A Summer Internship Report

submitted to

National Institute of Technology, Durgapur

In Partial Fulfilment For MES753

in

MECHANICAL ENGINEERING

under the guidance of

Dr. Ved Prakash,

Scientist at

CSIR-Central Mechanical Engineering Research Institute, Durgapur

Submitted by:

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ACKNOWLEDGEMENT

This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

I would like to express my gratitude to National Institute of Technology, Durgapur for including internship program as a three-credit course which has provided an opportunity to gain practical working experience in the organization.

My sincere gratitude to Dr. Biplab Choudhury, Skill and Innovation Promotion Group, for giving me a chance to do my internship in the Advanced Casting Research Group of this organization, Central Mechanical Engineering Research Institute. I am thankful to Dr. Ved Prakash for devoting time and explaining how tasks are done in ACRG and assigning me various tasks during these 4 weeks of internship period.

I would also like to extend special thanks to Dr. Saurav Kumar, and Dr. Jagannath Bindhani from Advanced Casting Research Group for their full assistance and guidance during my internship.

DECLARATION

I, Sahil Prasad Shaw, a student of Mechanical Engineering, at National Institute of Technology, Durgapur, hereby declare that the internship report entitled "*Investigation of Sand Moulding Parameters and Pre-Casting Simulation for Cast-Iron Product*", is an original work conducted and prepared by me under the guidance of Dr. Ved Prakash, Scientist at Central Mechanical Engineering Research Institute during 18th June, 2024 to 16th July, 2024 internship period. This document is submitted in partial fulfillment of the requirements for the degree of Bachelor of Technology at National Institute of Technology, Durgapur.

I affirm that this report is a result of my personal efforts. Any contributions have been properly acknowledged and any references have been cited in accordance with academic standards.

I understand the importance of this declaration and the potential consequences of any breach of academic integrity, including but not limited to disciplinary action by my institution. I hereby certify that the information presented in this report is true and accurate to the best of my knowledge and belief.

Date:

Place:

Signature:

Abstract

This report discusses the summer technical internship program for a period of 30 days (18th June, 2024 to 16th July, 2024) in CSIR-CMERI, Durgapur, West Bengal. This report describes about the casting and the processes involved in producing components through melting and casting route. It provides an overview of the metal casting process including the different types of casting processes like sand casting, investment casting, die casting, and others. It discusses key aspects of sand casting like the design elements, properties of molding sand, and methods of sand testing. It also covers topics like cores and core materials, furnaces, inspection and testing of castings. Hardness Test, Metallography and Microstructures analysis of various metal and alloys. Simulation on SOLIDCast, a casting simulation software program which can simulate filling and solidification process of a casting. It assists the user to visualize the solidification process of a particular casting. The main goal of the report is to provide an easy-to-understand overview of the metal casting process, its applications, and related testing and quality control methods.

About the Institute

The ***Central Mechanical Engineering Research Institute*** (also known as CSIR-CMERI Durgapur or CMERI Durgapur) is a public engineering research and development institution in Durgapur, West Bengal, India. It is a constituent laboratory of the Indian Council of Scientific and Industrial Research (CSIR). Being the only national level research institute in this field, CMERI's mandate is to serve industry and develop mechanical engineering technology so that India's dependence on foreign collaboration is substantially reduced in strategic and economy sectors. Besides, the institute is facilitating innovations and inventions for establishing the claims of Indian talent in international fields where Indian products shall ultimately compete.

In the new millennium, CMERI is poised to expand its horizon of research activities so as to steer the country forward in cutting-edge and sunrise fields.

Vision:

- To be a global R&D institute having confidence of industries and visibility to society in mechanical engineering sciences and technologies.

Mission:

- To research and develop cost effective and value-added technologies in mechanical engineering and allied domains.
- Contribute significantly to national skill development initiatives for sustainable empowerment.

Mandate:

- Carrying out research and development in relevant areas of national priority as evolved by bodies concerned with the overall planning for science and technology in the country.
- Undertaking R&D sponsored by public/ private sector industries in consonance with national priorities.
- Undertaking R&D directed towards continuous improvement of indigenous technology.

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Foundry Technology

Foundry engineering deals with the processes of making castings in moulds formed in either sand or some other material. The art of foundry is ancient, dating back to the dawn of civilization. Even in prehistoric times, as far back as 5000 BC, metallic objects in the form of knives, coins, arrows, and household articles were in use, as observed from the excavations of Mohenjo-Daro and Harappa. One of man's first operations with metal was melting the ore and pouring it into suitable moulds. The casting process is said to have been practiced in early historic times by the craftsmen of Greek and Roman civilizations.

The earliest use of the metals was mostly for making knives, arrow points, coins, and tools. The moulds were made in stone or sand. Around 500 BC, started the era of religious upheavals, and metals began to be used for making statues of gods and goddesses. Bronze was still the most popular metal. It was at this time that *lost-wax process* made its impact.

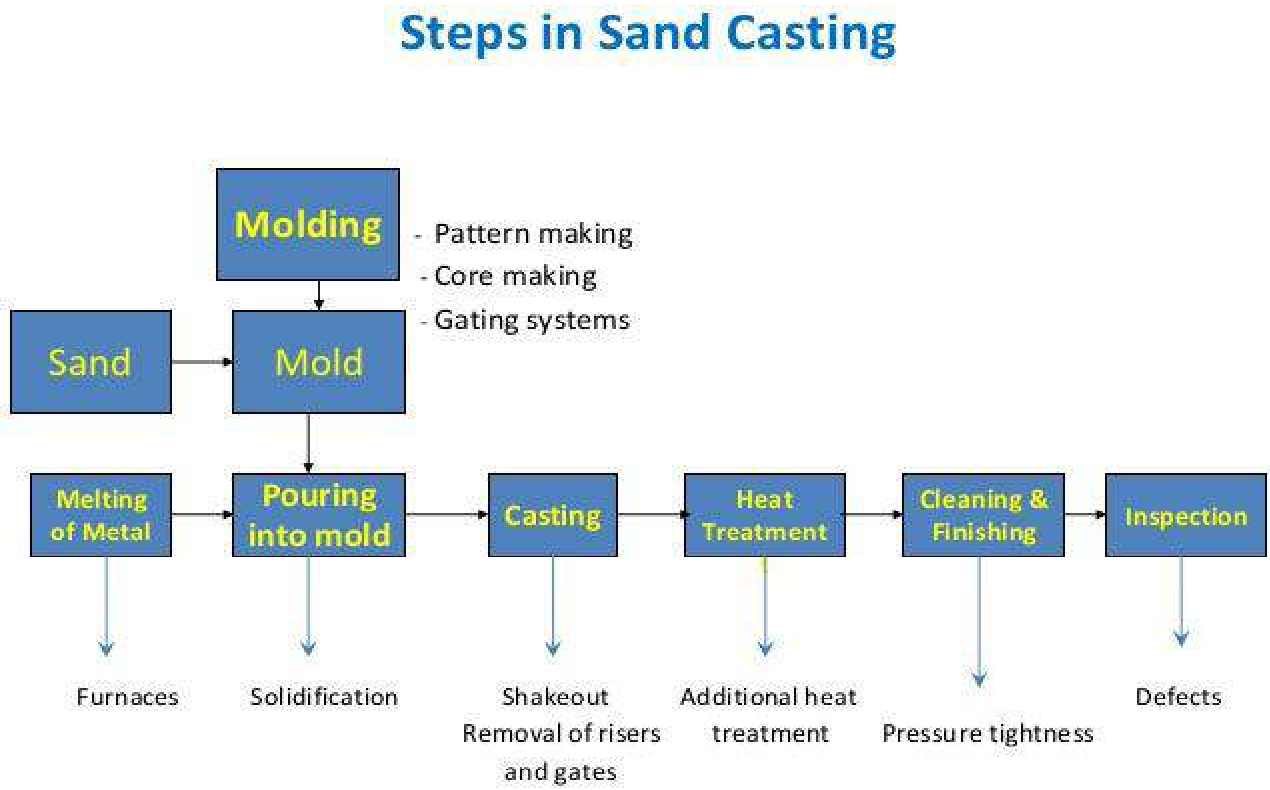
Castings have several characteristics that clearly define their role in modern equipment used for transportation, communication, power, agriculture, construction, and in industry. Cast metals are required in various shapes and sizes and in large quantities for making machines and tools, which in turn work to provide all the necessities and comforts of life.

Other metal-shaping processes, such as hot working, forging, machining, welding, and stamping, are of course, necessary to fulfil a tremendous range of needs. However, certain advantages inherent in castings—design and metallurgical advantages—and in the casting process itself, endow them with superiority over other methods.

Steps Involved

(i) Making the *Pattern* out of wood, metal or plastic.
(ii) In case of *Sand Casting*. Select, testing and preparing the necessary sand mixtures for mould and core making.
(iii) With the help of patterns, preparing the *Mould* and necessary *Cores*.
(iv) Melting the metal/alloy to be casted.
(v) Pouring the molten metal/alloy into the mould and removing the casting from the mould after the metal solidifies.
(vi) Cleaning and finishing, also called Fettling, the casting.
(vii) Testing and inspecting the casting.
(viii) Relieving the casting stresses by *Heat Treatment*.
(ix) Again, inspecting the casting.

The above-mentioned different phases of Sand Casting will be discussed in detail in the remaining part of the report.



Advantages

(i) Castings may weigh around 50 tonnes or be as small as a wire of 0.5-mm diameter.

(ii) The most simple or complex curved surfaces, inside or outside, and complicated shapes, which would otherwise be very difficult or impossible to machine, forge, or fabricate, can usually be cast.

(iii) Although mechanical working of wrought metals causes breaking up of coarse grains and promotes fine grain size, many castings have grain sizes not very different from those of the former.

(iv) The density of cast alloys is usually identical to that of wrought alloys of the same chemical composition and heat treatment, when both are fully sound.

(v) Castings offer the most complete range of mechanical and physical properties available in metals and, as such, fulfil a large majority of service requirements. In fact, some alloys can only be cast to shape and cannot be worked mechanically.

(vi) Castings can be made to fairly close dimensional tolerances by choosing the proper type of Moulding and casting process. Tolerances as close as ± 0.1 mm can be achieved depending on the cast metal, the casting process, and the shape and size of the casting. The surface finish can also be controlled and may vary from 5 microns to 50 microns.

(vii) As the metal can be placed exactly where it is required, large saving in weight is achieved. Such weight saving leads to increased efficiency in transportation and economy in transport charges.

(viii) Shapes difficult and uneconomic to obtain otherwise may be achieved through casting processes.

(ix) Castings can be designed for equal distribution of loads and for minimum stress concentration in order to achieve more strength and increased service life.

Technology of Patternmaking

A Pattern may be defined as a model or a form around which sand is packed to give rise to a cavity known as mold cavity in which when the molten metal is poured, the result is the CAST OBJECT. To be suitable for use, the pattern material should be:

(i) easily worked, shaped, and joined;
(ii) light in weight for facility in handling and working;
(iii) strong, hard, and durable (i.e., of high strength-to-weight ratio);
(iv) resistant to wear and abrasion, to corrosion, and to chemical action;
(v) dimensionally stable and unaffected by variations in temperature and humidity;
(vi) available at low cost;
(vii) such that it can be repaired or even re-used; and
(viii) able to take a good surface finish.

PATTERN MATERIALS

- **Wood:** Wood is the most commonly used material for patterns as it satisfies many of the aforementioned requirements. It can be easily shaped or worked and joined to form any complex shape, is light in weight, is easily available, and costs less than other materials. The common drawbacks, however, are its susceptibility to moisture, causing it to swell or shrink, its poor strength, and low resistance to wear.
- **Metals and Alloys:** Metallic patterns are used where repetitive production of castings is required in large quantities. The metals commonly used are aluminium alloys, cast iron, steel and copper-base alloys such as brass or bronze. Metallic patterns being employed for mass production are generally required in a large number. They are therefore prepared by casting from a master pattern, which may be made in wood, plastic, plaster, or metal. A comparative evaluation of these metals is given in table below:

Factors	GREY CAST	IRON STEEL	ALUMINIUM	BRASS
Availability	Good	Good	Good	Good
Castability	Good	Difficult	Less difficult	Good
Machinability	Good	Good	Very Good	Very Good
Surface finish	Good	Good	Very Good	Very Good
Lending to modification	Good	Good	Good	Very Good
Weight	Very heavy	Very heavy	Very light	Heavy
Brittleness	High	Low	Low	Low
Tendency to oxidation	Yes	Yes	No	No
Requiring machining	Yes	Less	Not much	Not much

- **Plasters:** Gypsum plaster (Plaster of Paris) when mixed with the correct quantity of water sets in a given time and forms a hard mass having high compressive strength, e.g., up to 300 kg/cm^2. Plasters, ordinarily available expand on solidification. By choosing a plaster of proper expansion rate, it is possible to completely offset the shrinkage of the casting; then no contraction need be separately provided for on the pattern.
- **Plastics and Rubbers:** Both thermosetting and thermoplastic materials are used for pattern work. The former is used for making long-lasting and durable patterns, and the latter for short runs or piece work. In the thermosetting variety, epoxy and polyester resins have found increasing use. In the thermoplastic type, polystyrene has become very popular. Silicone rubbers have been used for making dies in special cases.
- **Waxes:** Wax patterns are excellent for the investment casting process. The materials generally used are blends of several types of waxes and other additives, which act as polymerizing agents and stabilizers. The waxes commonly chosen are paraffin wax, carnauba wax, shellac wax, bees wax, cerasin wax, and microcrystalline wax.

ALLOWANCES AND OTHER TECHNOLOGICAL CONSIDERATIONS

Pattern allowances are a vital feature in pattern design as it affects the dimensional characteristics of the casting. Thus, when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specifications can be produced. The selection of correct allowances greatly helps to reduce machining costs and avoid rejections.

- **Contraction Allowance:** All metals used for casting contract after solidification in the mould, and the pattern must therefore be made larger than the casting by an amount known as patternmaker's contraction. Generally, the patternmaker is equipped with the patternmaker's contraction rule, which is used to compensate for the shrinkage value. To compensate for shrinkage, the graduations are oversized by a proportionate amount, e.g., on a 1-mm or 1% scale, each 100 cm is longer by 1 cm.

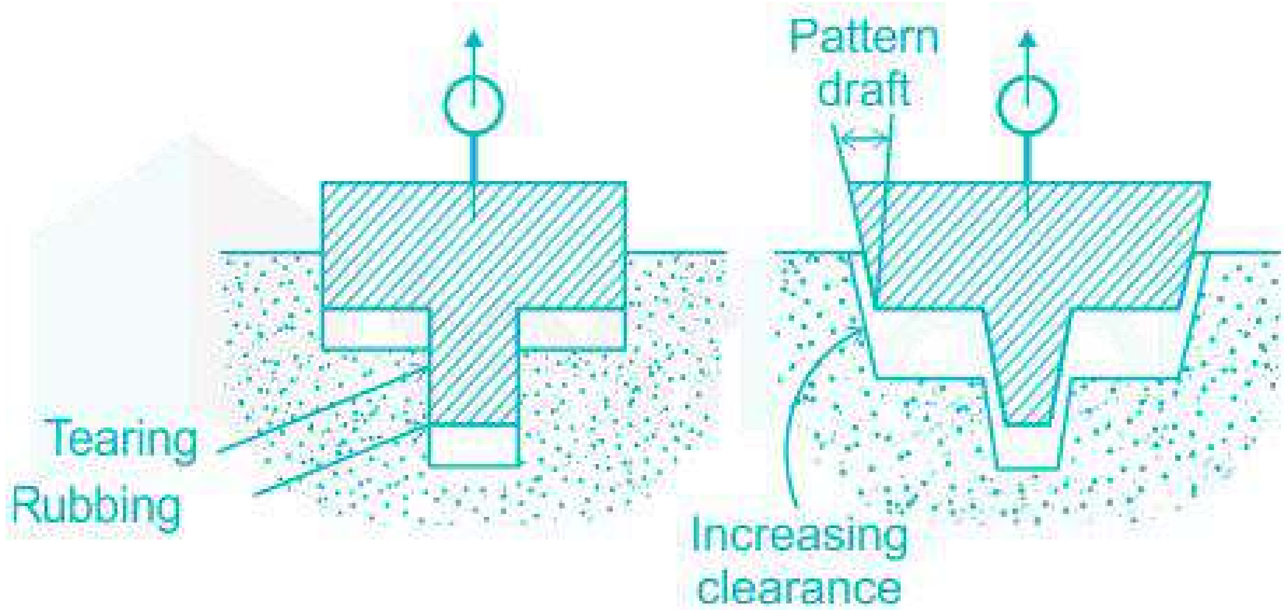
CAST METAL	DIMENSION (MM)	CONTRACTION (MM/M)	REMARKS
Cast iron	up to 600 600–1200 over 1200	10.5 8.5 7.0	—
Cast Steel	up to 600 600–1800 over 1800	21 16 13	—
Aluminium	up to 1200 1200–1800 over 1800	13 12 10.5	1.5 mm less for cored construction
Brass	-	16	-
Bronze	-	10.5–21	depends on composition
Malleable Iron	-	11.8 10.5 9.2 7.9 6.6 4.0 2.6	6 -mm section thickness 9 -mm section thickness 12-mm section thickness 15-mm section thickness 18-mm section thickness 22-mm section thickness 25-mm section thickness

Figure: *Rates of contraction for important cast metals*

- **Machining Allowance:** Machining or finish allowance is the extra material added to certain parts of the casting to enable their finishing or machining to the required size. The amount of machining allowance to be provided for is affected by:

(i) the method of moulding and casting used, viz., hand moulding or machine moulding, sand casting or metal-mould casting;
(ii) size and shape of the casting;
(iii) the casting orientation: greater allowance is required on the surface at the top in the mould;
(iv) the characteristics of the metal; and
(v) the functional requirements of the casting and the degree of accuracy and finish required.

