M 6103 MATERIALS PROCESSING I:

M.Sc Evening Classes. 12 hours Lectures.

LECTURE IV:

Casting processes: overview of conventional processes, advantages and disadvantages, process selection, recent developments in conventional processes, new casting techniques such as squeeze casting, thixomoulding, Osprey technique etc. Foundry technology: molten metal treatments, health and safety.

- 3 hours

4.1.0. CASTING PROCESSES: OVERVIEW OF CONVENTIONAL PROCESSES: ADVANTAGES AND DISADVANTAGES:

4.1.1. GREEN SAND MOULDING:

Green sand moulding is the most popular and widely used moulding process since the system lends itself most ably to all types of production processes from jobbing foundries to high production foundries.

Advantage: moulds may be produced , poured and knocked out in a continuous cycle of short duration.

Green sand consists of silica sand bonded with clay and water. However, other additions may be added, for example, in iron foundries coal dust is added.

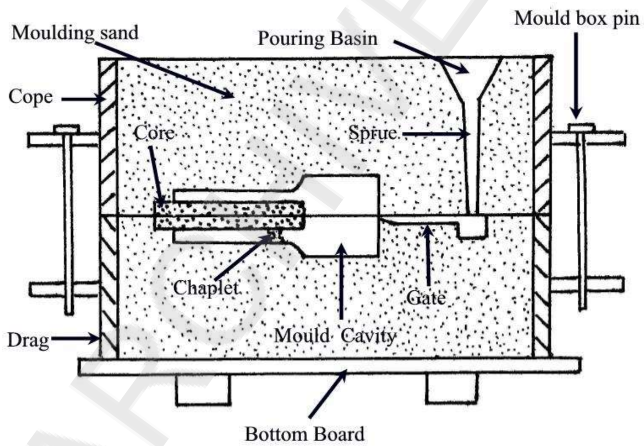


Fig: 1: Green sand moulding.

4.1.2.DRY SAND MOULDING:

The sand is rammed around the pattern by hand, jolt, squeeze or slinging and the completed mould stoved at about 250^{o}C to dry the sand. If the mould is too large portable heaters are used. It is rather an expensive process. A short cut can be accomplished by skin drying the mould and thereby produce only a layer of sand in contact with the metal in the dry state.

4.1.3.. LOAM MOULDING:

This method involves the use of sand of such consistency that it can be trowelled or strickled into shape. Once formed the mould has to be dried before pouring the molten metal.

4.1.4. SODIUM SILICATE BINDER:

There is a whole range of sodium silicate binders available which vary in the $Na_2O:SiO_2$ ratio and solids content. The popular choice is a ratio of 2:1.

The process is known as " CO_2 process". The mould is made with sand containing sodium silicate binder and CO_2 gas is passed through such a mould to produce a rigid mould. Sometimes finely divided ferrosilicon is added (Nishiyama Process) .

The advantages of this over clay bonded systems are:

a. Moulds are much more rigid and stronger .
b. Higher flowability and therefore compaction of sand is much simpler.
c. Because of the rigid mould there is an improvement in the dimensional accuracy.
d. Less likelihood of erosion and hence less sand inclusions.
e. Gas evolution is low.

Disadvantages:

a. Knock out is very difficult.
b. Bench life of the mixed sand is short.
c. Reclamation of sand is expensive.

4.1.5. CEMENT SAND MOULDING:

The mould is produced by using a mixture of sand with an addition of cement (6-12%) and the required quantity of water (4-8%). This produces a very rigid mould. Breakdown of the mould after casting is very difficult. Ease of ramming, the high dry strength, high permeability and the increased dimensional accuracy are the advantages. Long drying times and poor knock-out characteristics are the disadvantages.

4.1.6. FLUID SAND:

An innovation made to the sodium silicate bonded process was made in Russia during the early 60s whereby the binder was added to the sand together with a suitable hardener, dicalcium silicate being the most common, and the sand made fluid by adding water plus a foaming agent, the mixing action for the sands needs to be quite vigorous to attain the best fluidity from the sand. After completion of the mixing cycle the sand is capable of being poured into a mold box, no ramming is necessary.

Advantage: Sand can be mixed at one source and can be piped.

Disadvantage: Limited to large moulds.

4.1.7. SHELL MOULDING PROCESS:

The basis of the process is to take a suitable refractory material, silica or zircon sand, and coat the sand grains with a resin. The precoated is then placed in contact with a heated pattern causing the resin to transform to a thermosetting condition which produces a hardened sand retaining its shape without distortion when the pattern is removed. The layer of hardened sand produced is referred to as a "shell" hence the name "shell moulding process".

The most popular resin is phenol-formaldehyde type containing hexamine. The patterns are generally made of Cast Iron.

