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Fabrication Techniques

In industry most of the materials are fabricated into the desired shapes mainly by one of the four methods viz., casting, forming, machining and welding. The selection of a particular technique depends upon different factors which may include shape and size of the component, precision required, cost, material and its availability. Sometimes it is possible to use only one specific process to achieve the desired object. However, more often it is possible to have a choice between the processes available for making the end product. In the latter case economy plays the decisive role in making the final choice. Brief description of these four fabrication processes and their specific fields of application are given as follows.

1.1. CASTING

Casting is perhaps the oldest known method of giving shapes to metals and alloys. When found suitable, it is the shortest route from the ore to the end product and usually the most economical. Though these days techniques have been developed to cast almost all metals and their alloys but still there are certain specific materials which have very superior casting properties, for example grey cast iron.

The castability of a material depends upon a number of factors viz., fluidity, shrinkage, porosity, stresss and segregation characteristics. The castability index of a material is high if it has high fluidity, low shrinkage, low affinity for absorbing gases, low stresses and uniform strength. These characteristics are found to occur mainly in pure metals and eutectics which have, at least theoretically, a definite melting point. However, pure metals usually have low strength therefore mainly alloys are cast for most of the actual applications.Thus, the choice obviously falls on eutectics and near-eutectic alloys.*

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* **Eutectic Alloy** : An alloy with a specific composition having a definite but lower melting point than the constituent metals and which on cooling from the liquid state precipitates two solid phases simultaneously. In iron-carbon equilibrium diagram gray cast iron with 4·3% carbon is a eutectic alloy, having a melting point of 1130°C, as shown in Fig. 1.1.

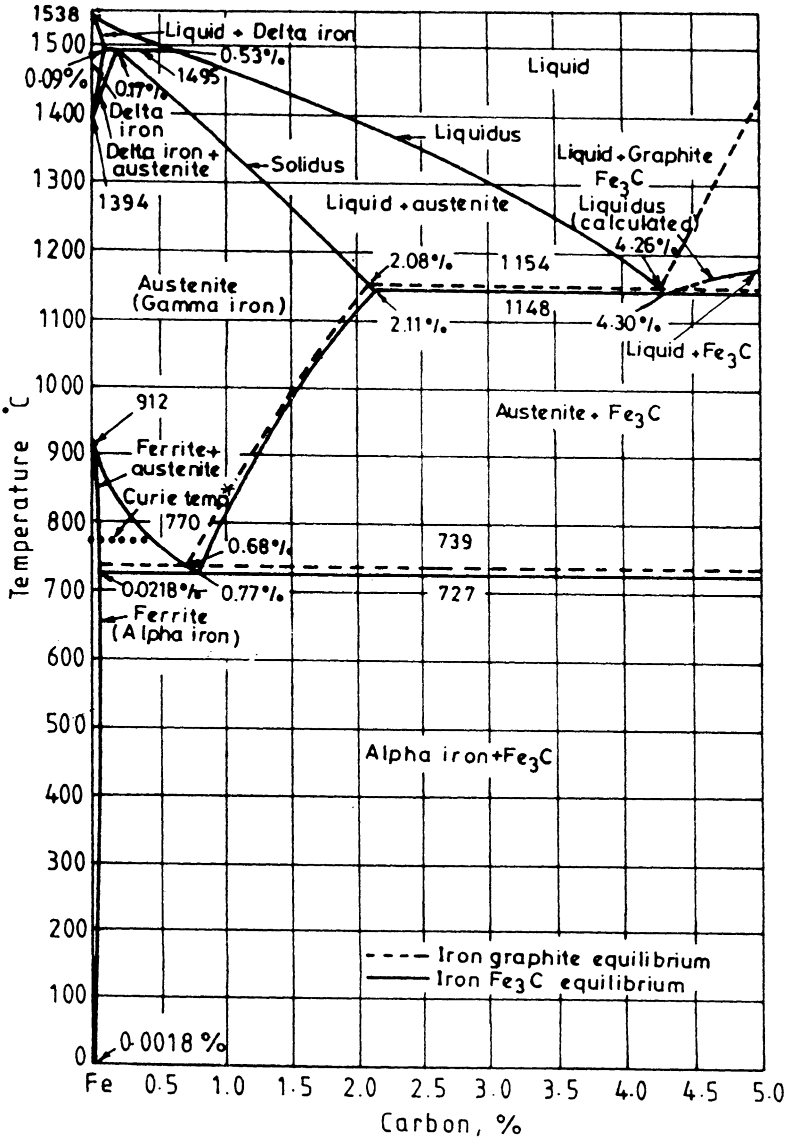


Fig. 1·1 Iron-carbon equilibrium diagram.