- **Draft or Taper Allowance:** By draft we mean the taper provided by the patternmaker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the Mould and without excessive rapping by the moulder. A draft is thus given to provide light clearance for the pattern as it is lifted up.



- **Rapping and Shake Allowance:** When the pattern is rapped for easy withdrawal, the mould cavity gets slightly larger in size. This also causes the casting size to increase. To compensate for this growth, the pattern should initially be made slightly smaller than the required size.
- **Distortion Allowance:** Sometimes castings get distorted during cooling due to their typical shape. For example, if the casting has the form of the

letter U, it will tend to contract at the closed end causing the vertical legs to look slightly inclined and out of parallel. This can be prevented by making the legs of the U-pattern converge slightly (inwards) so that the casting after distortion will have its sides parallel as shown in the figure below. This allowance is considered only for castings that tend to get distorted and have an irregular shape.

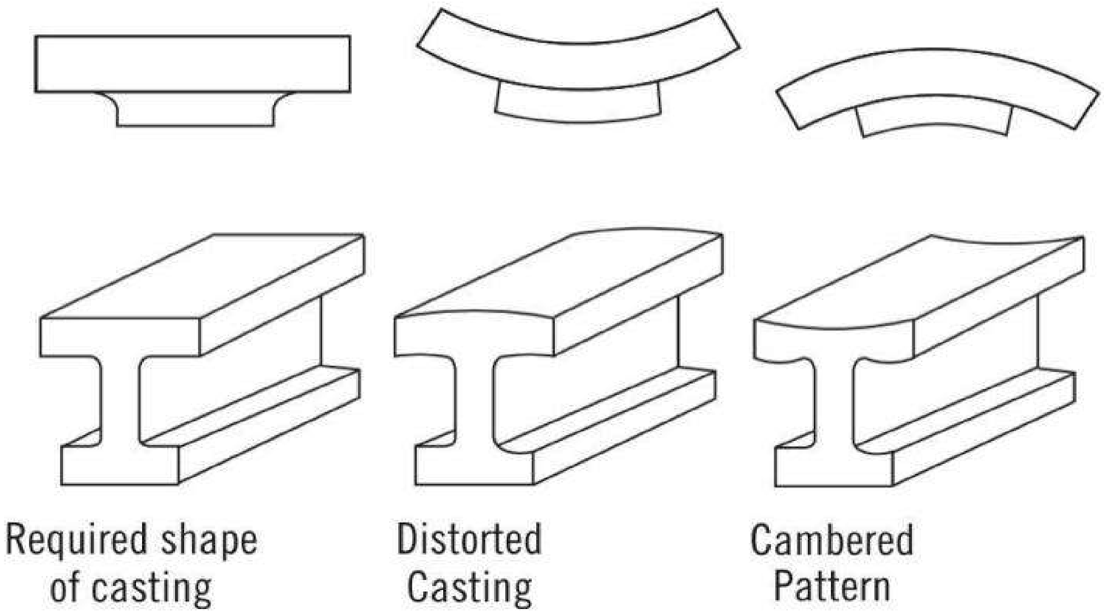


Figure: Distortion in casting

- **Core Prints:** Castings are often required to have holes, recesses, etc., of various sizes and shapes. These impressions can be obtained by using cores. Cores are separately made by pressing sand in boxes known as core boxes. For supporting the cores in the mould cavity, an impression in the form of a recess is made in the mould with the help of a projection suitably placed on the pattern. This projection is known as a core print. Thus, the core print is an added projection on the pattern and it forms a seat in the mould in which the sand core rests during the pouring of the mould. The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation.

Technology of Moulding and Core Making

MOULDING SANDS

Sand is the principal moulding material in the foundry shop where it is used for all types of castings, irrespective of whether the cast metal is ferrous or non-ferrous, iron or steel. This is because it possesses the properties vital for foundry purposes. The most important characteristic of sand is its refractory nature due to which it can easily withstand the high temperature of molten metal and does not get fused. Sand is the principal moulding material in the foundry shop where it is used for all types of castings, irrespective of whether the cast metal is ferrous or non-ferrous, iron or steel. This is because it possesses the properties vital for foundry purposes. The most important characteristic of sand is its refractory nature due to which it can easily withstand the high temperature of molten metal and does not get fused.

Principal Ingredients of Moulding Sands: The principal ingredients of moulding sands are (1) silica sand grains, (2) clay (bond), and (3) moisture.

(i) ***Silica Sand Grains:*** Silica sand grains are of paramount importance in moulding sand because they impart refractoriness, chemical resistivity, and permeability to the sand. They are specified according to their average size and shape. The finer the grains, the more intimate will be the contact and lower the permeability.

(ii) ***Clay:*** Clay imparts the necessary bonding strength to the moulding sand so that after ramming, the mould does not lose its shape. However, as the quantity of the clay is increased, the permeability of the mould is reduced. Clay is defined by the American Foundrymen's Society (AFS), as those particles of sand (under 20 microns in diameter) that fail to settle at a rate of 25 mm per minute, when suspended in water. Clay consists of two ingredients: fine silt and true clay. Fine silt is a sort of foreign matter of mineral deposit and has no bonding power. True clay supplies the necessary bond.

(iii) ***Moisture:*** When sand is rammed in a mould, the sand grains are forced together. The clay coating on each grain acts in such a way that it not only locks the grains in position but also makes them retain that position. If the water added is the exact quantity required to form the film, the bonding action is best. If the water is in excess, strength is reduced and the mould gets weakened. Thus, moisture content is one of the most important parameters affecting mould and core characteristics and consequently, the quality of the sand produced.

MOULDING PROCESSES

The moulding processes in common use may be classified according to different norms. When the common denominator is the method of preparation, the processes conducted with hand tools by the moulder are referred as hand moulding and those requiring the help of a machine are grouped under machine moulding. Hand moulding may be done either on the foundry floor or on a working bench. Accordingly, the process is termed floor moulding or bench moulding.

- **Floor Moulding:** Floor moulds may be either the open-sand type or the one-box type. In open sand moulding, the mould cavity is prepared in the floor and the molten metal is poured directly in the cavity; no passage is provided in the sand for the molten metal to reach the mould cavity. Such moulds are used for castings that do not require good surface finish on the upper face and are unsophisticated, such as floor plates, weights, mould boxes, manhole covers, and drain covers. To overcome the drawback, one-box moulding is used in which one part of the flask is placed atop the floor mould. This flask acts as a cope and carries the sprue and risers. For easy escape of gases from beneath the casting, especially in large moulds, a bed of coke ash should be made and the sides lined with bricks. Vent pipes can also be embedded into the floor beneath the coke bed.
- **Bench Moulding:** Bench moulding is favoured for small-sized castings, which are light in weight and can be easily handled. The various techniques applied for preparing the mould in bench moulding are now discussed.
  i) **Two-box Moulding:** The two-box moulding method makes use of a pair of moulding boxes, the upper part being called cope, and the lower one, drag. The two parts are fitted with a suitable clamping and a locating arrangement. The clamping is required to prevent the

cope from lifting due to the pressure of the molten metal when the latter is being poured.

ii) **Three-box Moulding:** In case the pattern is of the flanged type, and flanges are to be moulded horizontally, it is very difficult to prepare the mould in two boxes. Then, the mould can be easily formed by the use of three boxes, the pattern being made in parts as required. The procedure adopted is illustrated in figure given below for moulding a flanged type of rope pulley. The additional box in the middle is called cheek. During pouring, all the three boxes are clamped together.

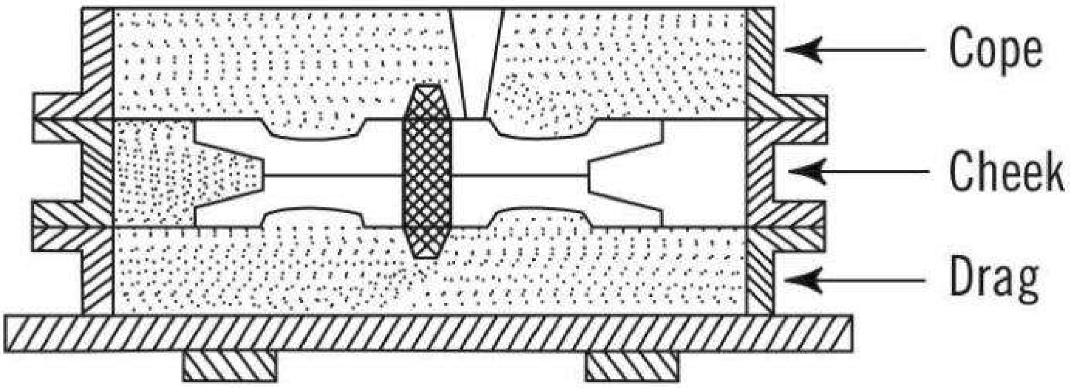


Figure: Three-box Mould

Types of Sand Moulding

Sand-moulding methods may also be classified according to the type of sand used for preparing the mould and the moisture content of the sample.

(i) **Green Sand Moulding:** When the mould is filled with molten metal while the sand is still moist, the method used is called green sand moulding. Due to the presence of moisture, the mould lacks permeability and strength and this may result in defects such as blowholes and pinholes in the casting. For all mechanized moulding, green sand moulding is largely employed due to its ease of adaptability and economical operation. The defects can also be minimized by a proper control of process parameters, particularly by keeping moisture initially low.

(ii) **Dry Sand Moulding:** The dry sand moulding method is used when the mould requires greater strength to withstand the weight of a large volume of metal or if a hard surface is required to avoid surface erosion. The mould is prepared with a specially processed sand and is then dried in an oven. The sand mixture for moulding may consist of moulding sand, burnt facing sand, clay, cinders (boiler ash), and moisture. The layer of facing sand surrounding the mould cavity is made up of fi ne moulding sand, river sand (new sand) of a fine-grained variety, and a bond such as pitch or flour and water. The water content in the dry sand mix is kept high (6–8%) so that green properties are satisfactory. After the mould is ready, its surface is sprayed with molasses water and the mould is dried in an oven maintained at 200–300°C, until all the moisture is eliminated. Alternatively, heated air may be circulated through or passed over the mould.

(iii) **Skin-Dried Moulding:** This is a process that dries the moisture from the surface layer of the rammed sand to a depth of about 25 mm or more by using gas torches or heaters. It has the advantages of both green sand and dry sand moulding to a certain extent. Since the time required for drying is less than in the case of dry sand, the method is also less expensive.

STEPS INVOLVED IN MOLD MAKING

1. Select the molding box which can accommodate mold cavity, risers and the gating system.
2. Mold cavity should have sufficient wall thickness as it will have to hold the molten metal.
3. Undersize flask may injure the molder and the produce defective casting.
4. Place the drag pattern with parting surface down on the bottom board.
5. Sprinkle the facing sand carefully all around the pattern so that the pattern does not stick with molding sand.
6. Fill the drag with loose molding sand.
7. Ram the sand uniformly in the molding box around the pattern.
8. Strike off the excess sand to bring it at the same level of the flask height. This completes the drag.
9. Sprinkle the parting sand over the top of the drag (and roll over the dowel pins).
10. Place the cope pattern on the drag pattern.
11. Place cope over the rammed drag.
12. Sprinkle parting sand all around the cope pattern.

13. Erect sprue and riser pins to form suitable sized cavities for pouring molten metal, etc.
14. Set the gaggers in the cope. Gaggers should not be too close to the mold cavity otherwise they may chill the casting.
15. Fill the cope with the sand and ram.
16. Strike off the excess sand from the top of the cope.
17. Remove the sprue and the riser pins.
18. Vent the cope with a vent wire.
19. Sprinkle parting sand over the top of the cope surface.
20. Roll over the cope on the bottom board.
21. Rap and remove both the cope and drag patterns.
22. Repair the mold, if necessary.
23. Cut the gate connecting the sprue basin with the mold cavity.
24. Apply mold coating with a swab.
25. Bake the mold in case of a dry sand mold.
26. Set the cores in the mold, if required.
27. Close the mold by inverting cope over drag.
28. Clamp cope with drag and the mold is ready for pouring.

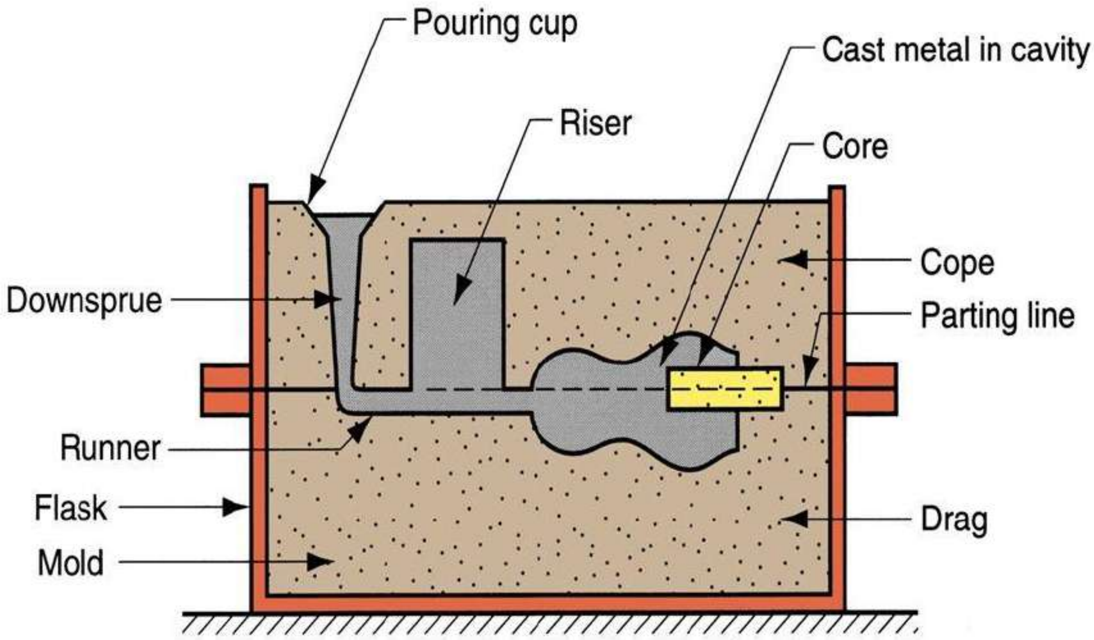


Figure: *Mould for a Sand Casting.*

CORE SANDS AND COREMAKING

A core may be defined as that portion of the mould which forms the hollow interior of the casting or a hole through the casting. Generally speaking, the word core means the mass of dry sand that is prepared separately by being baked in an oven and then placed in the mould. The *characteristics* of Cores and Core Sands are as follows:

(i) Cores must have sufficient hardness as well as strength in both dry and green states. Without these properties, the core will not be able to support its own weight and withstand the force of molten metal.
(ii) Cores must be permeable to allow the core gases to escape easily.
(iii) Cores should be able to withstand the high temperature of molten metal.
(iv) The core sand should produce a minimum amount of gas when in contact with molten metal so that very high permeability is not needed and greater strength is imparted to the core.
(v) Cores when prepared should be collapsible, i.e., they should disintegrate and collapse after the metal solidifies. If the core does not collapse, difficulty may be experienced in removing it from the casting.