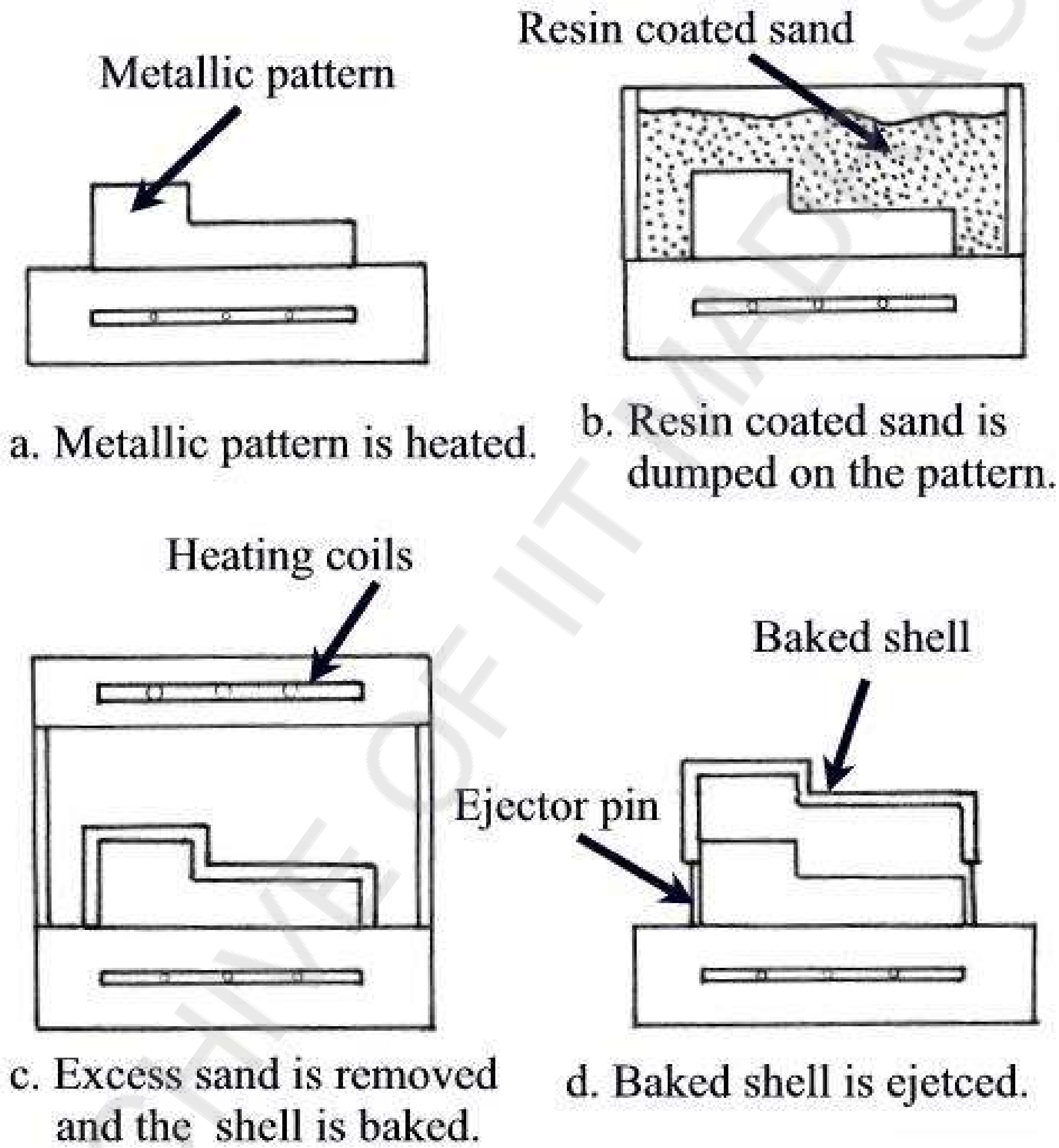


Figure:4-2:Shell Moulding Process

4.1.8. INVESTMENT CASTING:

" Lost-wax Process", Shang dynasty, 1715 BC.
The first step is to form an expendable pattern, normally produced by injecting a wax under pressure, into a split die. Polystyrene or frozen mercury are also sometimes used instead of wax.
The wax pattern is dipped into a slurry, the excess slurry is allowed to drain from the pattern and then a refractory aggregate is applied, the refractory particles attaching themselves to the wet slurry layer. This coating is then dries by heat. This procedure is repeated until and adequate thickness of material is obtained, usually between 5 - 15 mm.

Dewaxing : heating the shell to a temperature of $1000^{o}C$ for a short period of time. This is followed by a firing before casting metal into the mould.

Advantages:
Very close dimensional tolerances can be achieved.

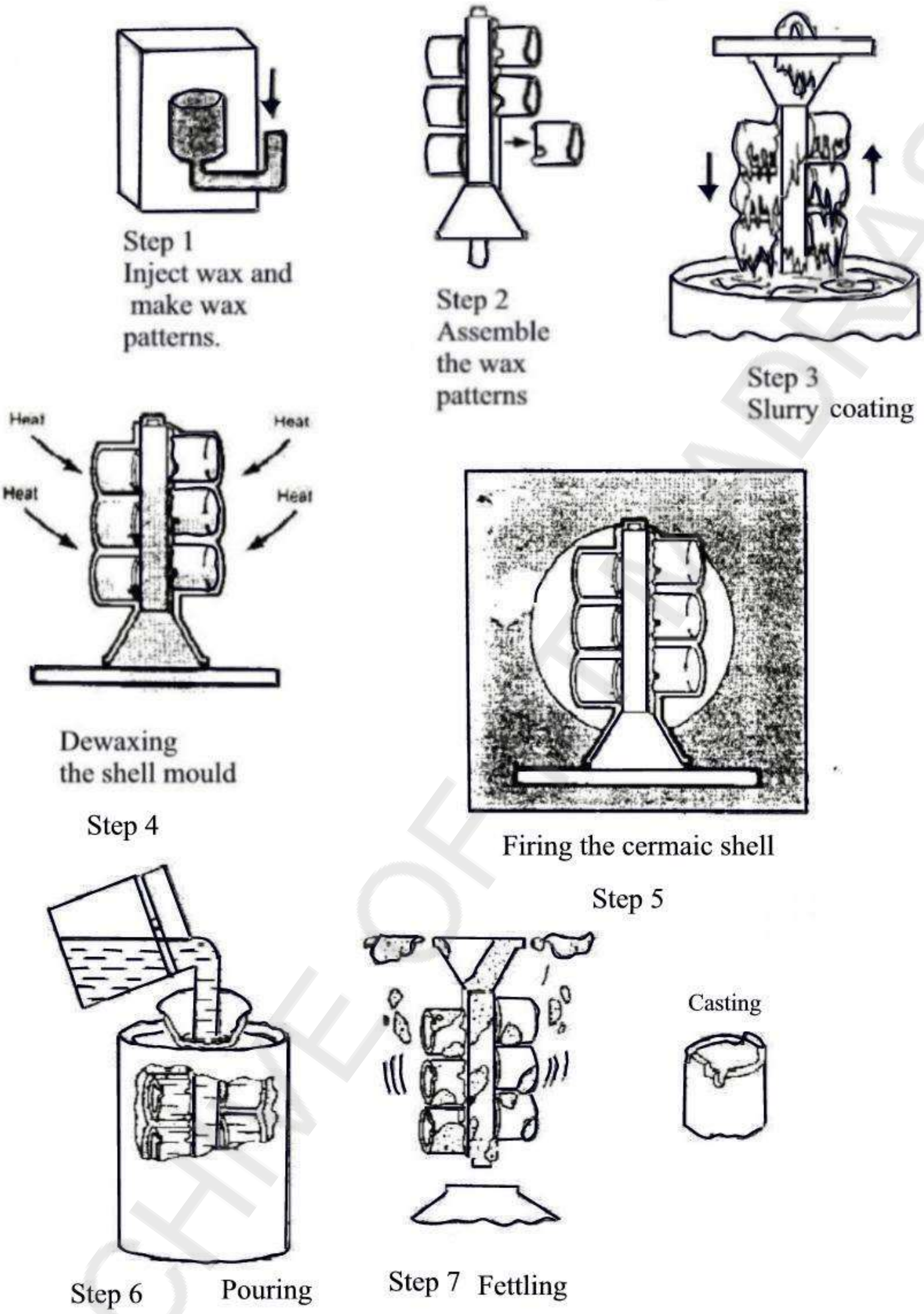


Figure:4-3: Investment Casting

4.1.9.GRAVITY DIE CASTING:

Gravity die castings are produced in metal moulds, referred to as dies.
The die is normally split in the vertical plane and any internal shape of the casting can be taken into account by the use of cores, produced in metal or sand. This method is used extensively for light alloys.
The castings have a good surface finish, superior mechanical properties, and very little machining is necessary. Mechanization is possible. The dies are made of Cast Iron.