Castings can be grouped into two main categories viz., ingots and shaped castings. Of the total materials cast nearly 75% are in the form of ingots. However, our main concern in the present discussion is shaped castings.

Castings may weigh from a few grams to many tons. Perhaps, the heaviest object ever made by casting was the bronze statue of Clossus of Rhodes which is included in the seven wonders of the world. However, leav-

* Curie Temperature is the temperature below which iron attains magnetic properties.

ing aside the wonder the present day heavy castings often include the machine structures, flywheels and base plates for turbines, etc.

Castings are, as a rule, good in compressive strength but have poor elongation and low tensile strength. The materials which are considered exceptionally good for casting include, apart from cast iron, the alloys of copper, aluminium, zinc nickel, and magnesium. Some of the typical castings include the following.

Pulleys, flywheels, engine blocks, machine tool beds, gear blanks, turbine blades, cast iron pipes, etc.

1.2. FORMING

After casting followed the forming process in which the metals and their alloys are given desired shapes by the application of pressure, either by sudden impact as in the case of hammer blows or by slow kneading action as in hydraulic presses. Mechanical working of a metal below its recrystallisation temperature is called 'Cold Working' and that accomplished above this temperature is known as 'Hot Working'. Both hot and cold working (or forming) are practised extensively in the industry.

Most of the materials can be formed or forged but, as a rule, the materials which are best suited to casting have poor forming qualities. In general the materials best suited for forming are those which have a long mushy range during solidfication for example, solid solution alloys*.

Many alloy properties are affected by the nature of solid solutions e.g. strength and hardness increase with the amount of solute present while ductility and electrical conductivity are lowered

Forming quality of a material is usually referred to as formability for sheet material and forgeability for thicker sections and is associated with ductility of the material. The processes which can be included in forming are the sheet forming methods like bending, deep drawing, extrusion, HERF (high energy rate forming), spinning, roll bending, stretch forming; whereas forging may include upsetting, cold heading, rotary swaging, coining, etc.

Formability testing is commonly done by Erichsen cupping test in which the sheet material is stretched till cracking. The forgeability on the other hand is the ability of a metal to be deformed under forging conditions without cracking. One of the best forgeability tests is the ***upsetting test***, expressed as the ratio of maximum upset diameter obtainable to initial bar diameter. For cold heading this ratio is usually referred to as heading limit.

$$\text{Forgeability Index, } F = \frac{D_m}{D_i}$$

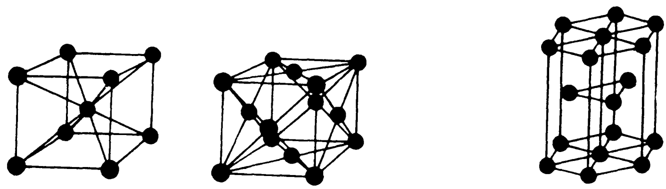
Where, D_i = initial bar diameter

D_m = maximum diameter that can be obtained by upsetting without cracking.

***Solid Solution Alloy** : When metals combine to form alloys by completely dissolving in each other and continue to remain so even in the solid state they are called solid solution alloys, for example Monel metal is a solid solution alloy of copper and nickel.

1.2.1. Materials for Forging

The materials are usually found to occur in three types of unit cells viz., BCC (body-centred cubic), FCC (face-centred cubic) and HCP (hexagonal close packed) as shown in Fig. 1.2 along with some of the well known metals under these three categories of cell structures.



Body centred cubic crystal structure BCC	Face centred cubic crystal structure FCC	Hexagonal close packed crystal structure HCP
Chromium (Cr)	Aluminium (Al)	Cadmium (Cd)
Columbium (Cb)	Copper (Cu)	Cobalt (Co)
Iron (Fe) at room temp. and near melting temperature	Gold (Au)	Magnesium (Mg)
Molybdenum (Mo)	Iron (Fe)– at intermediate high temperature	Tin (Sn)
Steels (most)	Lead (Pb)	Stainless steels (some)
Tantalum (Ta)	Nickel (Ni)	Titanium (Ti)
Tungsten (W)	Platinum (Pt)	Zinc (Zn)
Vanadium (V)	Silver (Ag)	Zirconium (Zr)
	Stainless Steels (some)	

Fig. 1·2 Crystalline structure of common metals.

