1.1 MANUFACTURING TECHNOLOGY

The manufacturing technology primarily involves sizing, shaping and imparting desired combination of the properties to the material so that the component or engineering system being produced to perform indented function for design life. A wide range of manufacturing processes have been developed in order to produce the engineering components ranging from simple to complex geometries using materials of different physical, chemical, mechanical and dimensional properties.

There are four chief manufacturing processes i.e. (1) welding, (2) casting, (3) machining and (4) forming. Selection of suitable manufacturing process for a product/component is determined by the following factors:

i. Complexity of geometry of the component
ii. Number of units to be produced
iii. Properties of the materials (physical, chemical, mechanical and dimensional properties) to be processed
iv. Economic factor

Based on the approach used for obtaining desired size and shape by different manufacturing processes; these can be termed as positive, negative and or zero processes.

- Welding (Joining): positive process
- Casting: zero process
- Forming: zero process
- Machining: negative process

Casting and forming are categorized as zero processes as they involve only shifting of metal in controlled (using heat and pressure singly or in combination) way from one region to another to get the required size and shape of product. Machining is considered as a negative process because unwanted material from the stock is removed in the form of small chips during machining for the shaping and sizing of a product purpose. During manufacturing, it is frequently required to join the simple shape components to get desired product. Since simple shape components are brought together by joining in order to obtain desired shape of end useable product therefore joining is categorized as a positive process. Schematic diagrams of few typical manufacturing processes are shown in Fig. 1.1.

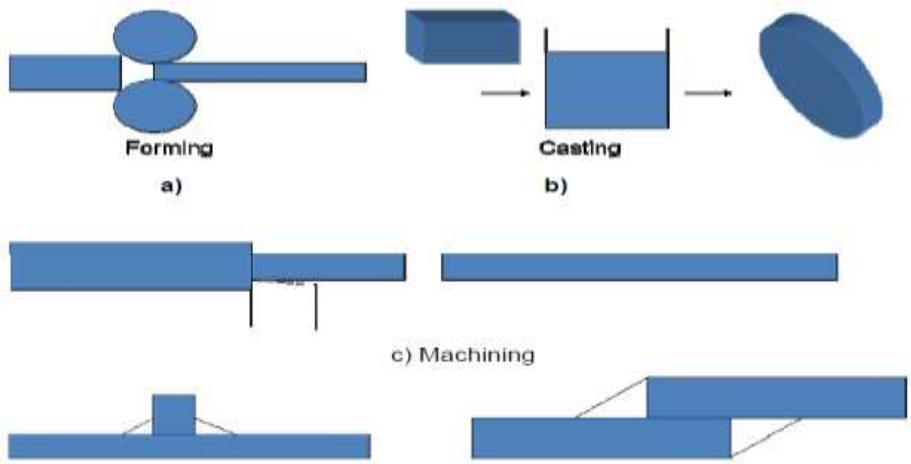

Fig. 1.1: Schematic diagram showing shaping approaches using different manufacturing processes a) forming, b) casting, c) machining and d) joining

1.2 SELECTION OF JOINT

The fabrication of engineering systems frequently needs joining of simple components and parts. There are Three (3) types of joining methods namely

i. Welding (welding, brazing and soldering)
ii. Mechanical joining (nuts & bolts, clamps, rivets)
iii. Adhesive joining (epoxy resins)

Welding (welding, brazing and soldering) are commonly used for manufacturing variety of engineering product/component. Each type of joint offers different load carrying capacity, reliability, compatibility in joining of similar or dissimilar materials besides their fitness for use in different environments and cost. It will be appropriate to consider following aspects while selecting type of joints for an application:

a. Type of joint required for an application is temporary or permanent
b. Whether similar or dissimilar materials are to be joined in order to take care of the compatibility aspect as metallurgical incompatibility can be disastrous for performance of the joints
c. Physical, chemical metallurgical properties of materials to be joined
d. Requirements of the service from the joint under special conditions of temperature, corrosion, environment, and reliability
e. Type and nature of loading conditions (static and dynamic loading under tension, shear, compression, bending etc.)
f. Economy or cost effectiveness is one most important factors influencing the selection of joint for manufacturing an engineering component

1.3 WELDING AND ITS COMPARISON WITH OTHER MANUFACTURING PROCESSES

Welding is one of the most commonly used fabrication techniques for manufacturing engineering components for power, fertilizer, petro-chemical, automotive, food processing, and many other sectors. Welding generally uses localized heating during common fusion welding processes (shielded metal arc, submerged arc, gas metalarc welding etc.) for melting the faying surfaces and filler metal. However, localized and differential heating & cooling experienced by the metal during welding makes it significantly different from other manufacturing techniques:

- Residual stresses are induced in welded components (development of tensile residual stresses adversely affects the tensile and fatigue properties of workpiece)
- Simple shape components to be joined are partially melted
- Temperature of the base metal during welding in and around the weld varies as function of time (weld thermal cycle)
- Chemical, metallurgical and mechanical properties of the weld are generallyanisotropic
- Little amount of metal is wasted in the form of spatter, run in and run off
- Weld joints for critical applications generally need post weld treatment such as heat treatment or mechanical working to get desired properties or reline residual stress.
- Problem related with ductile to brittle transition behaviour of steel is more severe with weld joints under low temperature conditions.