4.1.10.PRESSURE DIE CASTING:

This process differs from the gravity die process in that a positive pressure is maintained on the metal in the die during injection and solidification. There are two methods:

1. Hot chamber process.
2. Cold chamber process: For alloys with melting temperatures above 500^{o} C.

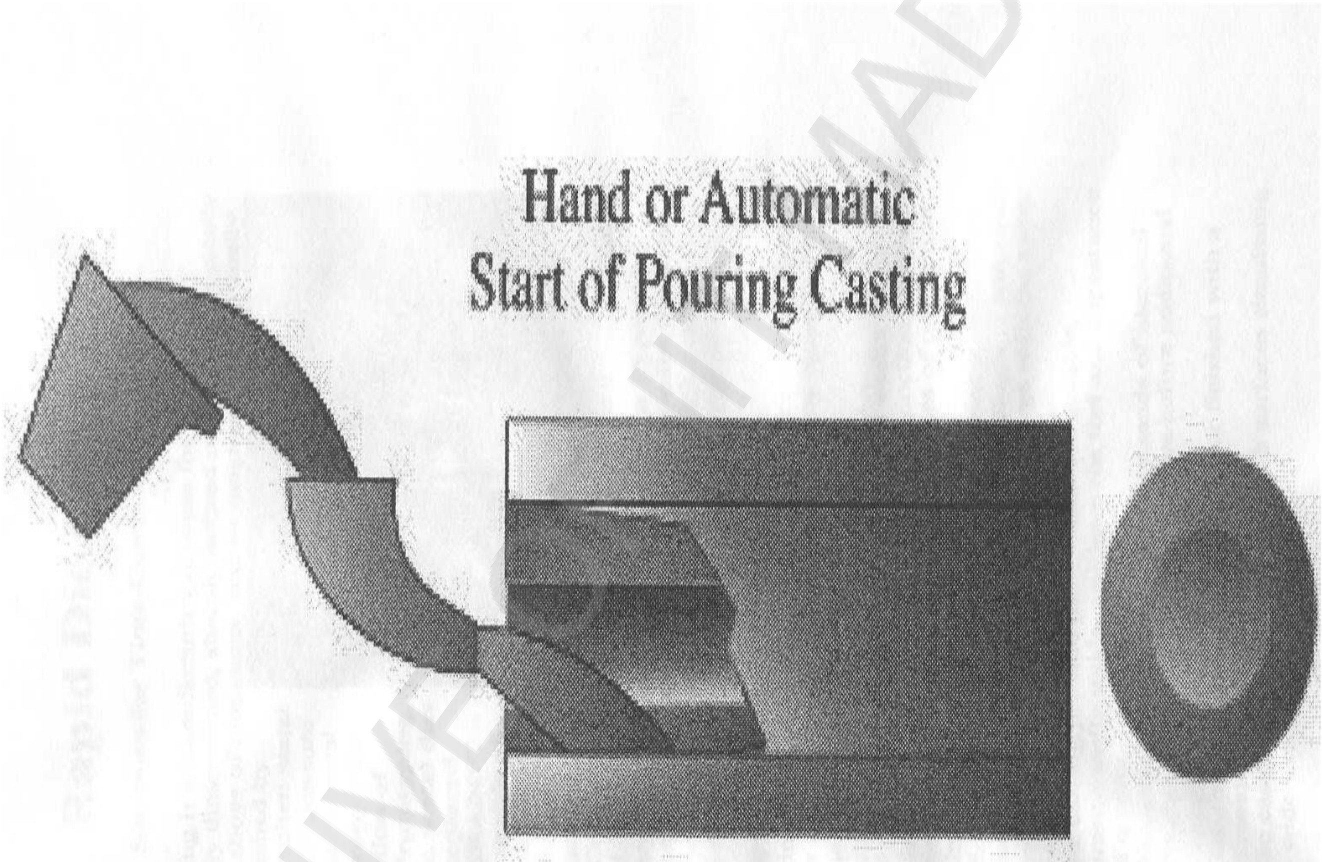
4.1.11.CENTRIFUGAL CASTING:

There are three basic types:
1. True Centrifugal
2. Semi-centrifugal.
3. Centrifuged.

In true centrifugal the casting is spun about its own axis. The majority of cast shapes produced by true centrifugal casting are cylindrical.

Advantages:

The castings have superior mechanical properties. Relatively the casings are free from gas, shrinkage etc.


Hand or Automatic
Start of Pouring Casting

4.2.0.PROCESS SELECTION:

4.2.1. ALLOY SYSTEM:

If steel is to cast, pressure and gravity die casting techniques cannot be used. In the case of Zinc base alloys pressure die casting is mostly used so that sound castings can be produced. Aluminium base alloys are usually cast by the gravity die casting process.

4.2.2. NUMBER OF PIECES NEEDED:

If only a few pieces are needed, usually green sand moulding is employed. Gravity and pressure die casting techniques are employed only when large number of castings have to be made. The making of dies is expensive.

4.2.3. SIZE OF THE CASTING:

Large casting (>1 ton) are usually made in CO_2 process. In pressure die casting, castings of small size are cast.

4.2.4.MINIMUM SECTION THICKNESS:

The minimum section thickness to be cast depends upon the process.

4.2.5. DIMENSIONAL ACCURACY NEEDED:

Where higher dimensional accuracy is needed, processes that make use of metallic dies are employed. Investment casting also yields castings of high dimensional accuracy.

4.2.6.SURFACE FINISH:

Though this may not be a criterion for structural applications, for certain type of castings surface finish may be of importance. Sand castings yield a very poor surface finish. Shell moulded castings show superior surface finish. Investment castings have very good surface finish.

4.2.7.COST:

Ultimately the cost the customer is willing to pay will decide the process. The self setting resins are expensive. The customer should be willing to pay for the increased costs.

4.3.0. RECENT DEVELOPMENTS IN CONVENTIONAL PROCESSES:

4.3.1. HIGH PRESSURE MOULDING:

By increasing the pressure in the green sand moulding process, better compaction may be achieved. Most machines use hydraulic pressure to apply the compaction force in green sand moulding. High pressure moulding is conventional green sand moulds are made with a pressure on the mould surface exceeding 700kPa. Noise in the foundry is substantially reduced. This is expected to facilitate flaskless moulding. However, springback is a major problem. In addition the castings exhibit expansion defects.