STEPS INVOLVED IN COREMAKING

(i) Core box is usually placed on work-bench; it is filled with already mixed and prepared core sand, is rammed by hand and the extra sand is removed from the core box.
(ii) Weak cores may be reinforced with steel wires to strengthen them.
(iii) Core box is inverted over the core plate and this transfers the core from the core box to core plate which is the core, is then baked in the oven.
(iv) Larger cores can also be made manually but on the floor. It needs more than one man to work and the cranes may also be used, if necessary.

SAND REPORT

Sieve Shaker Analysis

Sample A: Silica Sand Date:03/07/2024

US SIEVE NO. IN MESH	MESH NO. IN MICRON	WEIGHT OF EMPTY SIEVE	SAMPLE RETAINED ON SIEVE		MULTIPLIER	PRODUCT	RESULT
			GRAM	%			AFS GFN NO.
12	1700	296.96	0	0.00	6	0.00	
20	850	266.26	0.14	0.15	12	1.78	
30	600	245.79	2.02	2.14	20	42.81	
40	425	226.47	14.03	14.87	30	445.96	
50	300	232.91	13.61	14.42	40	576.82	
70	212	223.36	35.77	37.90	50	1895.00	52.23
100	150	232.82	23.15	24.53	70	1717.00	
140	106	210.85	4.28	4.53	10	45.35	
200	75	207.21	1.38	1.46	140	204.70	
270	53	206.66	0	0.00	200	0.00	
PAN	PAN	234.72	0	0.00	270	0.00	
TOTAL			94.38	100.00		4929.41	

Sample B: River Sand

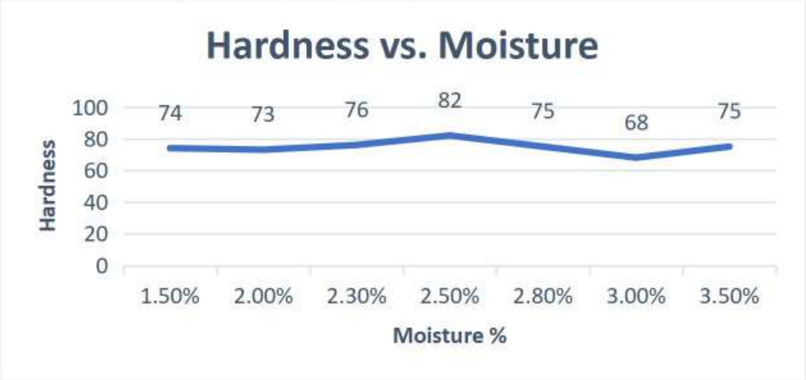
US SIEVE NO. IN MESH	MESH NO. IN MICRON	WEIGHT OF EMPTY SIEVE	SAMPLE RETAINED ON SIEVE		MULTIPLIER	PRODUCT	RESULT
			GRAM	%			AFS GFN NO.
12	1700	296.05	3.75	3.58	6	21.51	
20	850	265.18	17.72	16.94	12	203.27	
30	600	244.09	16.79	16.05	20	321.00	
40	425	224.85	28.64	27.38	30	821.34	
50	300	230.65	16.01	15.30	40	612.18	
70	212	221.67	15.49	14.81	50	740.37	31.18
100	150	230.86	3.1	2.96	70	207.44	
140	106	209.16	1.12	1.07	10	10.71	
200	75	206.71	0.55	0.53	140	73.61	
270	53	205.24	1.31	1.25	200	250.45	
PAN	PAN	234.04	0.13	0.12	270	33.55	
TOTAL			104.61	100		3261.87	

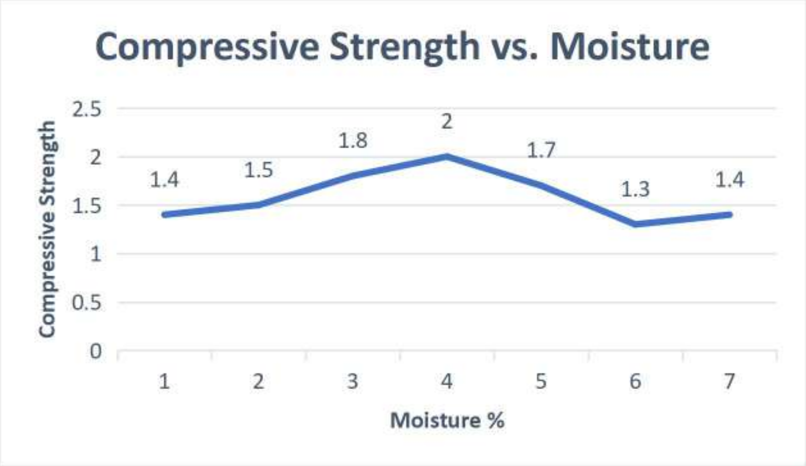
Properties Analysis

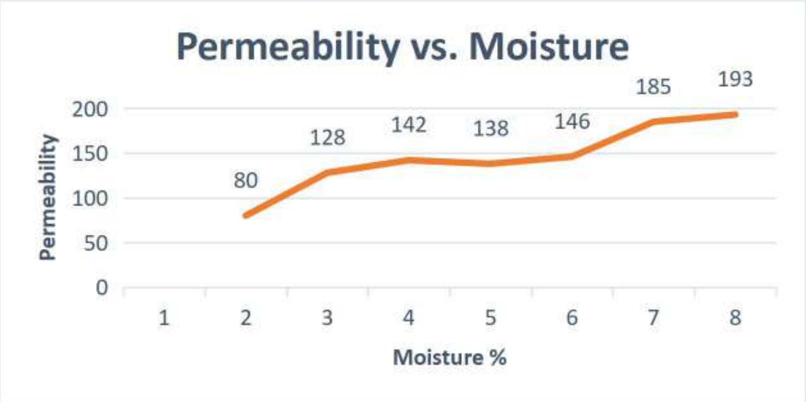
Date:03/07/2024

Total Mixture: 200 gram (without coal dust)

Sl. No.	Silica Sand (in gram)	Bentonite (8%) (in gram)	Moisture (in gram)	Hardness	Compressive Strength (in kg/cm^2)	Permeability
1.	181.0	16	3.0 (1.5%)	74	1.4	80
2.	180.0	16	4.0 (2.0%)	73	1.5	128
3.	179.4	16	4.6 (2.3%)	76	1.8	142
4.	179.0	16	5.0 (2.5%)	82	2.0	138
5.	178.4	16	5.6 (2.8%)	75	1.7	146
6.	178.0	16	6.0 (3.0%)	68	1.3	185
7.	177.0	16	7.0 (3.5%)	75	1.4	193

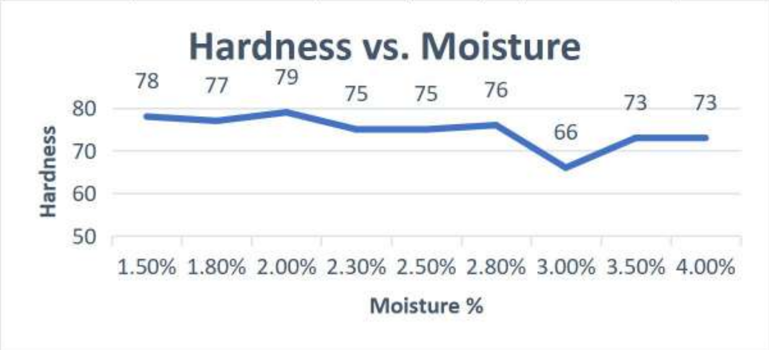


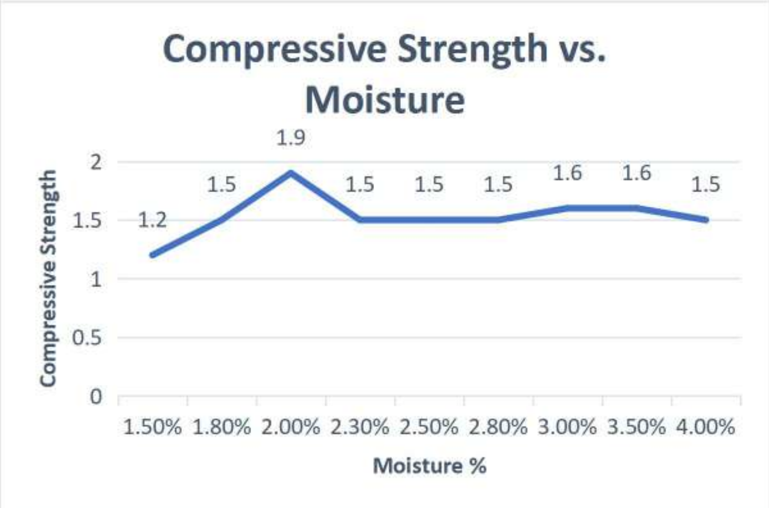


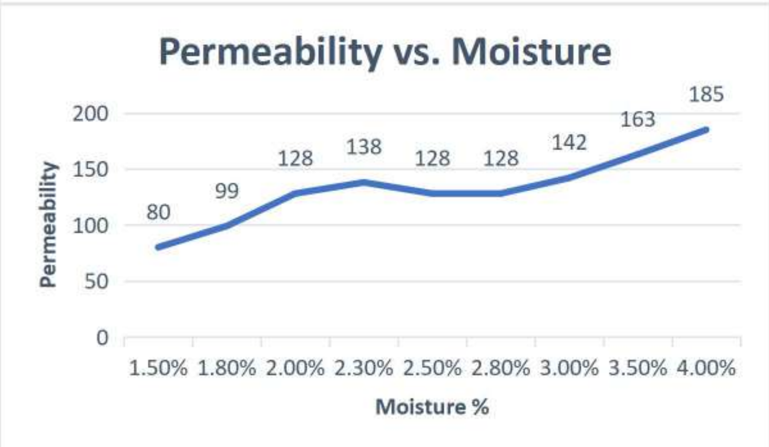


Total Mixture: 200 gram (with coal dust)

Sl. No.	Silica Sand (in gram)	Bentonite (8%) (in gram)	Coal Dust (2%) (in gram)	Moisture (in gram)	Hardness	Compressive Strength (in kg/cm^2)	Permeability
1.	177.0	16	4	3.0 (1.5%)	78	1.2	80
2.	176.4	16	4	3.6 (1.8%)	77	1.5	99
3.	176.0	16	4	4.0 (2.0%)	79	1.9	128
4.	175.4	16	4	4.6 (2.3%)	75	1.5	138
5.	175.0	16	4	5.0 (2.5%)	75	1.5	128
6.	174.4	16	4	5.6 (2.8%)	76	1.5	128
7.	174.0	16	4	6.0 (3.0%)	66	1.6	142
8.	173.0	16	4	7.0 (3.5%)	73	1.6	163
9.	172.0	16	4	8.0 (4.0%)	73	1.5	185







Principles of Gating

GATING SYSTEM

The term *gating system* refers to all passageways through which the molten metal passes to enter the mold cavity. The gating system is composed of the following:

a) Pouring cups and basin,
b) Sprues,
c) Runner,
d) Gates, and
e) Risers.

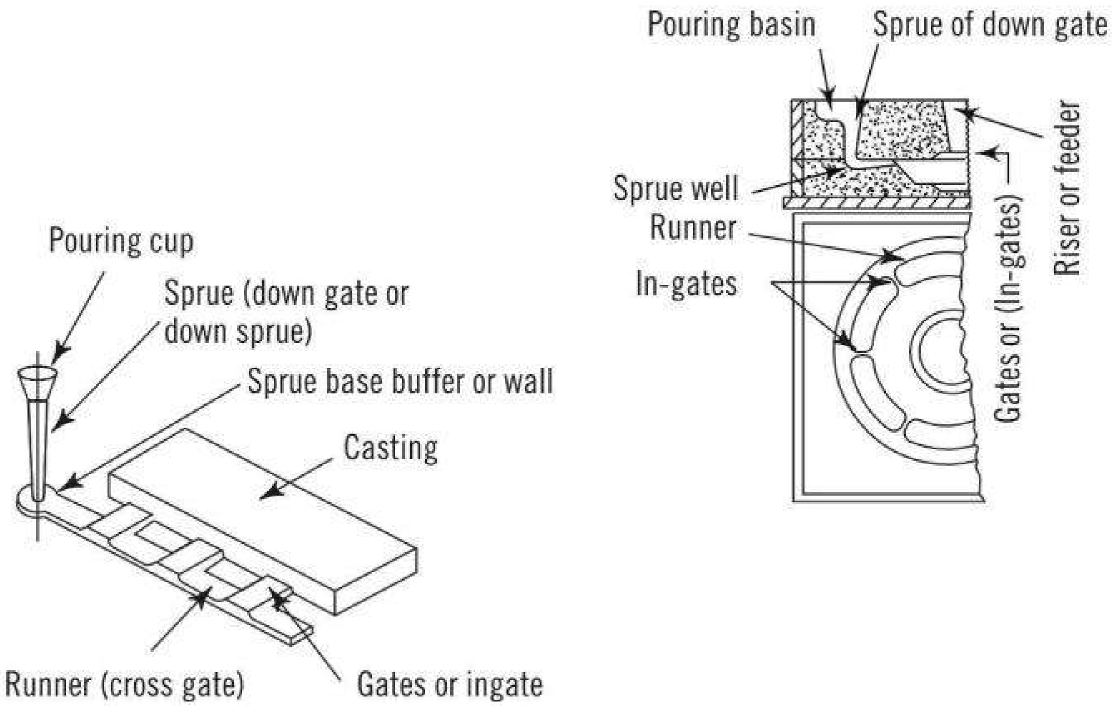


Figure: *Parts of the Gating System.*

The chief requisites of a gating system are the following:

(i) Metal should be able to flow through the gating system with a minimum of turbulence and aspiration of mould gases so as to prevent sand erosion and gas pick-up. Turbulence is the most important single factor affecting the design of the gating. Excessive turbulence results in the aspiration of air and the formation of dross.

(ii) The metal should be so introduced in the mould cavity that the temperature gradients established on the mould surfaces and within the metal facilitate directional solidification towards the riser.
(iii) The mould cavity should be completely filled with molten metal in the shortest possible time; the gating system should therefore be so designed that the rate of entry of metal into the mould cavity is well regulated.
(iv) The casting should be produced with a minimum of excess metal in gates and risers.
(v) Loose sand, oxides, and slag should be prevented from entering the mould cavity by providing a proper skimming action on the metal as it flows through the gating system.
(vi) Erosion of the mould walls should be avoided.

FUNCTIONS OF THE GATING SYSTEM

A Gating system should,

(i) Fill the mold cavity completely before freezing;
(ii) Introduce the liquid metal into the mold cavity with low velocity and little turbulence, so that mold erosion, metal oxidation and gas pick-up is prevented;
(iii) Help to promote the temperature gradients favourable for proper directional solidifications;
(iv) Incorporate traps for the separation of non-metallic inclusions which are either introduced with the molten metal or are dislodged in the gating system;
(v) Regulate the rate at which liquid metal enters into the mold;
(vi) Be practicable and economical to make and;
(vii) Consume least metal.

POURING CUPS AND BASINS: Molten metal is carried in a ladle from the furnace to some type of pouring basin on or in the top part of the mould. The main purpose of the pouring basin is to establish a proper flow system as rapidly as possible. For metals such as aluminium and magnesium, which react quickly when exposed to air, it is desirable to have a separate pouring basin made of dry sand core or cast iron on top of the mould. Sometimes, a funnel-shaped opening is made at the top of the sprue in the cope itself, which serves as a pouring basin.

Some typical designs of pouring basins are given in the figure below. The basin should be substantially large and should be placed near enough to the edge of the flask for the pourer to fill the mould quickly, keep it full during the entire pouring operation, and position the ladle lip at all times close to the pouring basin. If the pouring basin is designed to regulate the rate of metal entry, the metal flows smoothly into the sprue and turbulence is avoided. Good results are obtained by using a dam or a strainer core or both in the pouring basin. A sprue plug is also convenient for controlling the flow of metal into the mould cavity.

