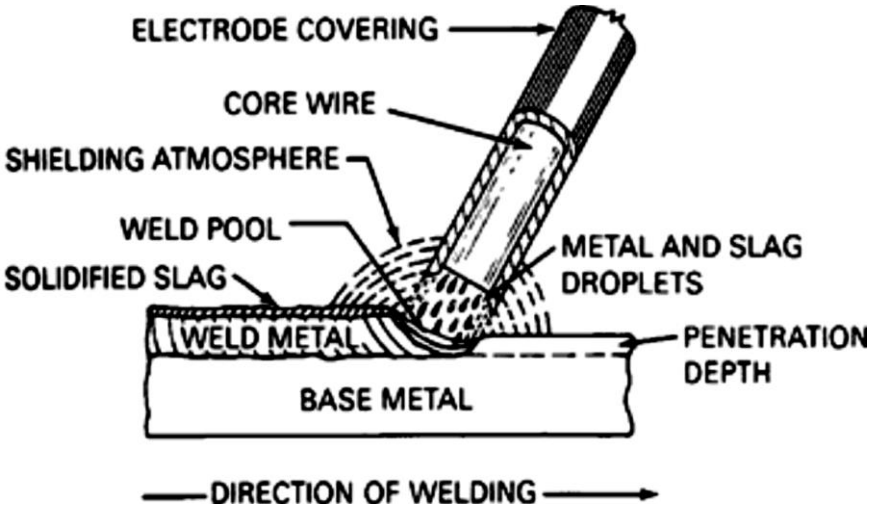

Fig 11 Schematic set-up for shielded metal arc welding process

***Gas metal arc welding process* (*GMAW*)**

In this process, an electric arc is struck between a continuously fed consumable electrode wire and the workpiece material as shown in *Fig 12*. The electrode wire is automatically fed from a spool into the weld pool by a wire feed system. The wire feeder draws the electrode through the welding torch. The shielding is supplied by an inert gas which flows around the wire through a gas cap attached to the torch [5].

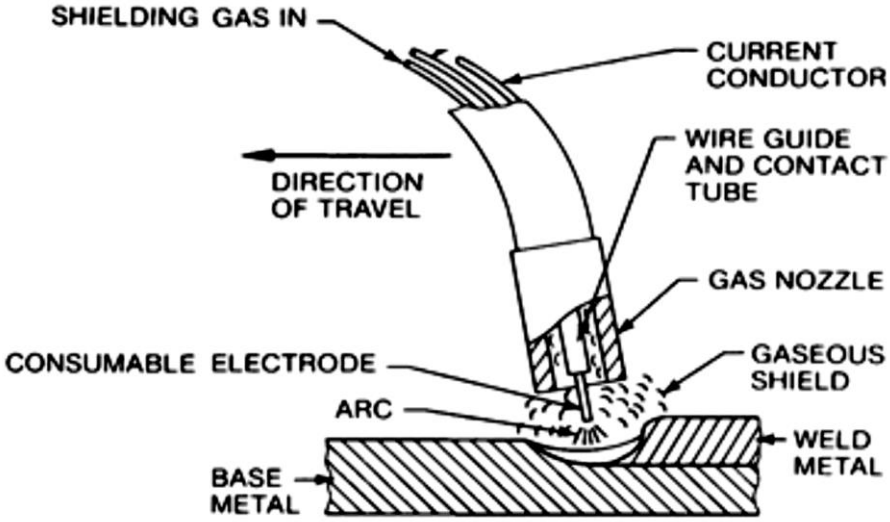

Fig 12 Schematic set-up for gas metal arc welding process

***Submerged arc welding process* (*SAW*)**

Submerged arc welding is almost similar to gas metal arc welding process to the fact that an electric arc is created between a continuously fed consumable solid or tubular electrode wire and workpiece materials. However, the arc and the molten weld pool is submerged under a blanket of granular fusible flux consisting of lime, silica, manganese oxide, calcium fluoride, and other compounds, which are being fed continuously ahead of the welding electrode. Furthermore, the molten flux being electrically conductive provides a current path between the electrode and the workpiece. The thick layer of flux completely covers the molten metal thus preventing spatter and sparks. The process is simple to mechanize and easily automated, and can be used on a wide variety of materials. *Fig 13* schematically depicts a set-up for typical submerged arc welding process [5].