4.3.2. SELF OR AIR SETTING SANDS:

Resins based on furfuryl alcohol are used extensively with a suitable acid catalyst for the production of moulds and cores where the sand is allowed to cure in contact with the pattern or core box at room temperature. This type of process is referred to as a " self setting" or "air setting" process, the hardening produced in the compacted sand is brought about by polymerisation of the resin.

Advantages:

1. Simple process.
2. Knock down characteristics are good. Reclamation of sand is simpler.

Disadvantage: It is very expensive.

4.3.3.SQUEEZE CASTING:

Squeeze casting is also known as liquid metal forging, is a process by which molten metal solidifies under pressure within closed dies positioned between the plates of a hydraulic press. The applied pressure and the instant contact of the molten metal with the die surface produce a rapid heat transfer condition that yields a pore-free fine-grain casting with mechanical properties approaching those of a wrought product. The squeeze casting process is easily automated to produce near-net to net-shape high-quality components. Aluminium, magnesium and copper alloys components are readily manufactured using this process.

Advantages: By pressurizing liquid metals while they solidify, near-net shapes can be achieved in sound, fully dense castings. Improved mechanical properties are additional advantages of squeeze cast products. Applications include aluminium alloy pistons for engines and disk brakes; automotive wheels etc.

The process consists of metering liquid metal into a preheated , lubricated die and forging the metal while it solidifies. The load is applied shortly after the metal begins to freeze and is maintained until the entire casting has solidified. Casting ejection and handling are done in much the same way as in closed die forging.

The high pressure (typically 55 to 100 MPa) is enough to suppress gas porosity. The tendency towards shrinkage porosity is limited by using a bare minimum of superheat in the melt during pouring.

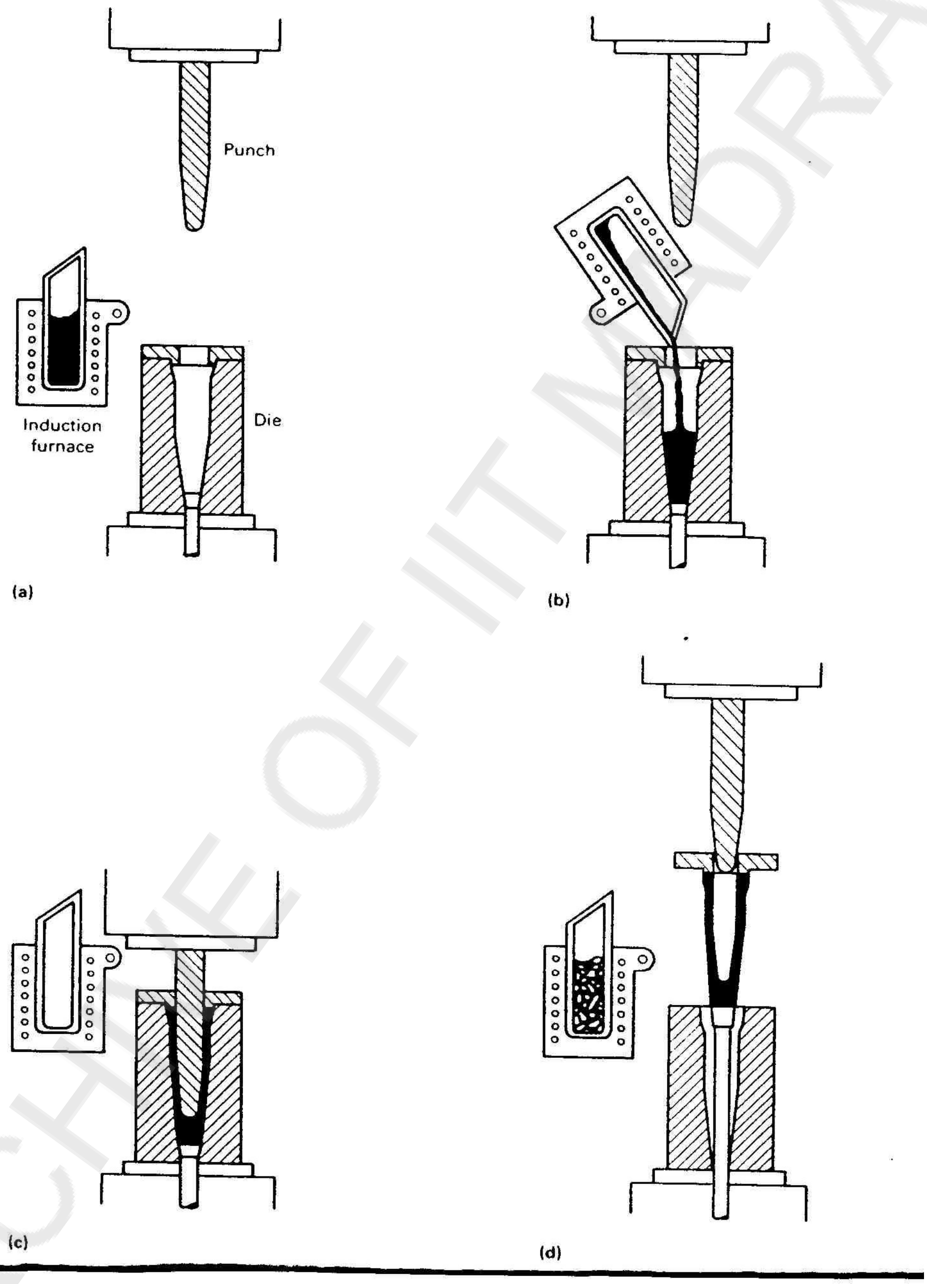


Fig:4-4:Squeeze Casting Process

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Microstructure:

Even moderately applied pressure causes intimate contact between the solidifying casting and the die for a tenfold increase in heat transfer rate over permanent mould casting. This results in relatively fine grains in the casting. Fine grain size is also promoted by the large number of nuclei formed because of the low casting temperatures and the elevated pressures.

Recently, this process has also been adopted to make composite materials at an affordable costs.

4.3.4.SEMISOLID METAL CASTING:

Introduction: Semisolid metalworking, also known as semisolid forming, is a hybrid manufacturing method that incorporates elements of both casting and forging. It was based on a discovery made at the MIT in the early 1970s. Process based on the discovery were identified by MIT as rheocasting, thixocasting or stir casting. Today it is a two step process for the near-net shape forming of metal parts using a semisolid raw material that incorporates a unique nondendritic microstructure.

4.3.4.1.ALLOYS CAST: Aluminium alloys and Copper alloy components have been manufactured by this technique.

4.3.4.2.THE PROCESS:

I STEP: The slurry is produced in a mixer and delivered directly into the die

II STEP: Forging of the mixer delivered is carried out.