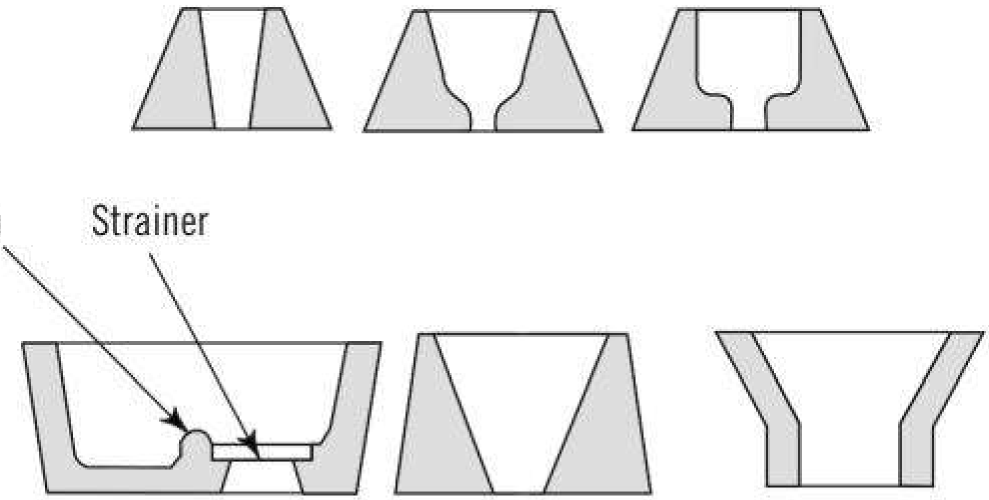


Figure: *Typical shapes of Pouring Basins.*

SPRUE: A sprue feeds metal to the runner which in turn reaches the casting through the gates. It is tapered with its bigger end at the top to receive the liquid metal. Sprues upto 20 mm in diameter are round in section whereas larger sprues are often rectangular. The sprue size should satisfy certain conditions, for instance, the sprue must be small enough for:

(i) the pourer to keep it full during the entire pouring operation, and

(ii) the metal to enter the mould cavity at a velocity that avoids spluttering and turbulence.

At the same time, the sprue must be large enough for:

(i) the mould cavity to fill completely without laps, seams, or misruns, and

(ii) a metal head to build up quickly enough to prevent mould gases from being aspirated into the metal.

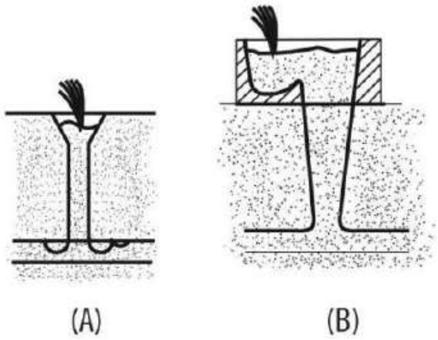


Figure: *Effect of sprue design on metal turbulence (A) Severe aspiration (B) Negligible aspiration and turbulence*

RUNNER: In large castings, molten metal is usually carried from the sprue base to several gates around the cavity through a passageway called the runner (Fig. 5.5). When a mould has more than one cavity, the common gate supplying metal to a number of cavities is also called a runner, and the branches from the runner to the respective mould cavities are referred as in-gates.

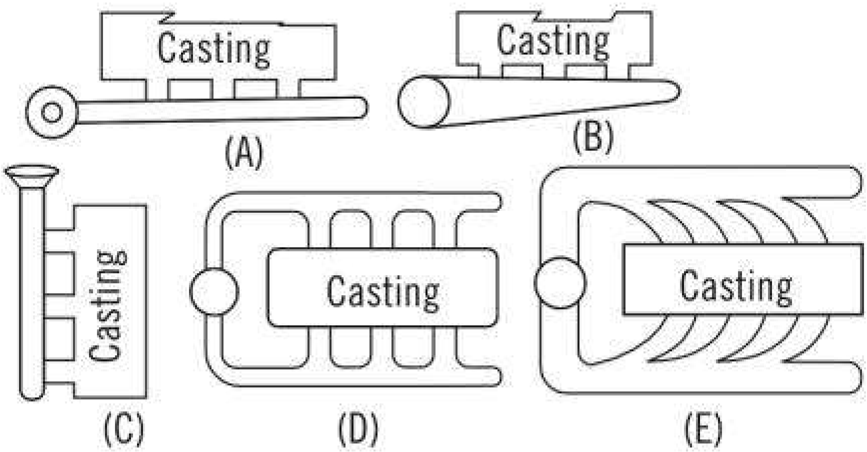


Figure: *Types of runners (A) Straight runner (B) Tapered runner (C) Step gate (may also act as feeder) (D) Uniform size runner (causes uneven metal distribution) (E) Runner for even distribution of metal (reduction in size of runner after each gate)*

GATES: The gate is the passage that finally leads molten metal from the runner into the mould cavity. The location and size of the gates are so arranged that the mould can be filled in quickly with a minimum amount of cutting of the mould surfaces by the flowing metal. The gates should be so placed that cracks do not develop when the metal cools. The gate connections should be located where they can be readily removed without damaging the castings.

According to their position in the mould cavity, gates may be broadly classified as (1) top gates; (2) parting gates; and (3) bottom gates.

(1)**Top Gates:** Molten metal is poured down the head or riser of the casting. Since the metal falls directly into the mould cavity, the mould should be hard and strong enough to resist erosion by the dropping metal. The advantage of top gating is that since all the metal enters the casting at the top, the hottest metal remains in this region. As such, proper temperature gradients are formed, and directional solidification towards the riser, located at the top of the casting, can be achieved. The gates themselves may be made to serve as risers.

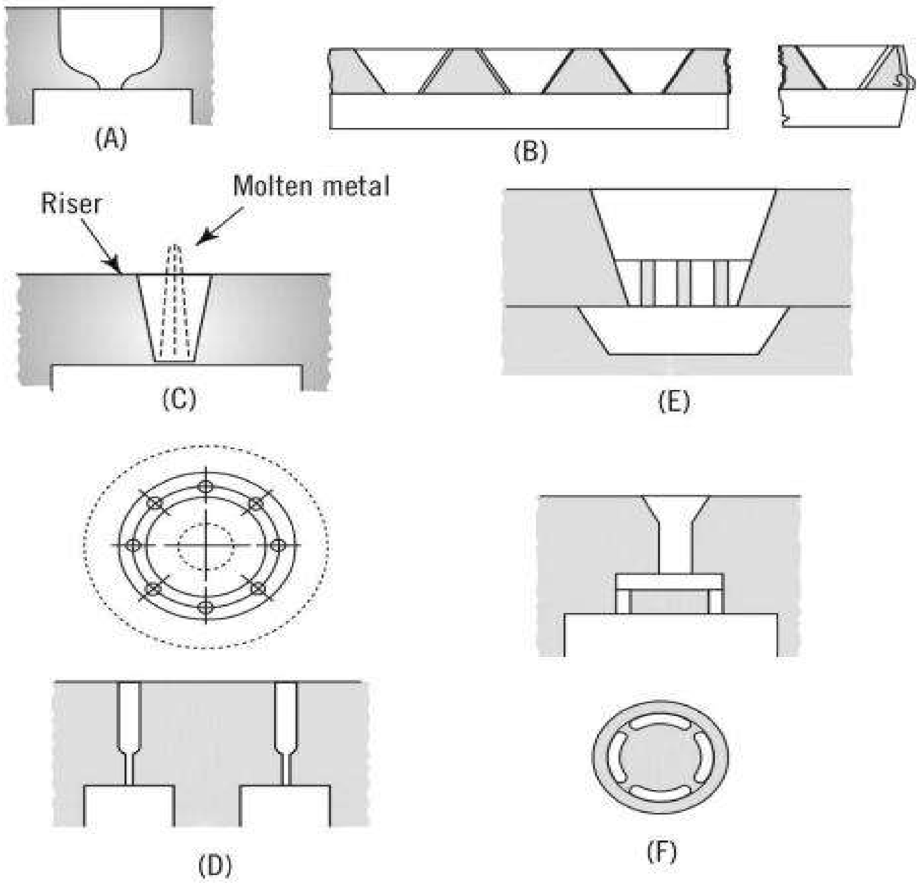


Figure: *Types of top gates (A) Top gate with pouring basin (B) Wedge gate (C) Top run gate (D) Pencil gate (F) Ring gate*

(2)**Parting Gates:** In the case of parting gates, metal enters the mould cavity at the same level as the mould joint or parting line. Molten metal enters through the sprue and reaches the parting surface where the sprue is connected to the gate in a direction horizontal to the casting. The arrangement of providing a gate at the parting line allows the use of devices that can effectively trap any slag, dirt, or sand, which passes with the metal down the sprue.

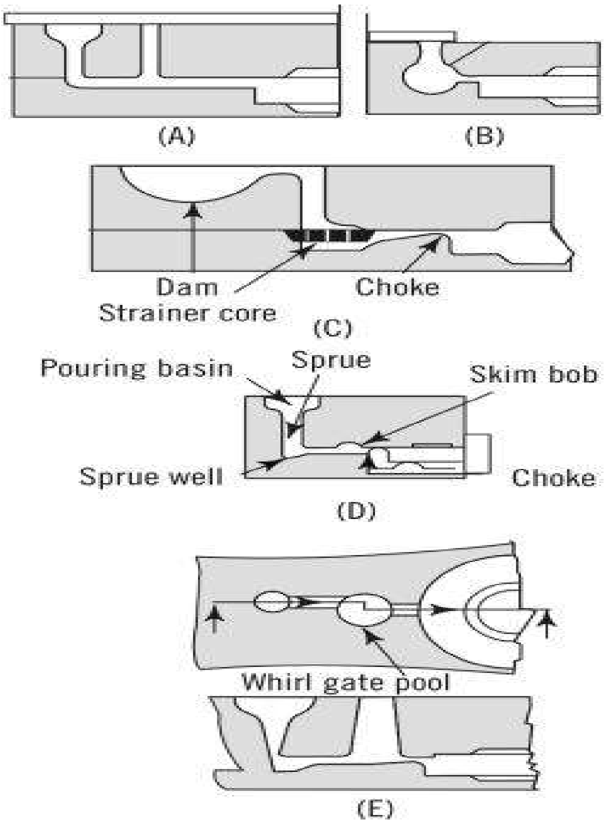


Figure: *Types of parting gates (A) Skimming gate (B) Parting gate with shrink-bob (C) Parting gate with dam type pouring basin (D) Parting gate with skim-bob (E) Whirlpool gate*

(3)**Bottom Gates:** In the case of bottom gates, usually favoured for large-sized casting, especially those of steel, molten metal flows down the bottom of the mould cavity in the drag and enters at the base of the casting. These are used to keep the turbulence of metal at a minimum while pouring and to prevent mould erosion. Metal is allowed to rise gently in the mould and around the cores.

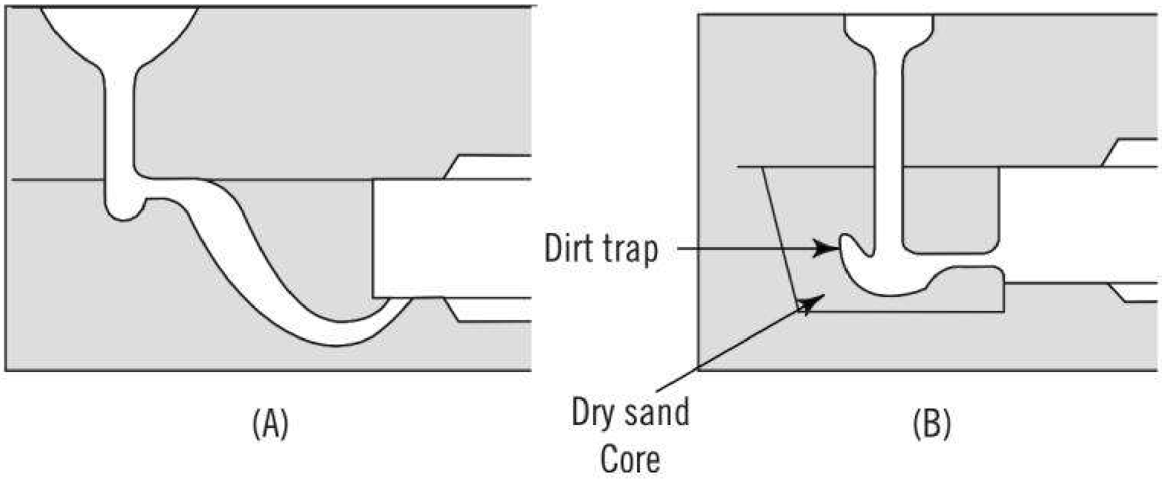


Figure: *Types of bottom gates (A) Horn gate (B) Bottom gate with dry sand core*

Gating Ratio: The term gating ratio is used to describe the relative cross-sectional areas of the components of a gating system. It is defined as the ratio of sprue area to the total runner area to the total gate area. A gating system having a sprue of 1 sq cm cross section, a runner of 3 sq cm cross section, and three gates, each of 1 sq cm cross section, will have a gating ratio of 1: 3: 3. Gating ratios are grouped in two classes, viz., pressurized and unpressurized systems.

The gating ratio reveals:

(a)Whether the total cross-section decreases towards the mold cavity. This provides the choke effect which pressurizes the liquid metal in the system.

(b)Whether the total cross-section increases so that the passages remain incompletely filled. It is the unpressurized system.

Pressurized Gating System	***Unpressurized Gating System***
1. Gating ratio may be of the order of 1: 0.75: 0.5.	1. Gating ratio may be of the order of 1: 3: 3.
2. Back Pressure is maintained on the gating system by a fluid flow restriction at the gates.	2. Primary restriction to fluid flow is near the sprue.
3. They are smaller in volume for a given flow rate of metal. Therefore, the casting yield is	3. They are larger in volume because they involve large runners and gates as compared

higher.	to pressurized systems and thus the casting yield is reduced.
4.Volume flow of liquid from every ingate is almost equal.	4. Volume flow of liquid from every ingate is different.

Principles of Risering

A riser is a hole cut or moulded in the cope to permit the molten metal to rise above the highest point in the casting. The riser serves a number of useful purposes. It enables the pourer to see the metal as it falls into the mould cavity. If the metal does not appear in the riser, it signifies that either the metal is insufficient to fill the mould cavity or there is some obstruction to the metal flow between the sprue and riser. The riser facilitates ejection of the steam, gas, and air from the mould cavity as the mould is filled with the molten metal. Most important, the riser serves as a feeder to feed the molten metal into the main casting to compensate for its shrinkage.

FUNCTIONS OF A RISER

The following are the functions of a riser:

(i) A riser permits the escape of air and mold gases as the mold cavity is being filled with the molten metal.

(ii) A riser full of molten metal indicates that the mould cavity has already been completely filled up with the same.

(iii) Risers promote directional solidification.

(iv) A casting solidifies under the liquid metal pressure of the riser is comparatively sound.

DIRECTIONAL SOLIDIFICATION

As the molten metal cools in the mould and solidifies, it contracts in volume. The contraction of the metal takes place in three stages:

(i) liquid contraction;
(ii) solidification contraction; and
(iii) solid contraction.

Liquid contraction occurs when the molten metal cools from the temperature at which it is poured to the temperature at which solidification commences. ***Solidification contraction*** takes place during the time the metal changes from the liquid state to the solid, e.g., when the metal loses its latent heat. ***Solid contraction*** spans the period when the solidified metal cools from freezing temperature to room temperature.

Since all the parts of the casting do not cool at the same rate, owing to varying sections and differing rates of heat loss to adjoining mould walls, some parts tend to solidify more quickly than others. This contraction phenomenon causes voids and cavities in certain regions of the casting. These voids must be filled up with liquid metal from the portion of the casting that is still liquid and the solidification should continue progressively from the thinnest part, which solidifies, first, towards the risers, which should be the last to solidify. If the solidification takes place in this manner, the casting will be sound with neither voids nor internal shrinkage. This process is known as ***directional solidification***, and ensuring its progress should be a constant endeavour for the production of sound castings.

Design and Positioning of Risers

Riser Shape and Size: The height of the riser must be tall enough to ensure that any pipe formed in it does not penetrate casting. The ratio of height to diameter usually varies from 1: to 1.5:1. The size of the riser, i.e., its diameter, is still largely a matter of experience, Chvorinov's rule is based on the assumption that freezing time is governed by its $(V/A)^2$ ratio, where V/A is the ratio of the volume of the casting to its surface area and is known as modulus. Chvorinov has stated that the freezing time of a casting, $t = (l/q^2)(V/A)^2$, where q is a solidification constant, depending on the composition of cast metal and the positioning of the mould cavity, i.e., along a horizontal or vertical axis. To determine a suitable riser diameter, the $(V/A)^2$ ratio of the given casting is computed and a riser whose $(V/A)^2$ is slightly larger than that of the casting (say 10–15% larger) is chosen.

Caine's method of evaluating riser size is based on the relative freezing time of the casting and the riser. It defines the relative freezing time to complete solidification as:

$$\frac{(surface\ area\ of\ casting)}{(volume\ of\ casting)} : \frac{(surface\ area\ of\ riser)}{(volume\ of\ riser)}$$

According to Caine, if the casting solidifies very rapidly, the feeder volume need be only equal to the solidification shrinkage of the casting.