The face-centred cubic metals have in general the best ductility. They usually are also the most forgeable. The hexagonal close packed metals, are the least forgeable at room temperature, but most of them can be hot forged. If a metal can be deep drawn in sheet form, it can be cold forged or cold headed in bar form, and it is so for all metals. Free-machining grades of metals have limited forgeability.

The best alloys for forging, cold or hot, are most aluminium and copper alloys, including the relatively pure metals. Carbon steels with 0.25 % carbon or less are readily hot forged or cold-headed. High carbon and high alloy steels are almost always hot forged. Magnesium being HCP has little ductility at room temperature but is readily hot forged.

Aluminium alloys are forged between 385°C and 455°C or about 40°C below the temperature of solidification. Aluminium alloys do not form scale during hot forging operations, die life is thus excellent.

Copper and brasses with 30% or less zinc have excellent forgeability in cold working operations. High zinc brasses can be cold forged to a limited extent but are excellent hot forging alloys. Magnesium alloys are forged on presses at temperature above 400°C. At higher temperatures, magnesium must be protected from oxidation or ignition by an inert atmosphere of sulphur dioxide.

The forgeability of different metals for close-die forging, in decreasing order, for some of the common alloys is as given in table 1.1.

Due to the kneading action in forging the components produced by forging are normally the strongest and require the least thickness of material. All critical components are therefore normally forged. Some of the typical examples of forged components include the following.

Crankshafts, connecting rods, traction and lifting hooks, coil springs, axles, seamless pipes and tubes, shell bodies, rods, plates, sections, tooth paste tubes, etc.

Table 1.1. Forging Temperatures of the Common Alloys

Material	*Range of forging temperature (°C)*
Al – alloys (least difficult)	400— 500
Mg – alloys	250— 350
Cu – alloys	600— 900
Carbon and low alloy steels	850—1150
Stainless steel (martensitic)	1100—1250
" (austenitic)	1100—1250
Maraging steels	1100—1250
Ni – alloys	1000—1150
Ti – alloys	700— 950
Tungsten alloys (most difficult)	1200—1300

1.3. MACHINING

It is the process of giving the desired shape to a given material by removing the extra or unwanted material by cutting in the form of chips. The cutting tool material is by necessity harder and stronger than the material to be cut. The machining processes commonly employed are turning, milling, drilling, shaping, planing, reaming, boring etc. Though lathes and milling machines were used in connection with watch making even in the fifteenth and sixteenth centuries but most of these processes were introduced into the high volume industries in their present forms for making steam engine parts in the late nineteenth century but have come of age in the present century.

Almost all materials can be machined though not by the same ease. As a rule, harder materials with high tensile strength are more difficult to machine. Also, very soft materials are troublesome to machine as seizure occurs between the work material and the tool. Thus, it can be said that there is a specific hardness range above and below which the machining efficiency decreases.

To compare the ease of cutting the materials are given machinability index. Machinability of a material depends upon the various factors and it is common to consider four of them, viz.,

(*i*) tool life (*ii*) cutting forces

(*iii*) surface finish (*iv*) power consumption.

Based on these factors, free cutting steel specified by AISI (American Institution of Steel and Iron) as B 1112 with the following composition and turned at 180 SFM (surface feet per minute) or 55 SMM (surface metres per minute) is given machinability index of 100.

$C = 0{\cdot}13\%$ (max.)

$Mn = 0{\cdot}9\%$

$P = 0{\cdot}1\%$

$S = 0{\cdot}2\%$

Iron = rest.

A number of formulae have been developed for determining the machinability index and one such formula put forward by Janitsky is as follows :

$$K = c\left[0{\cdot}25 - \left(\frac{Y.P.}{T.S.} - 0{\cdot}5\right)^2\right] \qquad \ldots\ldots\ldots(1{\cdot}1)$$

where,

c = a function of T.S.,

$T.S.$ = tensile strength,

$Y.P.$ = yield point.