1.4 SELECTION OF WELDING PROCESS

A wide range of welding processes are available to choose. These were developed over a long period of time. Each process differs in respect of their ability to apply heat for fusion, protection of the weld pool and soundmen of welds joint the so performance of the weld joint. However, selection of a particular process for producing a weld joint is dictated by the size and shape of the component to be manufactured, the metal system to be welded, availability of consumables and machines, precision required and economy. Whatever process is selected for developing weld joint it must be able to perform the intended function for designed life. Welding processes with their field of applications are given below:

S/N	***WELDING PROCESSES***	***FIELD OF APPLICATION(S)***
1	Resistance welding	Automobile
2	Thermite welding	Rail joints in railways
3	Tungsten inert gas welding	Aerospace and nuclear reactors
4	Submerged arc welding	Heavy engineering, ship building
5	Gas metal arc welding	Joining of metals (stainless steel, aluminium and magnesium) sensitive to atmospheric gases

1.5 ADVANTAGES AND LIMITATION OF WELDING AS A FABRICATION TECHNIQUE

Welding is mainly used for the production of comparatively simple shape components. It is the process of joining the metallic components with or without application of heat, pressure and filler metal. Application of welding in fabrication offers many advantages, however; it suffers from few limitations also. Some of the advantage and limitations are given below.

Advantages of welding are enlisted below:

i. Permanent joint is produced, which becomes an integral part of work piece.
ii. Joints can be stronger than the base metal if good quality filler metal is used.
iii. Economical method of joining.
iv. It is not restricted to the factory environment.

Disadvantages of welding are enlisted also below:

i. Labour cost is high as only skilled welder can produce sound and quality weld joint.
ii. It produces a permanent joint which in turn creates the problem in dissembling of sub-component required.
iii. Hazardous fumes and vapours are generated during welding. This demands proper ventilation of welding area.
iv. Weld joint itself is considered as a discontinuity owing to variation in its structure, composition and mechanical properties; therefore welding is not commonly recommended for critical application where there is a danger of life.

1.6 APPLICATIONS OF WELDING

General applications:

The welding is widely used for fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and general applications besides shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations.

Specific components need welding for fabrication includes:

- Transport tankers for transporting oil, water, milk etc.
- Welding of tubes and pipes, chains, LPG cylinders and other items.
- Fabrication of Steel furniture, gates, doors and door frames, and body
- Manufacturing white goods such as refrigerators, washing machines, nmicrowave ovens and many other items of general applications.
- The requirement of the welding for specific area of the industry is given in following section.

2.1 CLASSIFICATION OF WELDING PROCESSES

Welding is a process of joining metallic components with or without application of heat, with or without pressure and with or without filler metal. A range of welding processes have been developed so far using single or a combination above factors namely: ***heat, pressure and filler***. Welding processes can be classified on the basis of following technological criteria:

i. Welding with or without filler material
ii. Source of energy for welding
iii. Arc and non-arc welding

iv. Fusion and pressure welding

2.1.1 WELDING WITH OR WITHOUT FILLER MATERIAL

A weld joint can be developed just by melting of edges (faying surfaces) of plates or sheets to be welded especially when thickness is lesser than 5 mm thickness.

A weld joint developed by melting the faying surfaces and subsequently solidification only (without using any filler metal) is called “autogenous weld”.

Thus, the composition of the autogenous weld metal corresponds to the base metal only. However, autogenous weld can be crack sensitive when solidification temperature range of the base metal to be welded is significantly high (750^{o} - 100^{o}C). Following are typical welding processes in which filler metal is generally not used to produce a weld joint.

- Laser beam welding
- Electron beam welding
- Resistance welding,
- Friction stir welding

However, for welding of thick plates/sheets using any of the following processes filler metal can be used as per needs according to thickness of plates.

Application of autogenous fusion weld in case of thick plates may result in concave weld or under fill like discontinuity in weld joint. The composition of the filler metal can be similar to that of base metal or different one accordingly weld joints are categorized as homogeneous or heterogeneous weld, respecting.

In case of autogenous and homogeneous welds, solidification occurs directly by growth mechanism without nucleation stage. This type of solidification is called epitaxial solidification. The autogenous and homogeneous welds are considered to be of lesser prone to the development of weld discontinuities than heterogeneous weld because of a uniformity in composition and (b) if solidification largely occurs at a constant temperature. Metal systems having wider solidification temperature range show issues related with solidification cracking and partial melting tendency. The solidification in heterogeneous welds takes place in conventional manner in two stages i.e. nucleation and growth.

Following are few fusion welding processes where filler may or may not be used for developing weld joints:

- Plasma arc welding
- Gas tungsten arc welding
- Gas welding

Some of the welding processes are inherently designed to produce a weld joint by applying heat for melting base metal and filler metal both. These processes are mostly used for welding of thick plates (usually > 5mm) with comparatively higher deposition rate.