On the other hand, if the feeder and casting solidify at the same rate, the feeder must be infinitely large. The relative freezing time, X is given by:

$$X = \frac{L}{Y-B} + C$$

where Y is volume of riser/volume of casting, B is the relative contraction on freezing, and L and C are constants, depending on the metal to be cast. The values of L, C and B for three common cast metals are as given in table below:

CAST METAL	L	C	B
Aluminium	0.10	1.08	0.06
Grey Cast Iron	0.33	1.0	0.03
Steel	0.12	1.0	0.05

Table: *Values of L, C, B for three common cast metals*

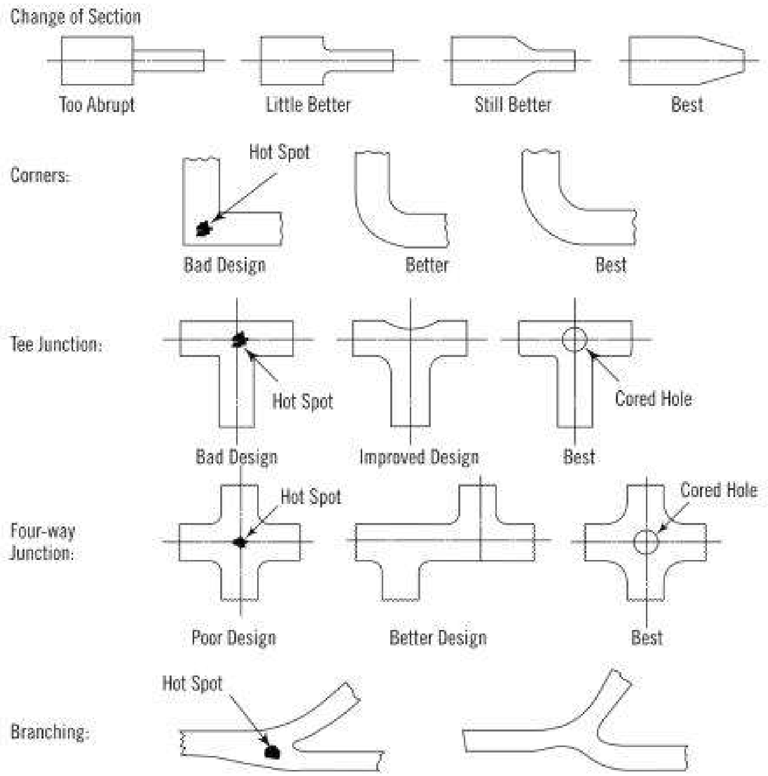


Figure: *Some design considerations.*

Riser Location: The location of the riser should be chosen keeping in view the metal to be cast, the design of the casting, and the feasibility of directional solidification. The riser may be located either at the top of the casting or at the side. Top risering is extensively used for light metals as it enables the benefit of metallostatic pressure in the riser. Frequently, the number of users has to be more than one so as to derive its most effective use. In such cases, their spacing should be carefully arranged so as to minimize the shrinkage.

Technology of Metal Mould– Casting Processes

Metal mould-casting processes are different from sand casting in that the moulds, being metallic, are of a permanent nature and are used repeatedly. These metal moulds are also called dies. Unlike sand moulds, metal moulds have superior surface characteristics and can produce castings to close tolerances and with distinctive surface finish.

The types of metal mould casting processes briefly discussed here are *permanent mould casting*; *pressure die casting*; *low-pressure casting*; *squeeze casting*; *centrifugal casting* and *continuous casting*.

PERMANENT MOULD CASTING: A large quantity of small-sized castings, particularly those in aluminium and magnesium, is cast by means of permanent moulds. These moulds, which are metallic, are ideal when numerous identical castings are required. Unlike sand moulds which are serviceable only once, as they have to be destroyed to extract the casting, permanent moulds are used many times without getting damaged. Permanent mould casting is also referred as gravity die casting. Since metal is fed into the moulds by the force of gravity, no external pressure is necessary. The moulds require repair and renewal only after long periods. The operations involved in permanent mould casting form a cycle which, when repeated in a certain rhythm, can determine the output rate of the equipment used. The cycle of work is as follows: The dies are closed and mechanically clamped; molten metal poured; the metal allowed to solidify; the dies opened; the casting taken out; and the dies cleaned for the next cycle of operation.

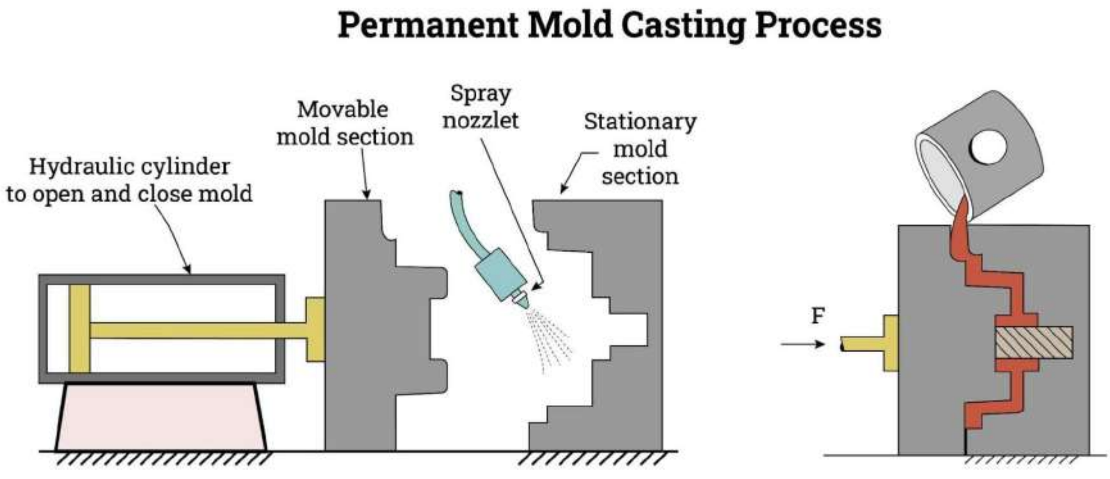


Figure: *Permanent Mould Casting.*

PRESSURE DIE CASTING: Die castings are prepared by forcing molten metal under high pressure into a metal mould called a die. The die resembles the common type of permanent mould in that it too has two halves which open and close along a vertical parting. On a die-casting machine, the die half called the cover die is stationary. The other die half, which opens and closes, is known as the ejector die.

LOW-PRESSURE DIE CASTING: Low-pressure die casting has been lately developed to enable production of castings that are flawless, have very thin sections, and register a yield approaching 100% even in metals such as aluminium and magnesium. The mould, which is made in metal (usually cast iron), is filled by upward displacement of molten metal from a sealed melting pot or bath. This displacement is affected by applying relatively low pressure of dry air (0.5~1.0 kg/mm^2) on the surface of the molten metal in the bath. The pressure causes the metal lo rise through a central cast iron tube and move into the die cavity. The dies are provided ample venting to allow the escape of air. The pressure is maintained till the metal is solidified; then it is released enabling the excess liquid metal to drain down the connecting tube back into the bath. As positive pressure is maintained to force the metal to fill recesses and cavities, casting with excellent surface quality, finish, and soundness are produced. Low pressure on the metal completely eliminates turbulence and air aspiration.

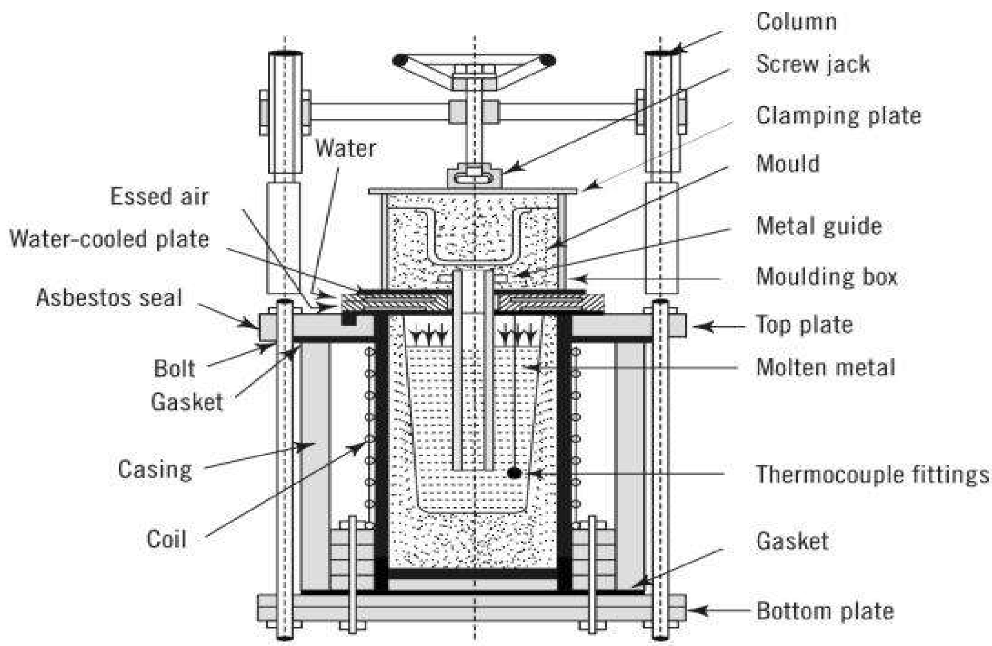


Figure: *Low-pressure die-casting machine*

SQUEEZE CASTING: The squeeze casting process incorporates the advantage of forging or mechanical deformation into the casting process. Molten metal is poured into a die whose half parts are initially separated and then brought together to squeeze the casting while it solidifies. Simultaneously, pressure is applied from a punch in a direction lateral to the movement of the dies, thereby triggering squeeze action from all directions. The pressure is applied on to the molten metal at the precise time when the metal temperature at the interface of metal and die has reached solidus. Delay may necessitate the use of higher pressures, and premature application of pressure may produce coarse and uneven surfaces and ragged edges. Compression time should be such that complete solidification takes place without any air gap. After withdrawal from the die, the casting is cooled in hot sand.

CENTRIFUGAL CASTING: In the centrifugal casting process, molten metal is poured into moulds while the latter are revolving. The metal falling into the centre of the mould at the axis of its rotation is whirled out by the power of centrifugal force towards the periphery, and the impurities, being lighter in weight, are left behind at the centre. Due to the application of centrifugal force, the castings are completely free from any porosity defect, denseness and strength are high and these castings have been proved as strong as similar forgings. The need for large gates, feeders, and cores is also eliminated, making the method less expensive.

CONTINUOUS CASTING: Continuous casting, a major technical phenomenon in the steel industry, is a process used for casting metal direct into billets or other such shapes. The process involves continuously pouring molten metal into a rapidly cooled copper mould and passing it through a system of water and air cooling. This is carried out either wholly along a vertical axis or partly along a vertical and partly along a horizontal axis. The molten metal is poured from the crucible first into a heated basin, called a tundish, and then into a vertical copper mould, which is water-cooled and open at both upper and lower ends. The mould is usually 300–350 mm long and the internal shape of the mould corresponds to that of the cross section of the casting required. By the time the metal leaves the bottom of the mould, a solid crust is formed, while the interior remains liquid. It then passes vertically downwards through a set of water-cooled rollers and is further cooled by jets of compressed air.

ELECTRO-SLAG CASTING: The process consists of a water-cooled iron or steel mould (C) which itself acts as a melting unit, and one or more consumable steel electrodes (E) to produced molten metal under a protective slag. Heat is produced by the passage of electric current between the electrodes and mould, through the conductive slag (D). As the temperature rises above the melting point of the electrode, it melts at the tip and flows through the basic slag into the molten metal pool (B) in the mould cavity. As the electrode gets consumed, it is continuously lowered at a controlled rate (G). Solidification takes place without any contact with the atmosphere. Besides refining action, the slag absorbs non-metallic impurities from the molten metal and protects it from atmospheric contamination. The electrode maintains a continuous pool of metal on top of the solidifying layer and therefore, feed metal is always available to guarantee a sound structure.

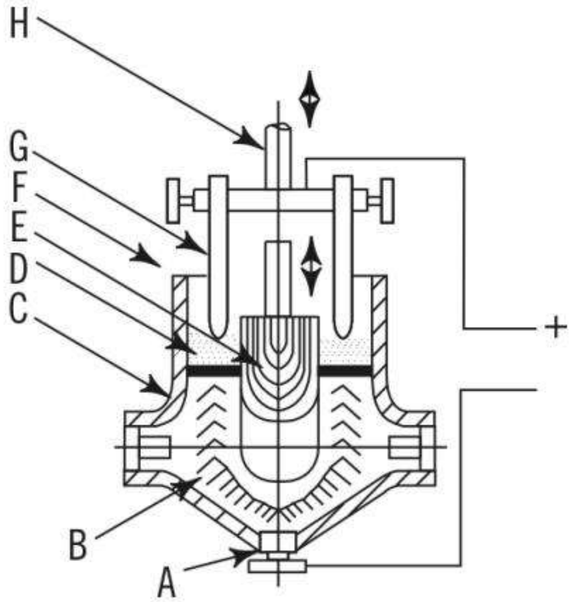


Figure: Electro-slag casting process

Technology Of Melting And Casting

Generally, the metals obtained from the blast furnace, steel-making furnaces, or from other smelting furnaces in cases of non-ferrous metals are not cast directly into the desired shapes of components or articles mainly for two reasons: first, the metal so obtained is not always in a sufficiently refined state to be directly cast; secondly, it is difficult from a practical viewpoint to pour a huge quantity of molten metal in moulds of different sizes and shapes. The iron obtained from the smelting furnaces is first cast into some regular forms, such as ‘pigs’ and ingots, and these forms are re-melted in foundries for casting the required objects. For remelting purposes, there is a wide range of equipment: *crucible furnace*; *open-hearth furnace*; *air or reverberatory furnace*; *cupola furnace*; and *electric furnace.*

CRUCIBLE FURNACE

A crucible furnace is very convenient for small foundries where the operation is intermittent and a variety of alloys are handled in small quantities. The metal to be melted is put in a heated crucible, which acts as a melting pot. The crucible is made of clay and graphite by moulding these materials into a standard shape, and it is produced in sizes from number 1 to 400.

Coke-fired Furnace: The coke-fired furnace is commonly used for melting non-ferrous metals, such as brass, bronze, and aluminium, owing to its low cost of installation, low fuel cost, and ease in operation. Generally, this furnace is installed in a pit and so is referred to as the pit type as shown in the figure. The furnace has a cylindrical steel shell, lined on the inner side with refractory bricks, closed at the bottom with a grate, and covered at the top with a removable lid. The metal to be melted is contained in the crucible, which is embedded in burning coke. Preparation of the furnace involves kindling a deep bed of coke and allowing it to burn until a state of maximum combustion is attained. Some coke from the top is removed and the crucible is lowered into the furnace. The coke is again added on all sides of the crucible. The metal is then charged in the crucible and the lid is replaced to facilitate the chimney draft. If forced draft is available from a blower, it is used to help in rapid combustion of the coke.

When the metal reaches the desired temperature, the crucible is drawn out with special long-handled tongs and carried away for pouring.

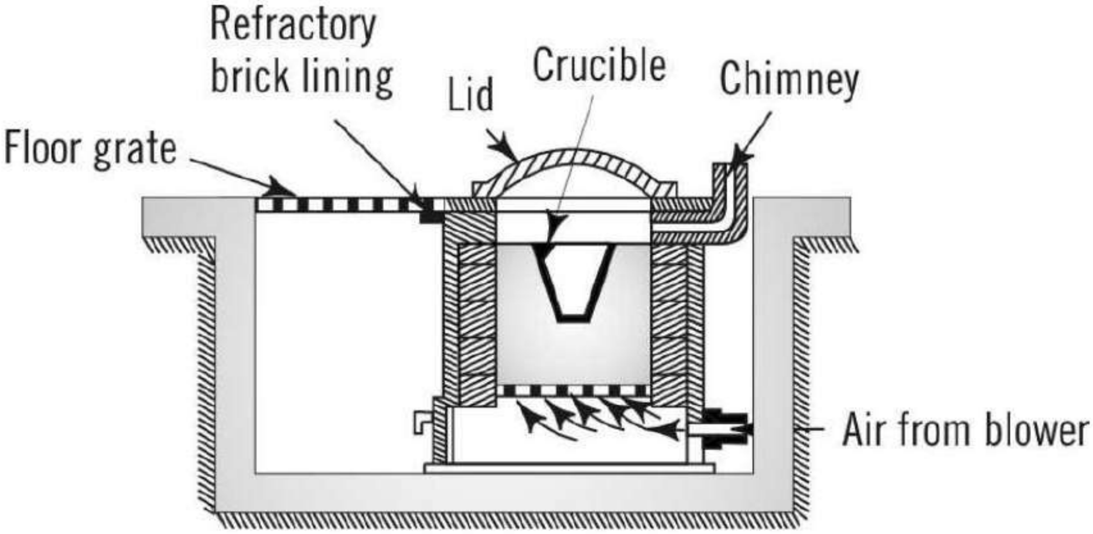


Figure: *Pit type coke-fired crucible furnace*

Oil- and Gas-fired Furnace: The furnace is cylindrical in shape and the flame produced by the combustion of oil or gas with air is allowed to sweep around the crucible and uniformly heat it. Gas or atomised fuel oil is fed through a manifold. It enters the furnace tangentially where it ignites and swirls upwards between the crucible and the refractory lining. The metal is charged through the opening in the centre of the head. Modem oil- and gas-fired furnaces are equipped for automatic proportioning—they produce a neutral flame by regulating the fuel and air ratio. The temperature is also controlled thermostatically. The oil- and gas-fired furnaces are generally the tilting or the bale-out type. The tilting type of furnace is raised above floor level, mounted on two pedestals, and rotated by means of a geared handwheel. The tilting gear is customarily so designed that the furnace tilts on a central axis. The bale-out or lift-out furnace is fixed, but, unlike the pit type, is installed on the floor. For extracting the molten metal, the crucible has to be lifted out of the furnace with the help of tongs.