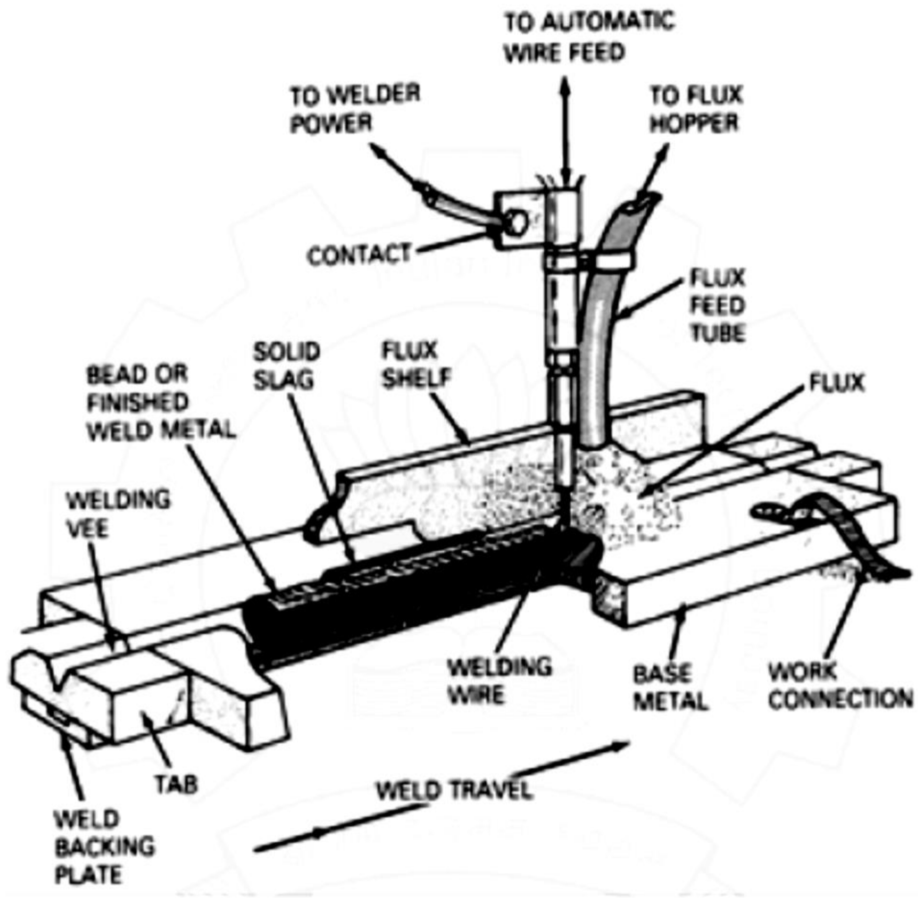

Fig 13 Schematic set-up for submerged arc welding process

***Gas tungsten arc welding process* (*GTAW*)**

In the gas tungsten arc welding (GTAW) process, the arc is established between the tip of a non-consumable tungsten electrode and the workpiece. Often an extra filler material is used if joint filling is important. Because the arc is created between a shaped (conical) non-consumable tungsten electrode and the workpiece, GTAW process provides a concentrated arc leading to very high heat energy density. An inert shielding gas protects the molten weld pool and the non-consumable tungsten electrode. *Fig 14* depicts a schematic set-up for GTAW process [5].