In the slurry process, 60 to 70 % of the material is liquid.

In a second approach:

I STEP: A billet is cast in a mould equipped with a mixer (which creates the spherical microstructure during casting) and is stored for subsequent use.
II STEP: If the volume of billet material required is known, the slug weight can be readily determined, later, a slug cut from the billet is heated to the semisolid state and formed in a die.Normally the cast billet is forged when 30 - 40 % is liquid.

Raw Material Production:
Casting Processes:

Raw material for semisolid metal forming requires the special microstructures. When semisolid, this structure comprises solid particles in the form of globules or spheroids suspended in a matrix of lower-melting alloy liquid. The following figure shows the typical microstructures obtained due to stirring.

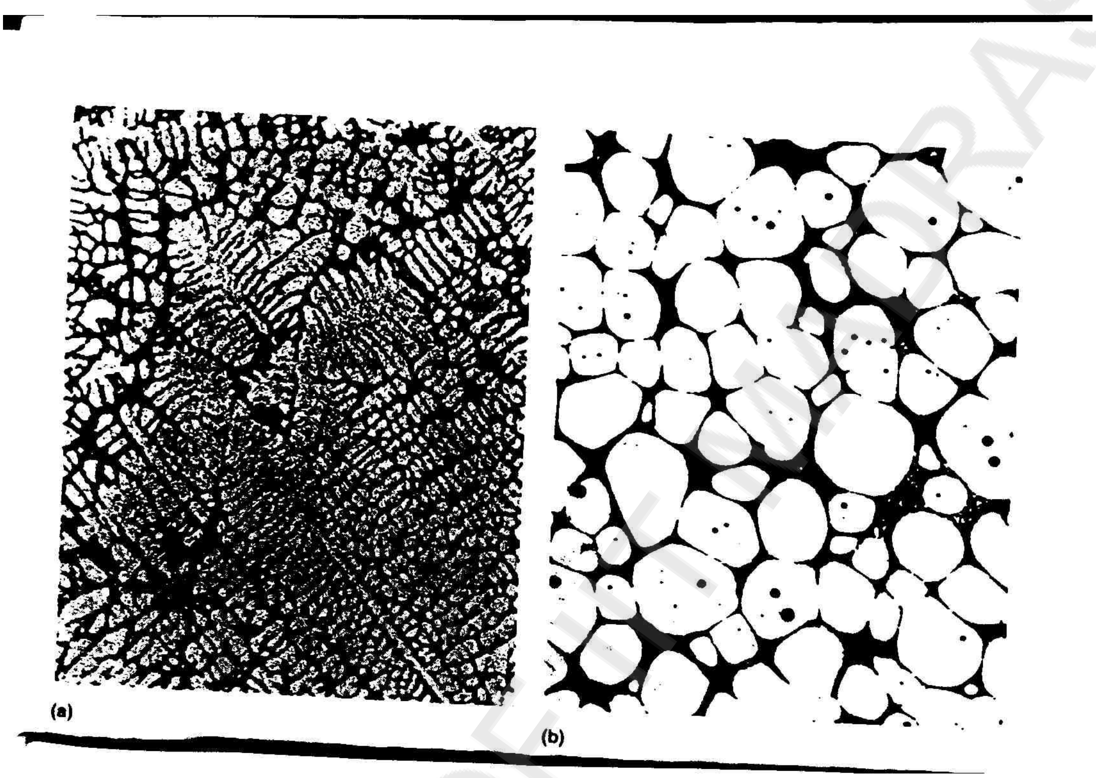


Fig:4-5: COMPARISON OF DENDRITIC CONVENTIONALLY CAST (a) AND NON-DENDRITIC (b) MISROSTRUCTURES OF ALUMINIUM ALLOY 357 (AL-7Si-0.5Mg).

Evolution of this stirring ranged from simple eggbeater-type mixers in slowly cooled crucibles to complex gas-shielded high-temperature continuous mixing systems for steels and superalloys. Typically solid-particle diameters ranged from 100 to 400 μm for normal solidification rates.

Magnetohydrodynamic (MHD) Casting: The industrial application of semisolid metalworking to metal parts used in military, aerospace, automotive, or other high quality applications demands integrity of the materials. The metal, near the freezing point in the mould, is vigorously stirred by a dynamic electromagnetic field, which creates the necessary shearing action. The MHD casting process provides the ability to control the shearing action precisely and hence is able to deliver the desired microstructures with a grain size of about 30 μm.

4.3.4.3.ADVANTAGES OF THE PROCESS:

1. Automation can be introduced into the material handling systems.
2. Lower temperature and short dwell time lead to longer die life.
3.Precision steel dies produce near-net shape parts that require less machining.
4. Semisolid charge produces less liquid solid shrinkage and less microporosity.

4.3.4.4.LIMITATIONS OF THE PROCESS:

1. Specially prepared raw material has to be used.
2. The tooling is expensive.
3. Special and expensive capital equipment are needed.
4. Highly skilled staff is required.

4.3.5.FULL MOULD PROCESS: LOST FOAM CASTING: UNBONDED SAND MOULDS:

No bonding medium is used between the sand grains. The pattern is produced from expanded polystyrene having a density of around 15-35 kgm^{-3}. The pattern is readily made by carving or cutting with hot wires or suitable instruments. The main advantage of this material is that the pattern need not be extracted from the mould since it vaporizes with very little gas evolution when the hot metal is poured into the mould. There is no need to produce split patterns and there is elimination of complicated joint lines in the mould. Dry silica sand is poured around the polystyrene pattern and since there is no bond the sand grains flow relatively easily into all the recesses of the pattern of the pattern to take up a faithful impression of the pattern profile.