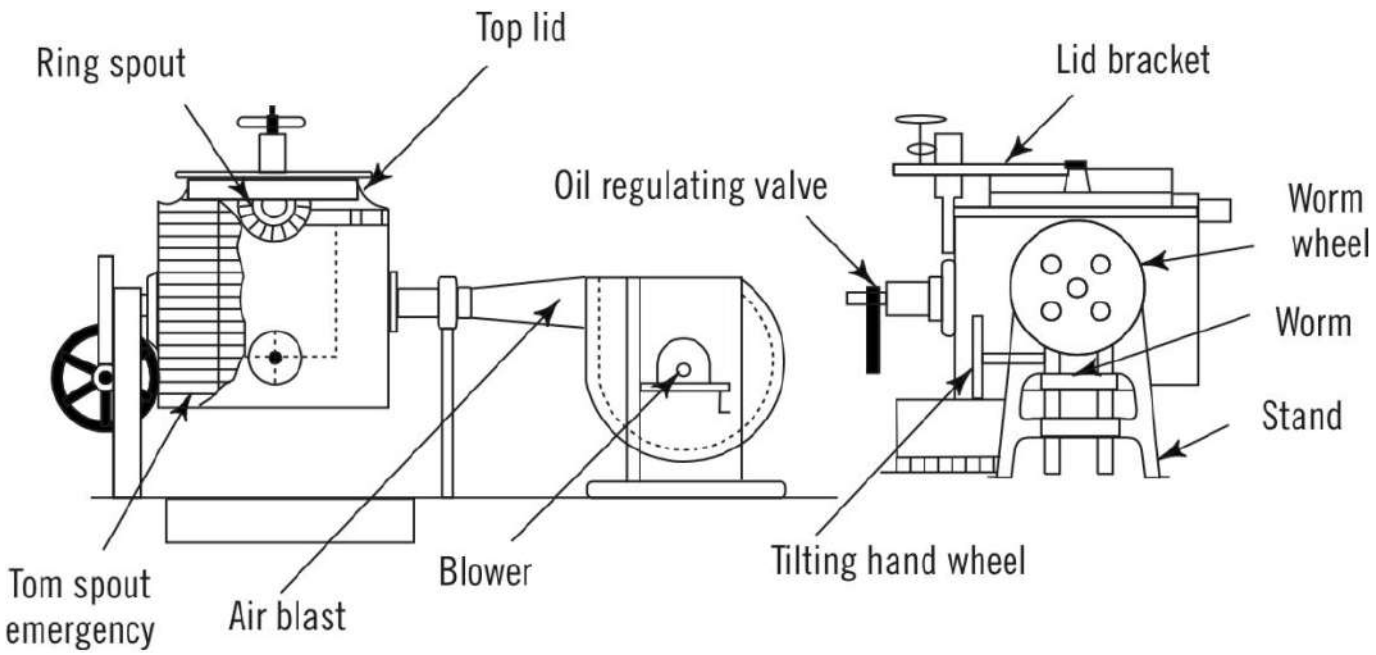


Figure: *Oil-fired tilting type crucible furnace*

OPEN-HEARTH FURNACE

Open-hearth furnaces have been used in the casting industry for melting steel or producing steel from pig iron direct for casting. Lately, however, these have been superseded by electric arc furnaces. The furnace may have basic or acid lining, depending on the type of pig iron used. The charge consists of pig iron in varying amounts along with steel scrap and limestone. The open-hearth process is based on the regenerative principle of heating and involves obtaining very high temperatures, as required for steel, by pre-heating the gaseous fuel and air by the outgoing products of combustion. The hearth of the furnace is shallow—about 13 m long, 5 m wide and 0.5 m deep—and made of suitable refractory material. It has gas and air ports at each end, and two pairs of regenerators, one for gas and the other for air, with the necessary flues and the chimney.

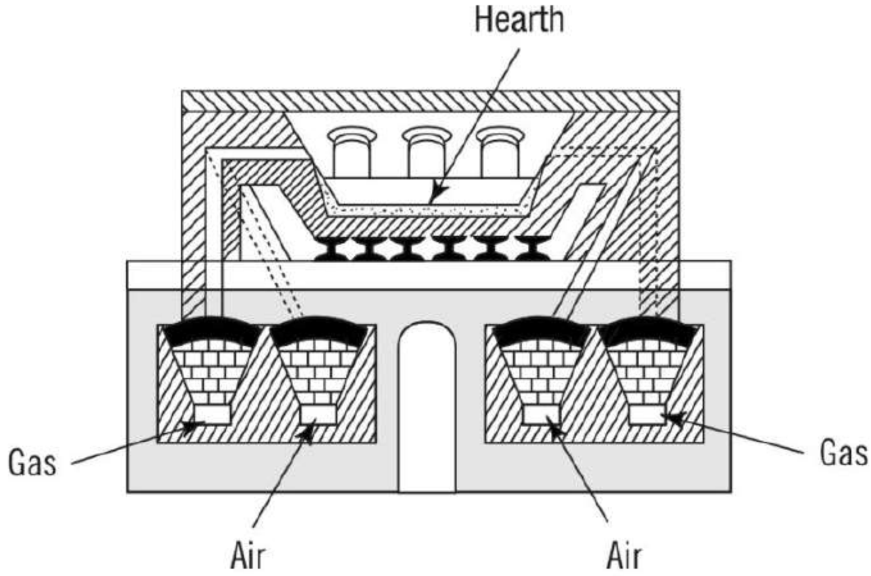


Figure: *Open-hearth furnace*

AIR FURNACE

An air furnace is sometimes used in the production of cast iron, particularly malleable iron, as also for non-ferrous metals, such as brass and bronze. The furnace works on the principle of a reverberatory furnace and has a long, low roof, which deflects the flame towards the metal lying in the shallow hearth. The hearth is formed of refractory bricks on which moulding sand is fused to form a hard surface. The bottom of the hearth slopes from both ends towards the centre where there is a tapping hole on each side of the long furnace. The size of the hearth for a 20-tonne capacity furnace may be about 8 m long and 2 m wide. The roof is made of arched sections called bungs. The charging and repairing involves removing these bungs from the roof. For stirring, skimming, etc., suitable openings are provided in the side walls. The fuel generally used is pulverised coal. Since the air furnace has a low ratio—about 2½ kg of metal per kg of coal, the metal is often melted in a cupola and transferred to the furnace for refining and adjusting the composition.

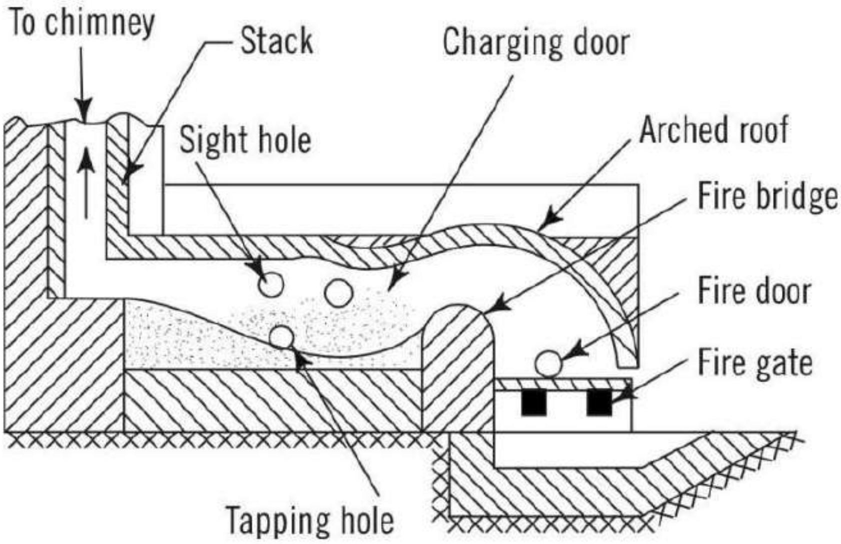


Figure: *Air Furnace*

CUPOLA FURNACE

A cupola furnace is most commonly employed for melting and refining pig iron along with scrap in the production of iron castings. The cupola furnace is made up of a vertical steel shell, 6–12 mm thick, lined with refractory material down the whole length. The lining is generally thicker in the lower region, i.e., beneath the charging door, where the temperatures encountered are higher than in the upper region. A constant volume of air for combustion is obtained from a motorised blower of the positive displacement type. The air is carried from the blower through a pipe called the windpipe, first to a circular jacket around the shell and then into the furnace through a number of openings called tuyeres. These tuyeres are generally 4, 6, or 8 in number, depending on the size of the cupola. The combined area of air inlets or tuyeres should be about one-fourth of the cupola plan area. The height of the tuyeres from the bed of the cupola is about 450–500 mm. Opposite each tuyere, a small window with mica covers makes the inspection of fi re conditions possible. At the bottom of the bed, a spout, called the tapping spout, is provided for the molten metal. Opposite this tap hole, and somewhat above it, is another hole, called the slag hole, which enables the slag to be taken out. The base of the cupola is made by thoroughly ramming moulding sand. It is prepared on drop-bottom plates, which are hinged on two sides and supported by a vertical rod called the prop. When the melting work is over, the furnace is emptied of the remaining contents by removing the prop; this causes the bottom plates to open out. The entire furnace is supported by four cast-iron pillars on the floor. Since the charging door is at a higher level from the floor, a charging platform is provided at a suitable height. At the top of the furnace, a conical cap, called the spark arrester, prevents hot sparks from emerging into the vicinity. The spark arrester cools down the sparks and allows only smoke to escape from the opening. The figure below also shows the outside view of a cupola, complete with the mechanical charging device.

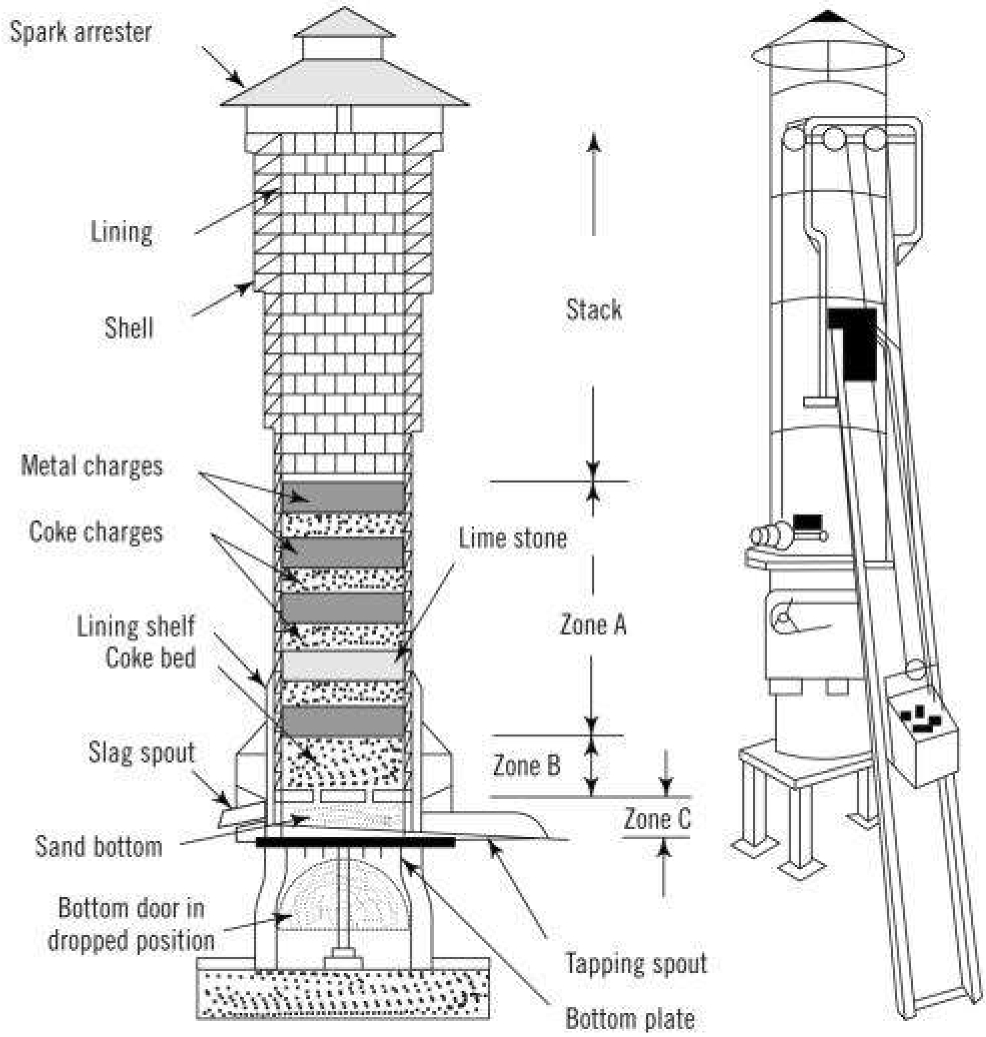


Figure: *Cupola Furnace*

ELECTRIC FURNACE

Electric melting is one of the major methods of melting in iron and steel foundries. Electric furnaces have proved a big asset in the production of good-quality metal as they attain high melting efficiency with minimum loss. Unlike cupola or air furnaces, electric furnaces possess greater adaptability and flexibility and provide precise control over the temperature of molten metal. The high cost of electric power is a limitation, but this is outweighed by several overwhelming advantages. Electric furnaces are of three types:

(i) direct arc furnace;
(ii) indirect arc furnace; and
(iii) electric induction furnace.

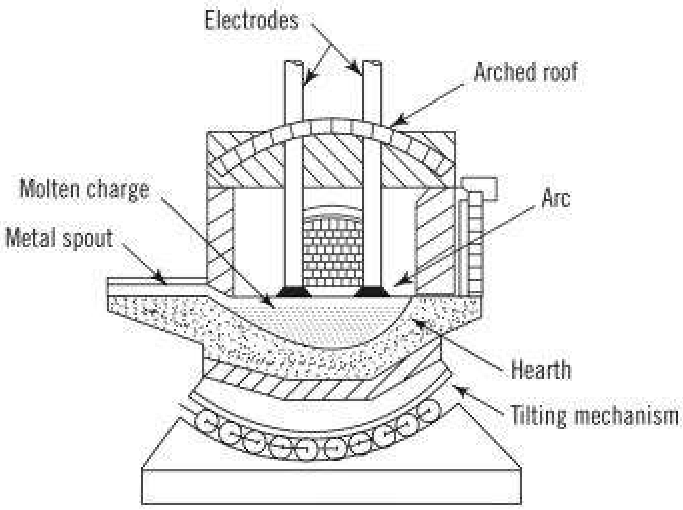


Figure: *Direct arc electric furnace*

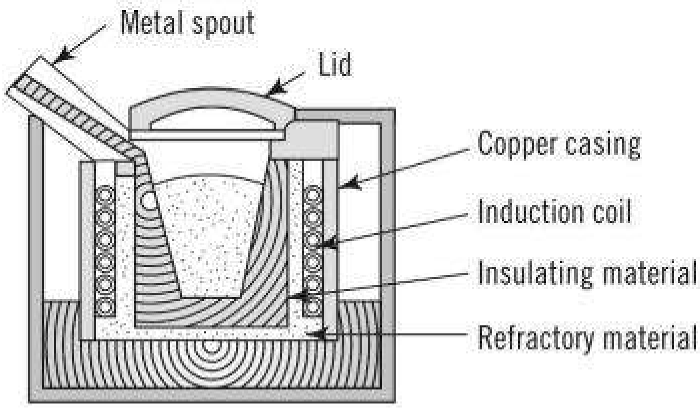


Figure: *High frequency induction furnace*

Vickers Hardness Test

A Vickers indenter is used in the Vickers microhardness test. The Vickers microhardness indenter is made of diamond in the form of a square-base pyramid having an angle of 136° between faces. The indenter should be applied under a predetermined constant load. The diagonals of the square indentation are measured using the microscope and a mean value is calculated. The Vickers hardness number (VHN) is then calculated according to the formula:

$$VHN = 2P\,sin(\theta/2)/d^2 = 1854.4P/d^2$$

, where P is the applied load in grams (g), θ is the indenter face angle of 136°, and d is the mean diagonal length in μm. The constant 1854.4 incorporates the value of sin(θ/2) and other conversion factors to give VHN a unit of kg/mm^2.