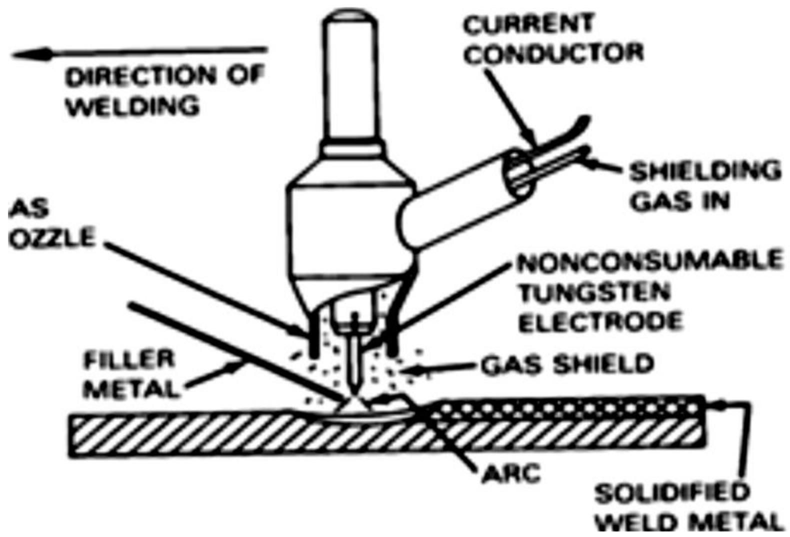

Fig 14 Schematic set-up for gas tungsten arc welding process

***Plasma arc welding process* (*PAW*)**

The objective of the Plasma Arc Welding (PAW) process is to increase the intensity of the of the arc plasma in a controlled manner such that greater thickness can be welded with the minimum spread of the welding arc. This objective is achieved by providing a special gas nozzle around a tungsten electrode operating on direct current electrode negative (DCEN) polarity. The constricted plasma formed is highly ionized and concentrated. Two variants of the Plasma Arc Welding (PAW) process are commonly used. One is referred to as the *transferred arc process* and the second is referred to as the *non-transferred arc process*. In the *transferred arc process*, the workpiece is connected to the negative polarity so that the arc plasma irradiated on the workpiece has greater intensity. In the *non-transferred arc process*, the gas nozzle forms part of the electric circuit and hence, the arc plasma is formed between the tungsten electrode and the nozzle. The tail of the arc plasma that irradiates on the workpiece is therefore of lesser intensity. *Fig 15* schematically shows the set-ups for *transferred arc* and *non-transferred arc* PAW processes.

Surface Treatment Methods

The surface treatment processes are used to improve the properties of the surface only. In many applications, it is necessary to harden the surface to prevent abrasive wear. Different types of hardening methods such as quenching, induction hardening, carburizing, nitriding, physical vapour deposition (PVD), chemical vapour deposition (CVD) are some of the commonly used surface treatment method. Similarly, thermal coating like cladding, thermal spraying, hot dipping etc. surface treatment processes such as painting, electrolytic coating, etc. and conversion coating like oxidizing, phosphating, chromating etc. are also employed to improve surface properties [5].

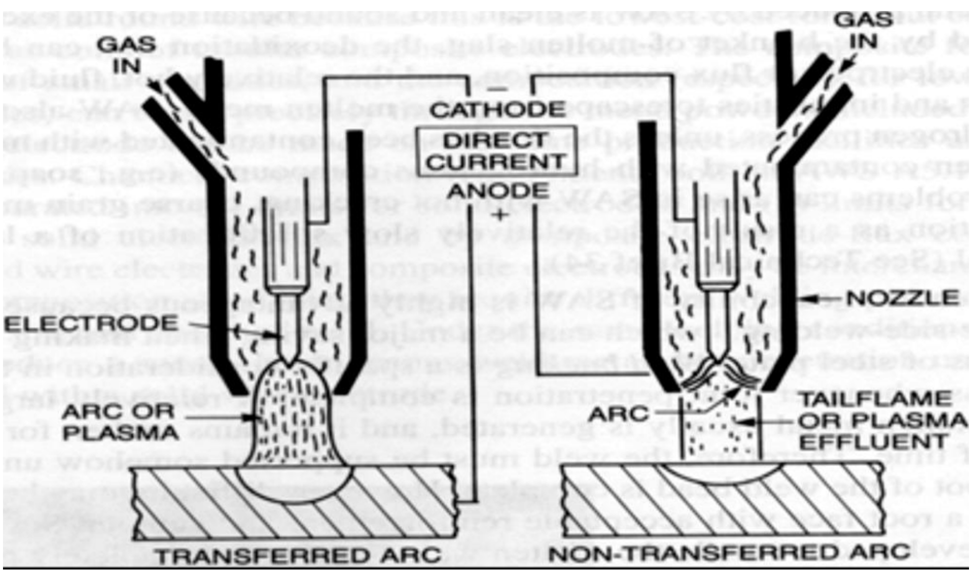

Fig 15 Schematic set-up for plasma arc welding process

Strategy for Selecting Proper Processes

Out of numerous manufacturing processes only a few are listed above. The selection of an appropriate manufacturing process for a given material, requisite shape, dimensional accuracy and service is critical and broadly requires the following steps to follow.

- Consider all processes as probable candidates.
- Screen them.
    - compatibility to material and / or shape and / or precision.
- Rank them using objective.
    - economic batch size-ranges.
    - relative cost
- Seek for supporting information for the top candidates.

Exercise

1. Sort the following processes in the decreasing order of specific energy:
   [i] Sheet metal forming [ii] Forging [iii] Machining [iv] Casting.
2. Which of the following processes is suitable for components/assemblies with high fatigue life?
   [i] Machining [ii] Forging [iii] Casting [iv]Sheet metal forming.
3. List two significant advantages of Investment Casting over sand casting.
4. Give examples of permanent and detachable type of mechanical fastener.

References

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