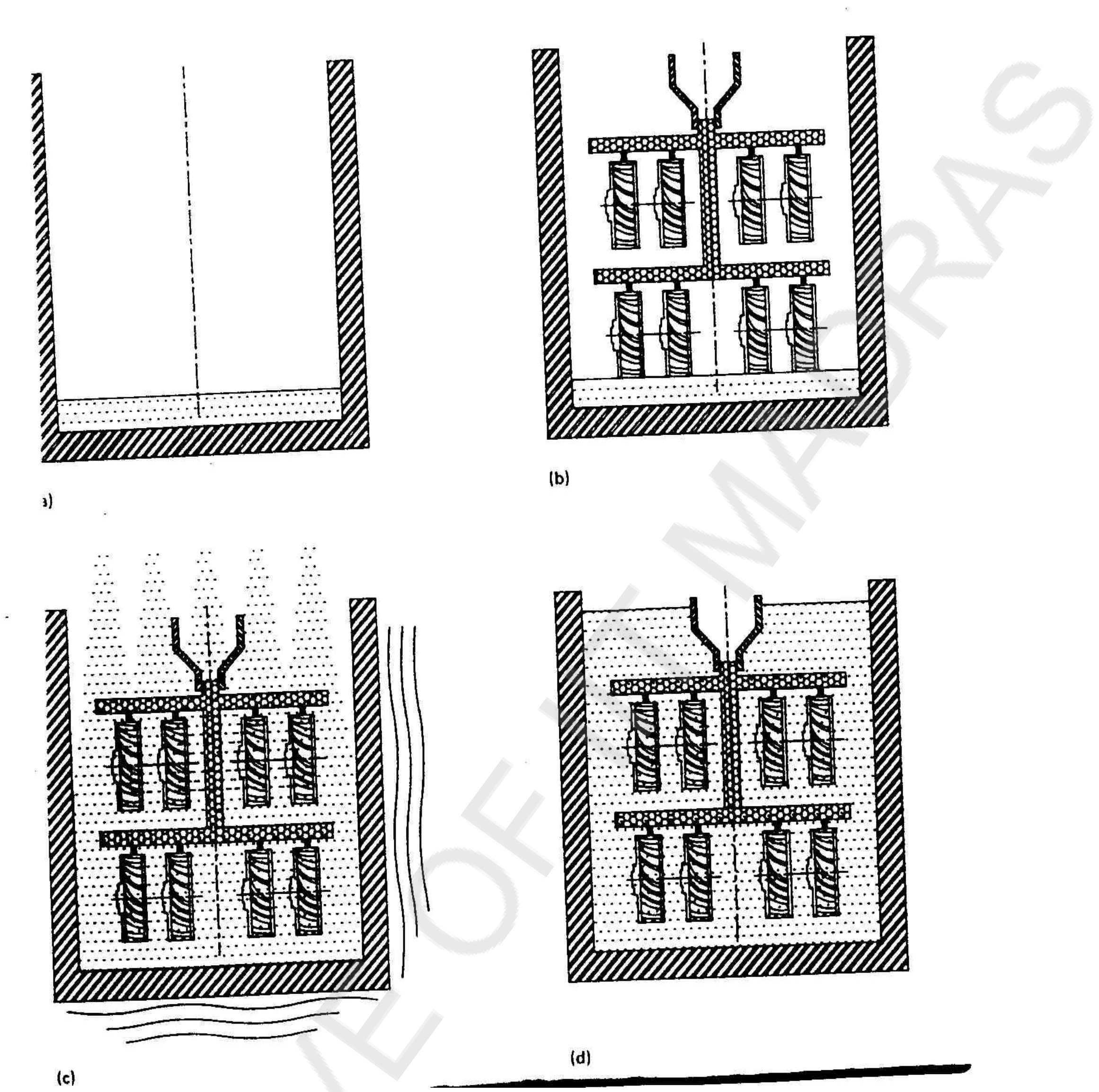


FIGURE:4-6: LOST FOAM PATTERN SYSTEM.

(a) FLASK THAT CONTAINS A 25 TO 75 MM SAND BASE.

(b) POSITIONING THE PATTERN.

© FLASK BEING FILLED WITH SAND, WHICH IS SUBSEQUENTLY VIBRATORY COMPACTED.

(d) FINAL COMPACT FOR POURING.

4.3.6. Metal-Matrix Composite Production Methods

4.3.6.1. Melt STIRRING (Vortex Method)

Mixing methods have been amongst the most popular methods to fabricate particulate reinforced cast composites. Mechanical stirring using impellers or electromagnetic force creates a **vortexing** flow in the fully liquid or semi-solid alloy, and assists introduction and mixing of particles in the slurry. The suspension of ceramic particles in liquid metal is then solidified to obtain the cast composites. Mixing methods are routinely used in the large-scale manufacture of cast composites reinforced with SiC, Al_2O_3 and other ceramic reinforcements. Aluminium, copper, magnesium and nickel base composites containing SiC,Al_2O_3, carbon and other oxide, boride and carbide reinforcements have been produced by the high shear mixing processes.