Figure: Experimental Setup

Material: High Entropy Alloy
Details of the specimen:

Raw Material: Al-Si alloy; Cu-Zn (Brass bar); Pure Mg
Process: Metal Moulding; Melting in Resistance Heating Furnace at 835°C.
Time: 5-6 hours
Flux Used: Coveral, Boric Acid/Borax

Load: 500 grams

Specimen: Post-Ageing (7 hours) Date: 05/07/2024

Sl. No.	Readings	D1	D2
1	148.91	79.43	78.34
2	154.47	77.02	77.90
3	149.84	79.21	78.12
4	152.43	77.68	78.34
5	144.09	79.87	80.53
6	150.21	77.46	79.65
7	153.73	78.56	76.81
8	146.50	79.21	79.87
9	150.76	77.24	79.65
10	156.33	76.81	77.24
Average	150.73		

Specimen: Post-Ageing (8 hours)

Sl. No.	Readings	D1	D2
1	155.77	76.37	77.90
2	147.05	77.68	81.18
3	151.50	75.71	80.74
4	150.21	77.02	80.09
5	148.91	77.46	80.31
6	148.17	78.77	79.43
7	147.42	79.65	78.99
8	151.13	77.90	78.77
9	146.13	77.46	81.84
10	148.17	78.56	79.65
Average	149.45		

Specimen: Post-Ageing (9 hours)

Sl. No.	Readings	D1	D2
1	155.77	77.68	76.59
2	157.99	75.93	77.24
3	159.85	75.49	76.81
4	158.92	76.15	76.59
5	159.48	75.71	76.81
6	158.55	76.59	76.37
7	156.70	75.93	77.90
8	154.10	76.59	78.56
9	157.25	75.71	77.90
10	155.03	78.77	75.93
Average	157.36		

Specimen: Post-Ageing (10 hours)

Sl. No.	Readings	D1	D2
1	149.84	77.02	80.31
2	143.72	78.99	81.62
3	140.75	80.74	81.62
4	134.81	82.93	82.93
5	140.38	79.65	82.93
6	149.46	78.56	78.99
7	134.44	83.15	82.93
8	154.10	76.37	78.77
9	154.10	78.99	76.15
10	150.21	77.46	79.65
Average	145.18		

(A) (B) (C)

Figure: *High-Entropy Alloys of different composition.*

Specimen A:

Sl. No.	Readings	D1	D2
1	309.87	52.74	56.67
2	331.94	53.39	52.30
3	338.98	52.08	52.52
4	318.59	55.58	52.30
5	337.69	49.23	55.58
6	336.20	52.08	52.95
7	326.56	54.92	51.64
8	334.72	51.42	53.83
9	333.42	53.17	52.30
10	325.26	56.89	49.89
Average	329.32		

Specimen B:

Sl. No.	Readings	D1	D2
1	285.39	54.70	59.30
2	306.16	55.36	54.70
3	275.75	57.55	58.42
4	292.07	56.24	56.46
5	253.31	59.08	61.93
6	272.60	59.08	57.55
7	283.17	52.52	61.93
8	268.52	57.55	59.96
9	266.66	58.21	59.74
10	276.86	56.89	58.86
Average	278.05		

Specimen C:

Sl. No.	Readings	D1	D2
1	127.03	83.81	87.09
2	120.72	86.21	89.06
3	122.02	87.90	87.31
4	123.13	86.43	87.09
5	126.10	84.46	87.09
6	122.95	88.18	85.56
7	127.40	85.34	85.34
8	127.58	83.81	86.65
9	121.09	88.40	86.65
10	118.31	93.22	83.81
Average	123.63		

Metallographic Analysis and Microstructures

Metallography Analysis typically uses microscopy to provide important information about the structure and properties of metal and alloy samples. As metals are subjected to melting, cooling, and working processes, the grains and the crystalline structure change. So, the study of the material's microstructure is performed to evaluate the effects on material's properties.

Setup:

The microscope interacts with the specimen to create images, either by sending a beam of light or electrons to a sample in its optical path, or by scanning across, and a short distance from, the surface of a sample using a probe. The image is captured by software named Metallurgical Image Analysis Software.

Specimen Preparation

The metallographic specimen preparation process for microstructural investigations specimens usually consists of five stages: sampling, grinding, polishing, and etching with a suitable etchant to reveal the microstructure.

i. Sampling: It is the first step in which selecting the test location to be evaluated metallographically. Samples can be obtained by cutting them out from either a large or small casting.

ii. Grinding: The surface of the sample is flattened by grinding wheel.

iii. Paper Polishing: After grinding, paper polishing is done using SiC grit papers P80, P200, P400, P800, P1000, P1200, and P2500 one by one.

Figure: Grits paper

iv. Cloth Polishing: Cloth polishing is done on napped synthetic polyurethane pad using diamond paste as abrasive and water. Polishing is done around 12 minutes for high entropy alloys.

Figure: *Polishing Machine*

Etchants

Etching is used to highlight, and sometimes identify, microstructural features or phases present. Microscopic examination of a properly polished, unetched specimen will reveal only a few structural features. Only the non-metallic inclusions, porosities and cracks may be easily seen from the surface.

Thus, it is beneficial to investigate the sample structure under the microscope after the polishing step. The crystalline structure (grains and grain boundaries) of the polished surface is revealed by etching with a proper etchant. This process is named as "chemical etching" or "etching" in brief. It is based on the rate difference in chemical attack depending upon chemical composition, energy content, and grain orientation of the sample.

Microstructure of specimen under microscope (at different lens):

Lightweight high entropy alloys (HEAs) have great application potential in automobile and many other fields. Herein, novel low-cost $Al_{35}Mg_{30-x}Zn_{30}Cu_5Si_x$ (x = 5,10,15) lightweight high entropy alloys were designed and prepared by electric melting.

Etchant: Keller's Etchant

For a 100 ml mixture,

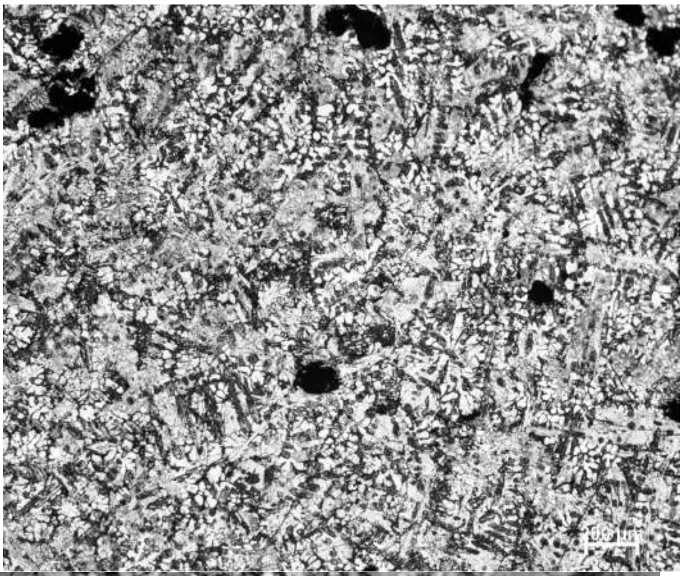
Distilled water: 95 ml

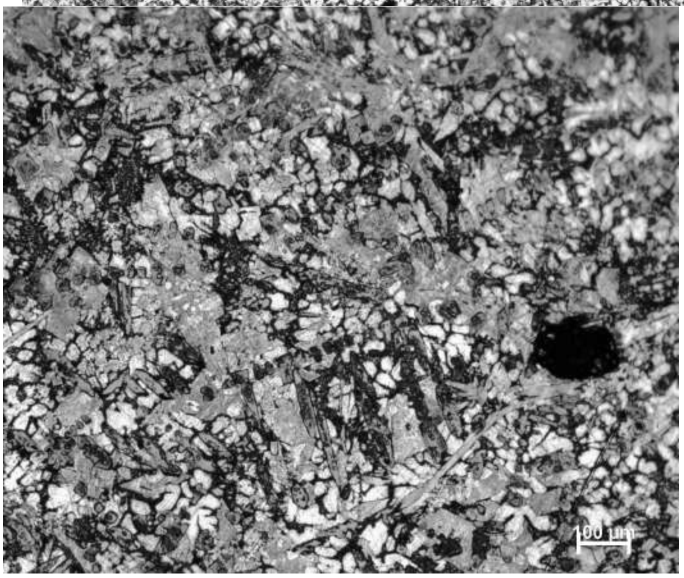
Nitric Acid: 2.5 ml

Hydrochloric Acid: 1.5 ml

Hydrofluoric Acid: 1 ml

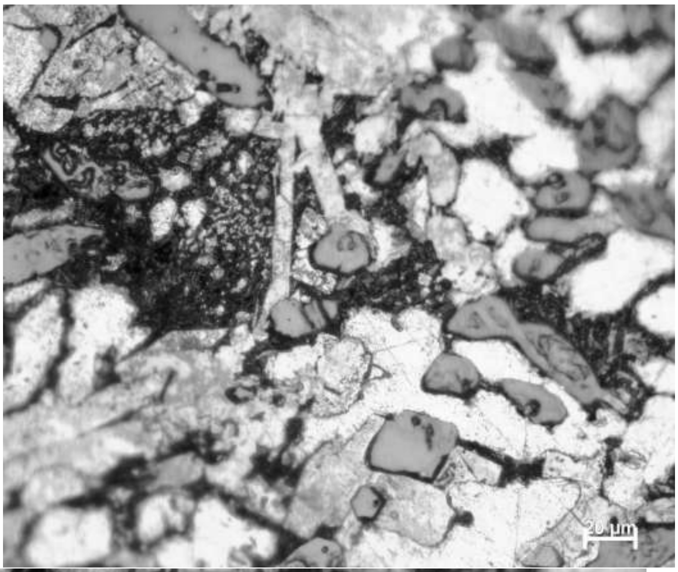
Specimen A:

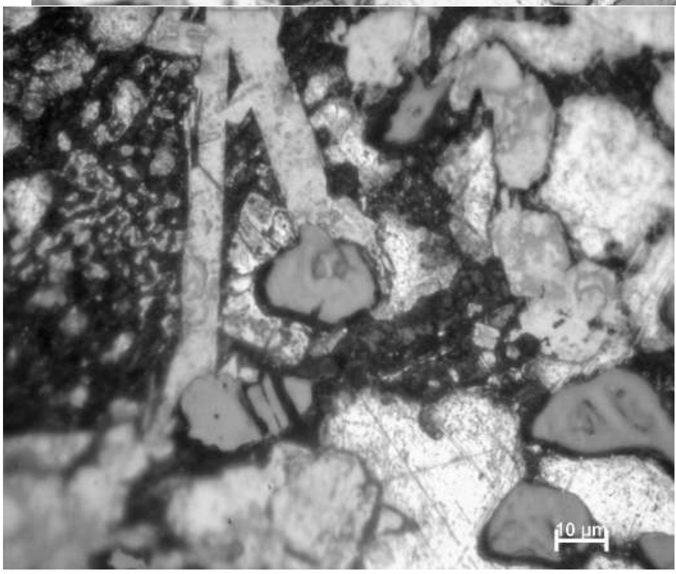




(i)5x (ii)10x

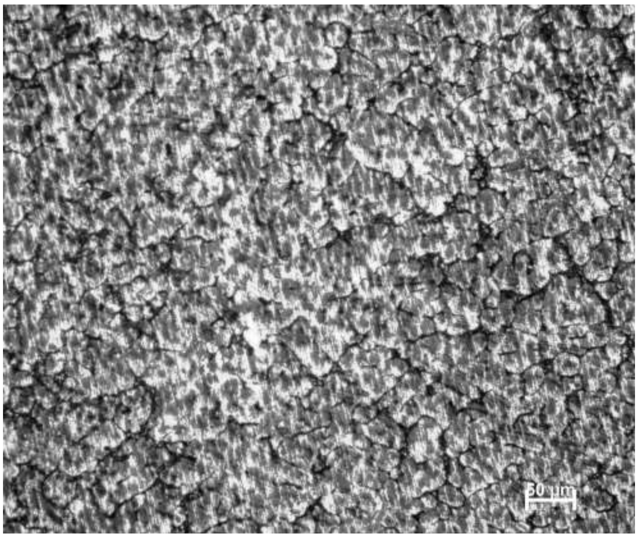
The black spots are large and deep corrosion pits.

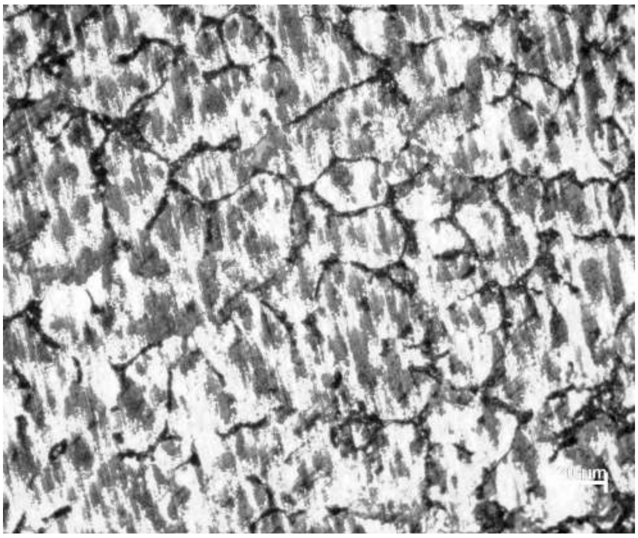




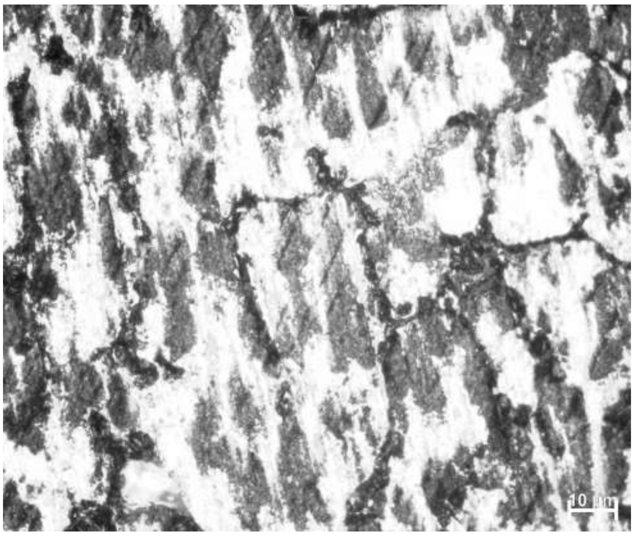
(iii)50x (iv)100x

Specimen C:





(i)20x (ii)50x



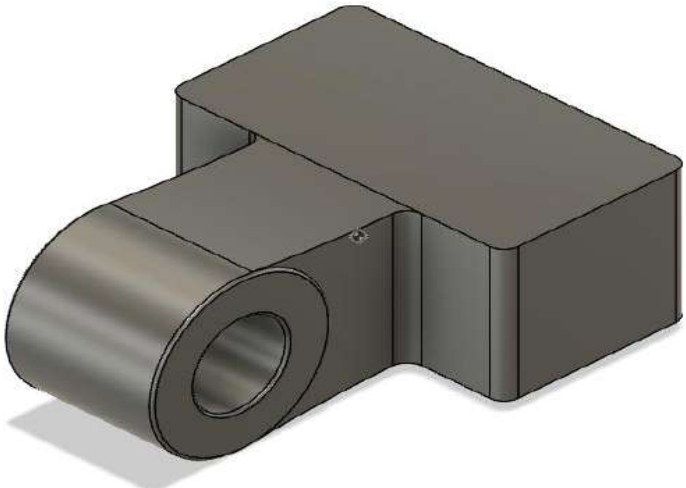
(iii)100x

Simulation

The computer aided analysis is carried out by using a Finite Difference and vector modulus-based software, “SOLIDCast”. It is a PC based tool that is used for simulating the pouring of hot metal of virtually and casting alloy into the sand, shell, investment, or permanent molds and subsequent solidification and cooling process.