The material characteristics that affect machinability of a metal include the following.

1. **Material Composition.** High alloy content and the presence of hard inclusions like Al_2O_3 in steels as also carbon content below 0·30% or above 0·60% decrease machinability while small amounts of lead, manganese, sulphur and phosphorus improve it.

2. **Metal Structure.** Uniform microstructure with small undisturbed grains improves machinability. Lamellar structure in low and medium carbon steels and spheroidal structure in high carbon steels also result in better machinability.

3. **Working and Heat Treatment.** Hot working of hard alloys and cold working of soft alloys result in improved machinability.

Annealing, normalizing and tempering, in general, improve machinability. Quenching normally reduces machinability.

The machinability indexes of some of the well known materials are given in table 1·2.

Table 1·2. Machinability Ratings of Some Engineering Materials

Material	*Machinability Index*
Steels	
Free machining steel (wrought)	100
Plain carbon steel (annealed)	90
" " " (normalised)	75
Cr– Mo steels (annealed)	55
" " (normalised)	50
Ni–Cr–Mo Steels (annealed)	35
" " (normalised)	55
" " (quenched & tempered)	20
Mn–Cr–Ni steels (annealed)	65
" " (normalised)	40
Stainless steels (austenitic)	50—55
" " (ferritic)	70
" " (martensitic)	90
Iron	
Malleable	110—120
Gray (flake graphite)	110
Ductile	90—110
Meehanite*	76
Gray (pearlite)	68
Aluminium alloys	240

Some typical examples of machined components include vee-ways, valve seats, automobile cylinder liners, gear teeth, screwed spindles, machine parts, nuts and bolts, etc.

1.4. WELDING

Welding as it is normally understood today is comparatively a new comer amongst the fabrication processes though smith forging to join metal pieces was practised even before Christ. Though there are a number of well established welding processes but arc welding with coated electrodes is still the most popular welding process the world over.

Arc welding in its present form appeared on the industrial scene in 1880's. Though there are conflicting claims about the inventor of this process but very often it is attributed to a Russian named Slavianoff who is claimed to

* Meehanite is an inoculated iron of a specially made white cast iron composition which is graphatised in the ladle with calcium silicide. Useful even for high temperature applications.

have patented it in 1881. Arc welding, however, was not accepted for fabrication of critical components till about 1920 by which time coatings for electrodes had been well developed. However, the demand for large scale production of heavy items like ships, pressure vessels, construction of bridges and the like provided the necessary impetus for welding to come of age and the second world war firmly established it as the major fabrication process.

Welding, which is a process of joining two or more parts of material (s) though provides a permanent joint but does normally affect the metallurgy of the components. It is therefore usually accompanied by post weld heat treatment (PWHT) for most of the critical components.

Most materials can be welded by one process or the other. However, some are more easy to weld than others. To compare this ease in welding a term 'weldability' is often used. Weldability of a material depends upon various factors like the metallurgical changes that occur due to welding, changes in hardness in and around the weld, gas evolution and absorption, extent of oxidation, and the effect on cracking tendency of the joint. Depending upon these factors plain low carbon steels ($C \leq 0{\cdot}12\%$) have the best weldability amongst metals. Quite often materials with high castability usually have low weldability.

Welding processes widely used in the industry include oxy-acetylene, manual metal arc or shielded metal arc (SMA), submerged arc (SA), gas metal arc (GMA), gas tungsten arc (GTA) welding, resistance welding, thermit welding and cold pressure welding. Most of these processes have special fields of influence like resistance welding is popular with the automobile industry, thermit welding for joining rails in situ, GMAW is particularly suited for welding of low carbon steel structures as also welding of stainless steels and aluminium, GTAW is more popular with aeronautical and nuclear industries, SAW for ship building, Cold pressure welding by food processing industry, and the like. However, SMAW or stick electrode welding and oxy-acetylene welding processes are the general purpose processes with a wide range of applications.

Some of the typical applications of welding include the fabrication of ships, pressure vessels, automobile bodies, off-shore platforms, bridges, welded pipes, sealing of nuclear fuel and explosives, etc.

The subsequent chapters deal with different aspects of welding processes and other related topics, the knowledge of which is essential to make welded fabrications a success.