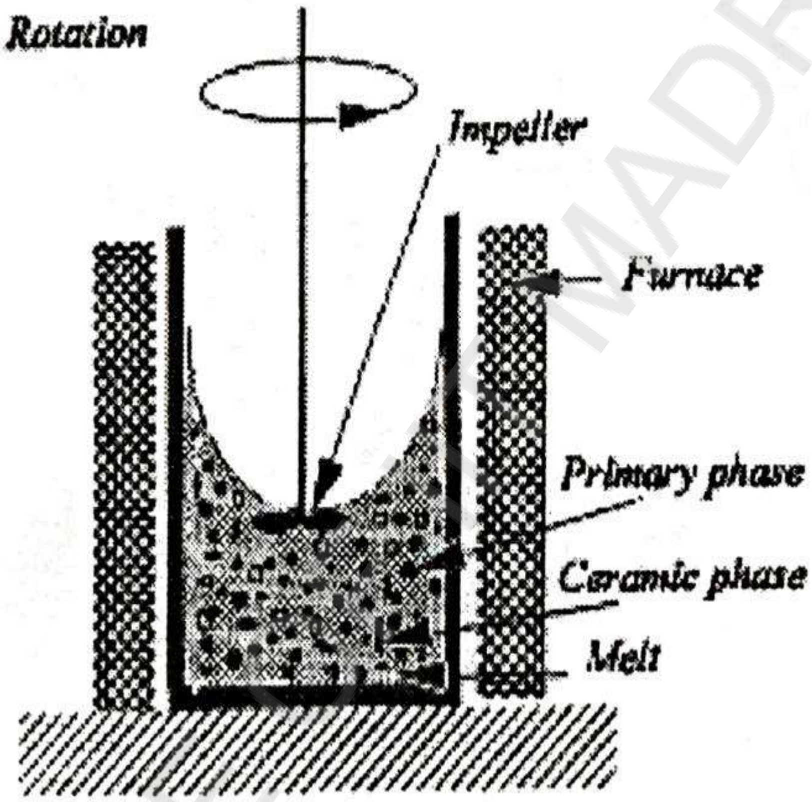


Figure:4-7 -:VORTEX METHOD

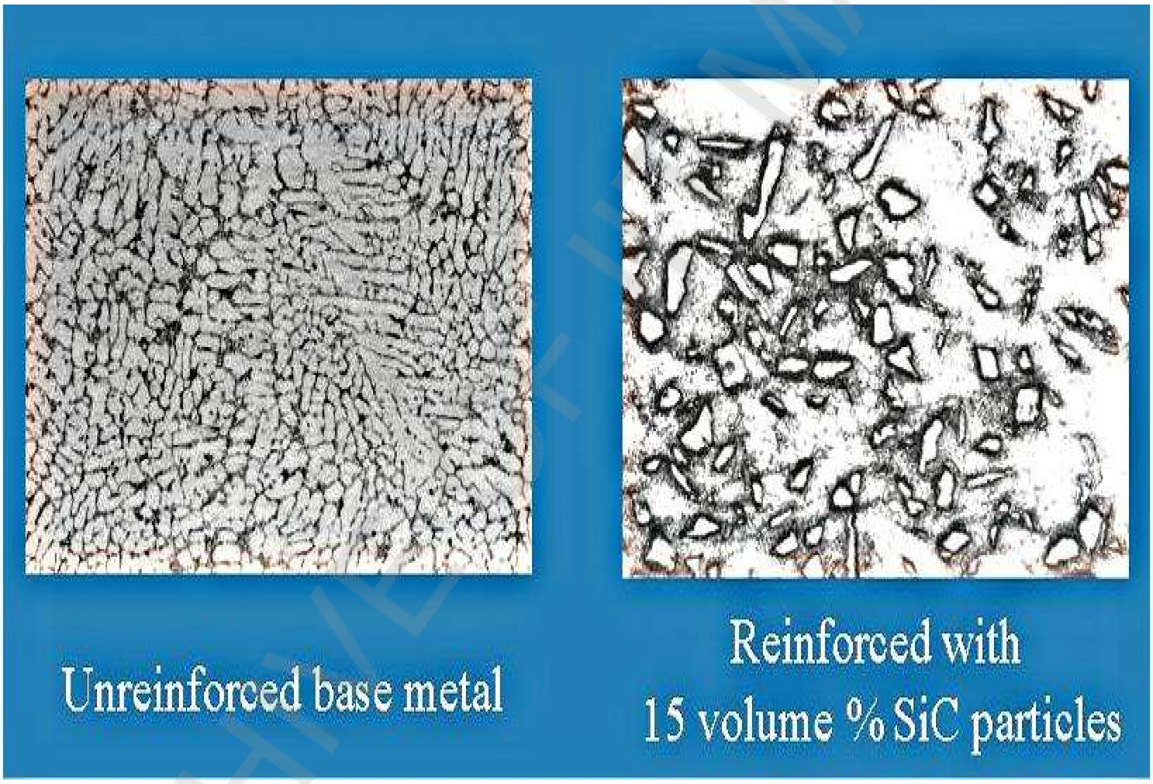


Figure:4-8: MICROSTRUCTURE

4.3.6.2. PROCESS VARIABLES

The process variables in the agitation technique are:

(i)stirring speed,
(ii)gas atmosphere
(iii)the geometry and dimension of the impeller (iv)relative to the shape and size of the mixing (v)vessel
(vi)prior reinforcement treatment
(vii)size, shape and volume fraction particles added to the melt
(viii)melt temperature

(vii)rate of particle addition
(viii)mixing and holding times and
(ix)the degassing practice.

Experiments show that in the absence of suitable surface treatment most ceramic particles are visibly rejected by the melt.
For a given volume percent of the ceramic reinforcement added to the melt, the concentration of particles recovered in the solidified casting varies with the size of the particles.
Generally, coarse particles give better recoveries compared to finer particles.
On the other hand, coarser particles show a tendency to settle.

High rates of particle addition leads to particle agglomeration.

Degassing the melt before particle addition is not preferable. Using chlorine as the degassifier impairs the wettability and may result in the rejection of the particles.

The position of the stirrer relative to the mixing vessel determines the development of flow pattern and degree of particle incorporation. For a given stirrer speed, an optimum position corresponds to maximum particle incorporation in the melt.

4.3.6.3. Squeeze infiltration

The distinctive feature of all infiltration processes is the use of a pressure differential to drive a liquid matrix into the interstices of a preform.

The application of a pressure overcomes the capillary forces between the fiber and the melt.

4.3.6.4. Interface REACTIONS

Interfaces in composites are regions of finite dimensions at the boundary between the reinforcement and the matrix where compositional and structural discontinuities can occur over distances ranging from an atomic monolayer to over five orders of magnitude.

The nature of interfaces that develop in composites during fabrication and subsequent service is critical to their response to mechanical stress and thermal and corrosive environments.

The nature and properties of the interface (thickness, continuity, chemistry, strength and adhesion) are determined by factors both intrinsic to the reinforcement and matrix materials (chemistry, crystallography and defect content) as well as extrinsic to them (test conditions like time, temperature, pressure, atmosphere).

4.3.6.5. Problems associated with casing COMPOSITES

(i).Settling effect

(ii).Reduction in viscosity

4.3.6.6. The role of Magnesium:

The presence of magnesium in aluminium alloy matrix composites not only has the beneficial effects of alloying and reduction of surface tension, but also aids in better wetting and dispersion.

In Al-SiC composites, the presence of magnesium in the matrix alloy:

(I))scavenges the oxygen from the surface of the SiC if present, and thus improving wetting and reducing agglomeration tendency.

(ii)Helps in reducing the SiO_2 layer to form $MgAl_2O_4$ spinel, by combining with Al_2O_3 if SiC_p is oxidized.

(iii)Magnesium reduces the aluminium oxide film present in the melt, as well as that formed at the dispersoid-matrix interface, as the result of reaction between the adsorbed oxygen and aluminium. This allows fresh molten metal to come into contact with the dispersoid surface, to give better wetting. The $MgAl_2O_4$ spinel formation at the interface also promotes wetting.

Otherwise, magnesium has no specific role during composite
synthesis because SiC has no direct reaction with magnesium.

NOT IN THE NOTES. PL TAKE IT DOWN

The role of Silicon:

SiC is unstable in molten aluminium at melt temperatures exceeding about 1000 K. It dissociates into $A1_4C_3$, rejecting metallic silicon in the matrix according to reaction

$$4\ Al_{(liquid)} + 3\ SiC_{(solid)} \rightarrow Al_4C_{3(solid)} + Si_{(solid)}$$