- Metal inert gas welding: (with filler)
- Submerged arc welding: (with filler)
- Flux cored arc welding: (with filler)
- Electro gas/slag welding: (with filler)

Comments on classification of welding processes based on with/without filler

The gas welding process was the only fusion welding process earlier using which joining could be achieved with or without filler material. The gas welding performed without filler material was termed as autogenous welding. However, with the development of tungsten inert gas welding, electron beam, laser beam and many other welding processes, such classification created confusion as many processes were falling in both the categories.

2.1.2 SOURCE OF ENERGY FOR WELDING

Almost all weld joints are produced by applying energy in one or other form to develop atomic/metallic bond between metals being joined and the same is achieved either by melting the faying surfaces using heat or applying pressure either at room temperature or high temperature (0.5^{o} to 0.9^{o} Tm). Based on the type of energy being used for creating metallic bonds between the components to be welded, welding processes can be grouped as under:

- **Chemical energy:** Gas welding, explosive welding, thermite welding
- **Mechanical energy:** Friction welding, ultrasonic welding
- **Electrical energy:** Arc welding, resistance welding
- **Radiation energy:** Laser beam welding, electron beam welding

Comments on classification of welding processes based on source of energy

Energy in various forms such as chemical, electrical, light, sound, mechanical energies etc. are used for developing weld joints. However, except chemical energy all other forms of energies are generated from electrical energy for welding. Hence, categorization of the welding processes based on the source of energy criterion also does not justify classification properly.

2.1.3 ARC OR NON-ARC WELDING

Metallic bond between the plates to be welded can be developed either by using heat for complete melting of the faying surfaces then allowing it to solidify or by apply pressure on the components to be joined for mechanical interlocking. All those welding processes in which heat for melting the faying surfaces is provided after establishing an arc either between the base plate and an electrode or between electrode & nozzle are grouped under arc welding processes. Another set of welding processes in which metallic bond is produced using pressure or heat generated from sources other than arc namely chemical reactions or frictional effect etc., are grouped as non-arc based welding processes. Note that Arc or Electric Arc is a continuous stream of electrons flowing through some sort of medium between two conductors of an electric circuit and accompany by intense heat generation. Welding processes corresponding to each group are given below.

Arc based welding processes

- **Shielded Metal Arc Welding SMAW:** Arc between base metal and covered electrode
- **Gas Tungsten Arc Welding (GTAW):** Arc between base metal and tungsten electrode
- **Plasma Arc Welding (PAW):** Arc between base metal and tungsten electrode
- **Gas Metal Arc Welding ((GMAW):** Arc between base metal and consumable electrode
- **Flux Cored Arc Welding (FCAW):** Arc between base metal and consumable electrode
- **Submerged Arc Welding (SAW):** Arc between base metal and consumable electrode

Non-arc based welding processes

Resistance welding processes: uses electric resistance heating

Gas welding: uses heat from exothermic chemical reactions

Thermit welding: uses heat from exothermic chemical reactions

Ultrasonic welding: uses both pressure and frictional heat

Diffusion welding: uses electric resistance/induction heating to facilitate diffusion

Comments on classification of welding processes based on arc or non arc based process

Arc and non-arc welding processes classification leads to grouping of all the arc welding processes in one class and all other processes in non-arc welding processes. However, welding processes such as Electro Slag Welding (ESW) and Flash Butt welding were found difficult to classify in either of the two classes as ESW process starts with arcing and subsequently on melting of sufficient amount flux, the arc extinguishes and heat for melting of base metal is generated by electrical resistance heating by flow of current through molten flux/metal. In flash butt welding, tiny arcs i.e. sparks are established during initial stage of the welding followed by pressing of components against each other. Therefore, such classification is also found not perfect.

2.1.4 PRESSURE OR FUSION WELDING

Welding processes in which heat is primarily applied for melting of the faying surfaces are called fusion welding processes while other processes in which pressure is primarily applied (with little or no application of heat for softening of metal up to plastic state) for developing metallic bonds are termed as solid state welding processes.

Pressure welding

Resistance welding processes (spot, seam, projection, flash butt, arc stud welding)

- Ultrasonic welding
- Diffusion welding
- Explosive welding

Fusion welding process

- Gas Welding

- Shielded Metal Arc Welding
- Gas Metal Arc Welding
- Gas Tungsten Arc Welding
- Submerged Arc Welding
- Electro Slag/Electro Gas Welding

Comments on classification of welding processes based on Fusion and pressure welding

Fusion welding and pressure welding is most widely used classification as it covers all processes in both the categories irrespective of heat source and welding with or without filler material. In fusion welding, all those processes are included in which molten metal solidifies freely while in pressure welding, molten metal if any is retained in confined space (as in case of resistance spot welding or arc stud welding) and solidifies under pressure or semisolid metal cools under pressure. This type of classification poses no problems and therefore it is considered as the best criterion.