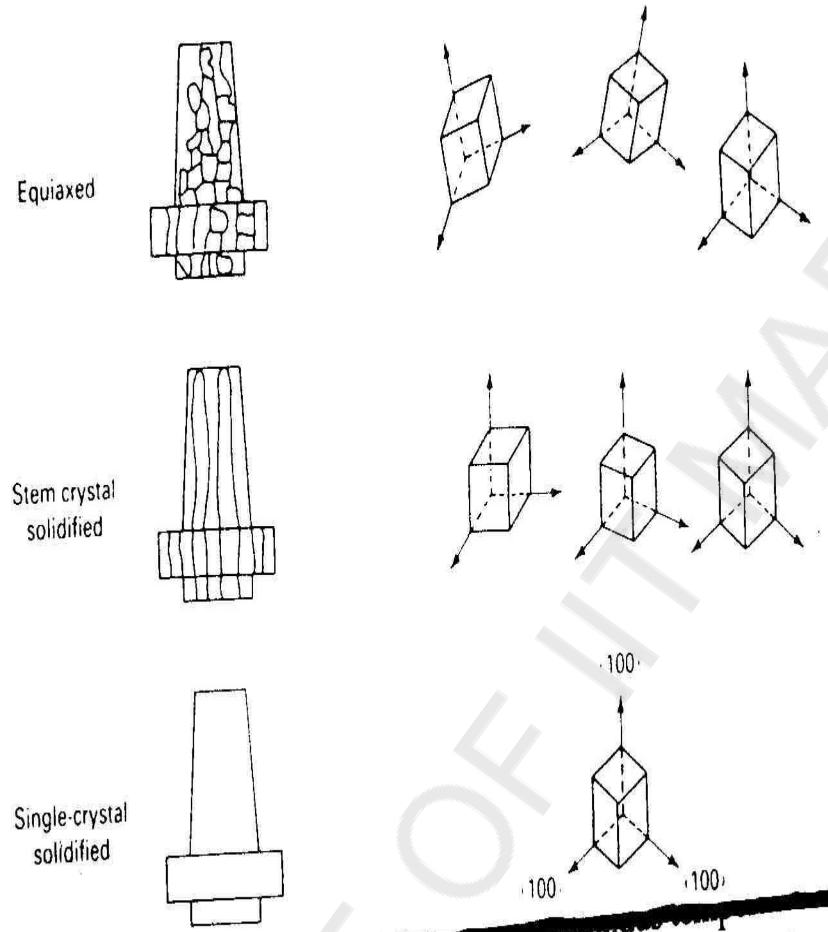
The above tendency can be reduced by having a higher silicon content in the matrix. A minimum silicon content of 7-8 wt% is required to prevent this reaction

4.3.6.7. IN-SITU COMPOSITES

Liquid-gas, liquid-solid, liquid-liquid and mixed salt reactions are used to create a fine dispersion of thermodynamically stable refractory compounds in the matrix phase. These refractory compounds serve as he reinforcing phase, and are usually monocrystalline and homogeneously distributed in the matrix phase. For example, in order to grow titanium carbide reinforced aluminium composites, titanium and carbon are added to he molten alloy, and these react to form titanium carbide particles within the matrix. Titanium is prealloyed in aluminium, whereas carbon is produced from decomposition of a carbonaceous gas, such as methane, which is bubbled through the AlTi melt at the appropriate temperature.

4.4.3. DIRECTIONALLY SOLIDIFIED CASTINGS:

In the most common directional solidification process, an investment casting mould , open at the bottom as well as the top , is placed on a water cooled copper chill and raised into the hot zone of the furnace. The mould is heated to a temperature above the liquidus temperature of the alloy to be poured. Meanwhile the alloy is melted (usually under vacuum) in an upper chamber of the furnace. When the mould is at the proper temperature and the charge is molten, the alloy is poured into the mould. After a pause of a minutes at allow the grains to nucleate and begin to grow on the chill, during the most favourably oriented grains are established, the mould is withdrawn from the hot zone to the cold zone.



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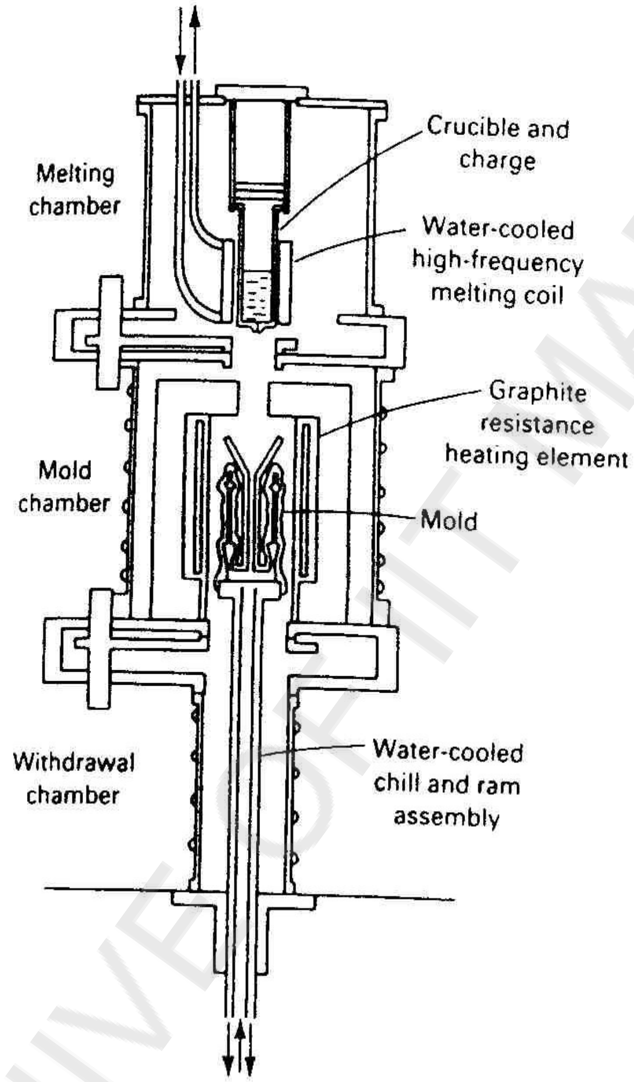

Fig. 4 Configuration of one type of directional solidification furnace. Source: Ref 7

4.5.0.MOLTEN METAL TREATMENTS:

ARGON OXYGEN DECARBURIZATION (AOD) :

Argon oxygen decarburization (AOD) is a secondary refining process. In the AOD process , oxygen,argon and nitrogen are injected into a molten metal bath through submerged, side mounted tuyeres.The AOD process is duplexed, with molten metal supplied from a separate melting furnace.This process is usually employed to produce stainless steel.

4.6.0.HEALTH AND SAFETY:

Many of the resins and Sulphur that are employed in a foundry are harmful to the human beings. Hence good ventilating system shoud be provided in a foundry. In addition, masks and other protective clothings should be supplied to workers. The melters and pouring personnel should be given protective glasses, boots and gloves.All the hot castings should be kept away in a clearly marked area. Silicosis is a common problem for the foundry personnel. A good exhaust system that sucks out the all the silica dust should be provided in the interest of the workers.Periodical medical examination of the moulding and core making personnel should be done.

THE END OF LECTURE IV