Software: SOLIDCast, Autodesk Fusion

Job: Swing Hammer

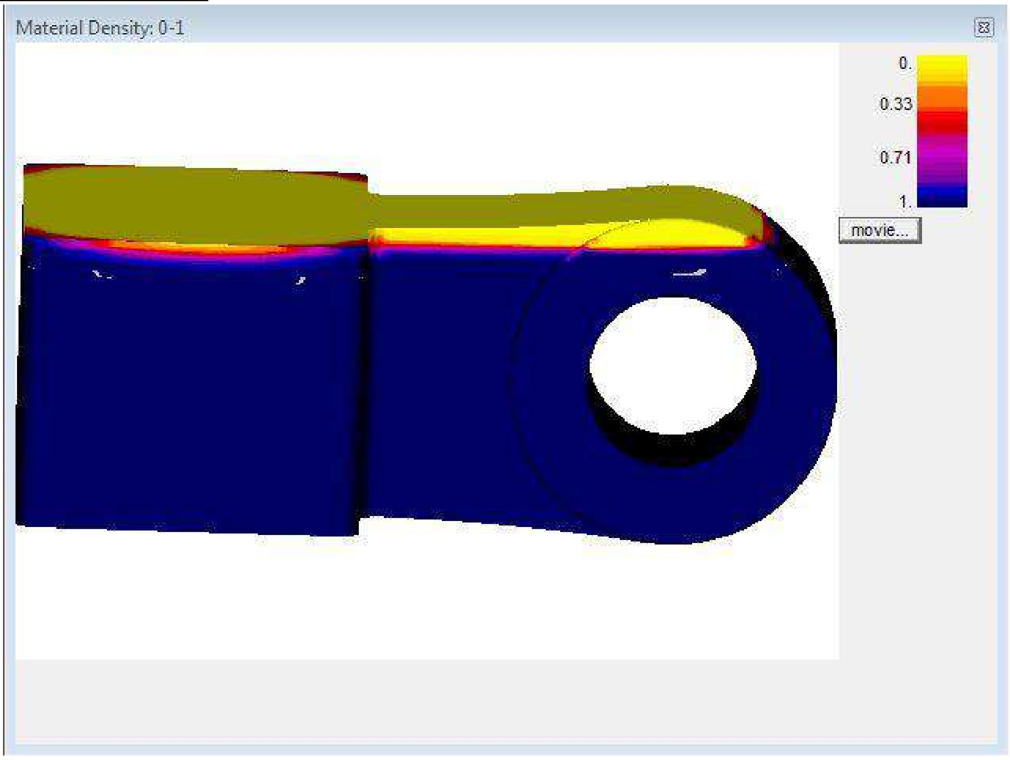


Pattern Material: Cast Iron (Ductile Iron)
Type of mold: Silica Sand
Pouring Temperature: 1371°C
Properties Studied:

(i) **Material Density:** This criterion is a result of a calculation in which the contraction of the casting and resulting flow of liquid metal is taken into account during solidification. Areas having metal removed due to feeding liquid metal to other areas of the casting will have lower material density numbers. In this way, potential shrinkage can be predicted. The material density is a number varying between 0 and 1; 0

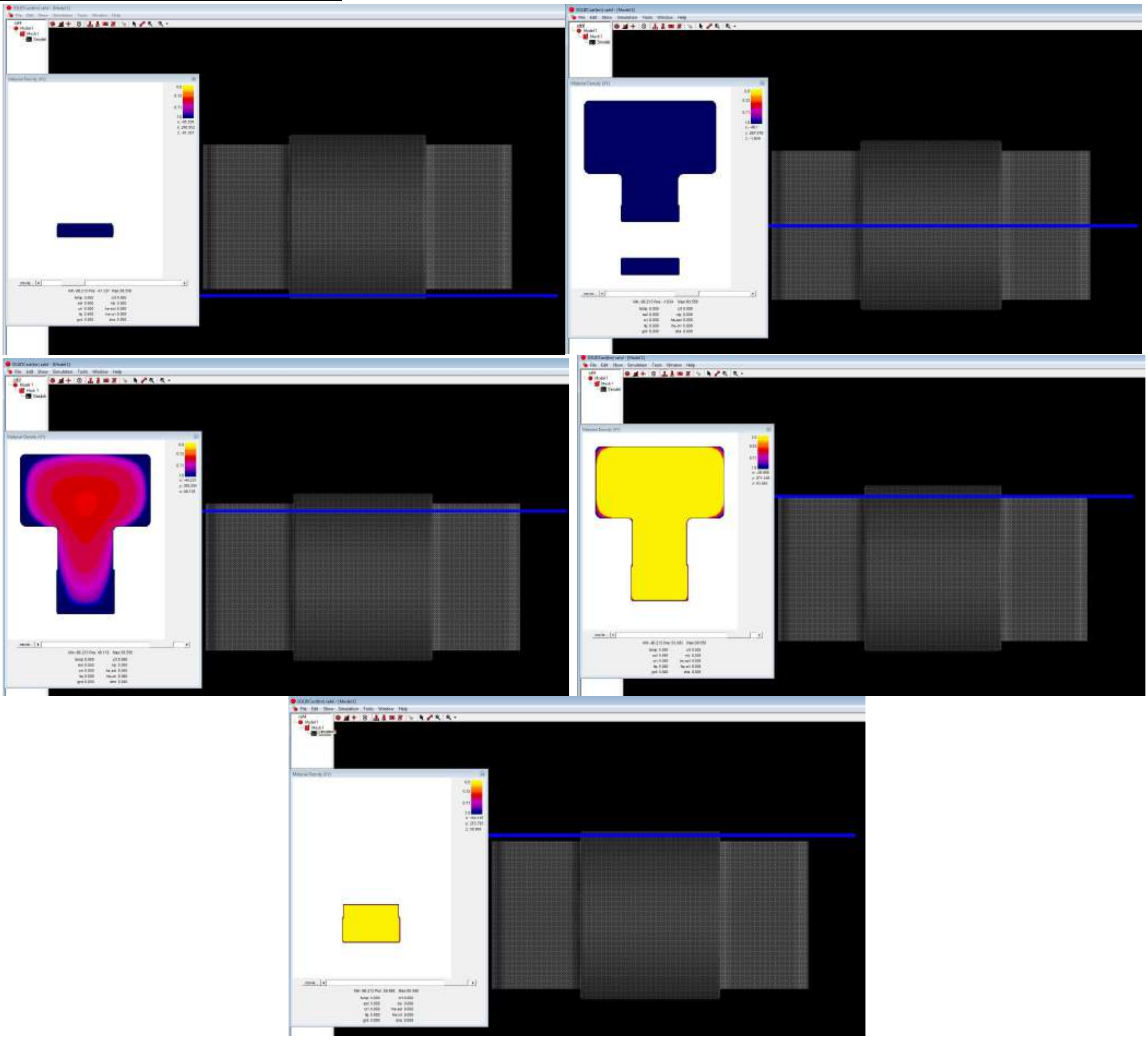
meaning that the metal has been completely drained from that part of the casting while 1 indicates completely sound metal. It is found that, in general, values in the range between 0.95 or 0.99 and below are areas of detectable shrinkage porosity in castings.

Analysis in CASTPIC Plot:



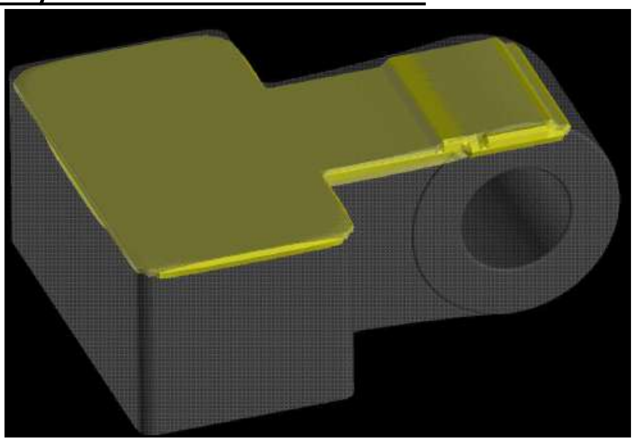
The blue zone shows a sound casting with values close to 1. However, because of shrinkage the job is empty at the top layer shown by yellow with values close to 0. The solution can be achieved by the use of riser and gating system.

Analysis in Plot Cut Plane:



At different planes the density of the component is analyzed. In the third figure, a red zone called hot spot can be seen.

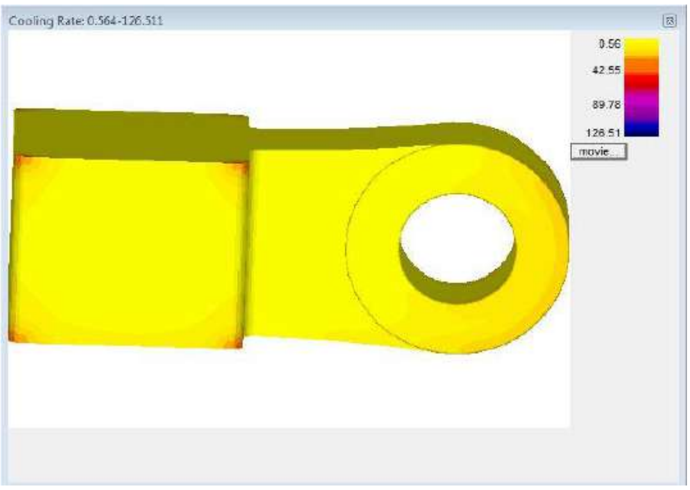
Analysis in Plot Iso Surface:



The empty void is generated and represents no material.

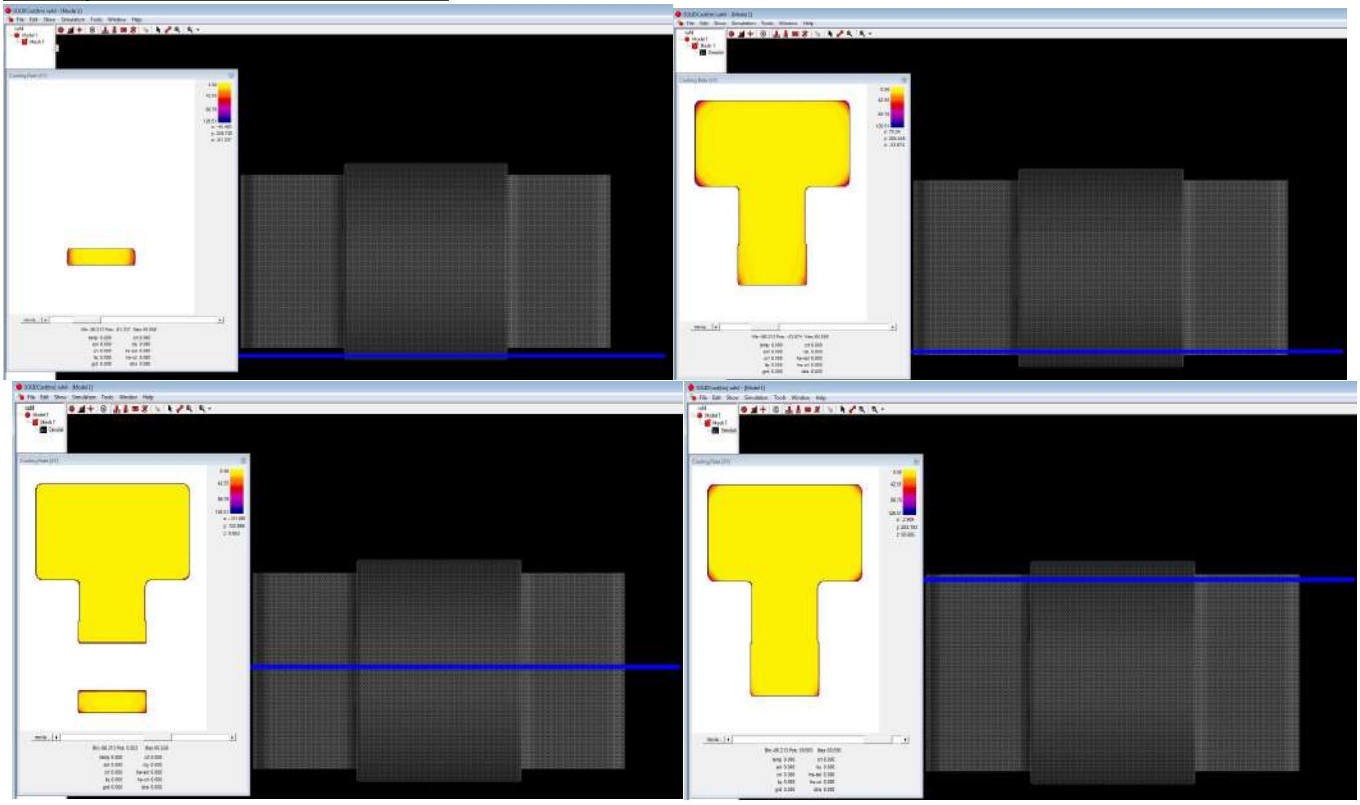
(ii) **Cooling Rate:** It is a measure of how quickly a casting is cooling down measured at each point in the casting as that point hits the Niyama Point on the cooling curve. Cooling Rate can be an indication of material quality. Areas of the casting that cool rapidly generally have a more favourable grain structure, with less deposition of partially-soluble compounds at the grain boundaries.

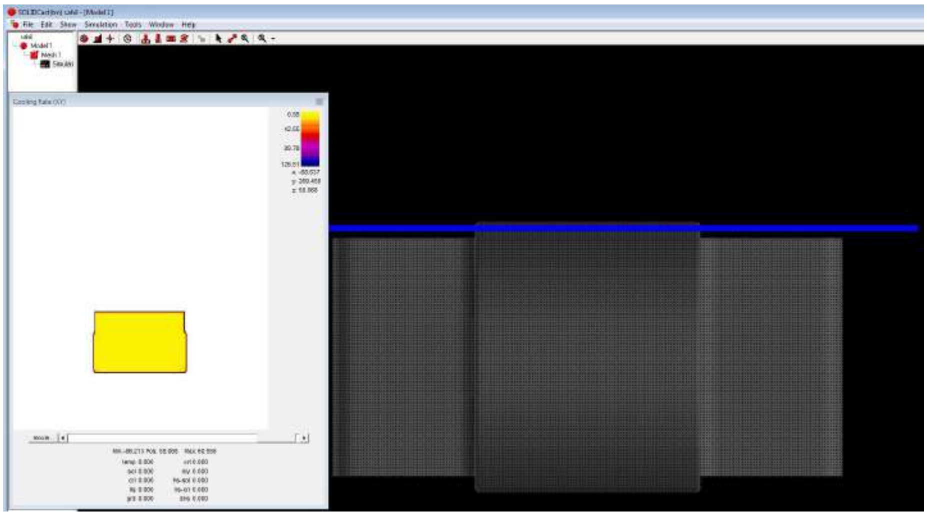
Analysis in CASTPIC Plot:



The cooling rate can be observed where cooling begins at edges and corners with a faster rate than the other parts of the job.

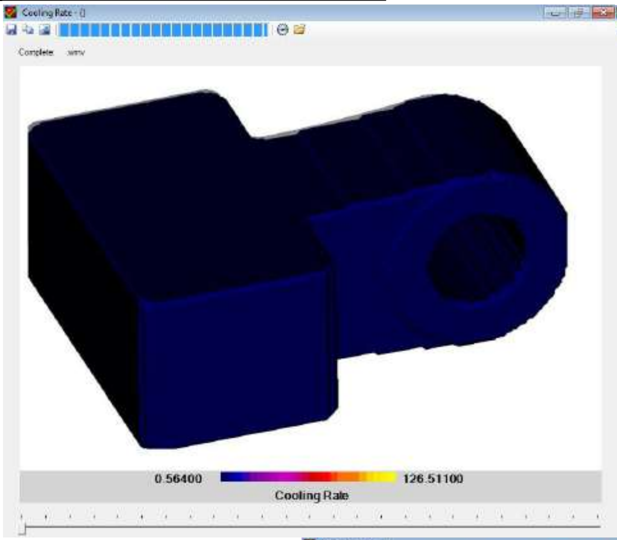
Analysis in Plot Cut Plane:

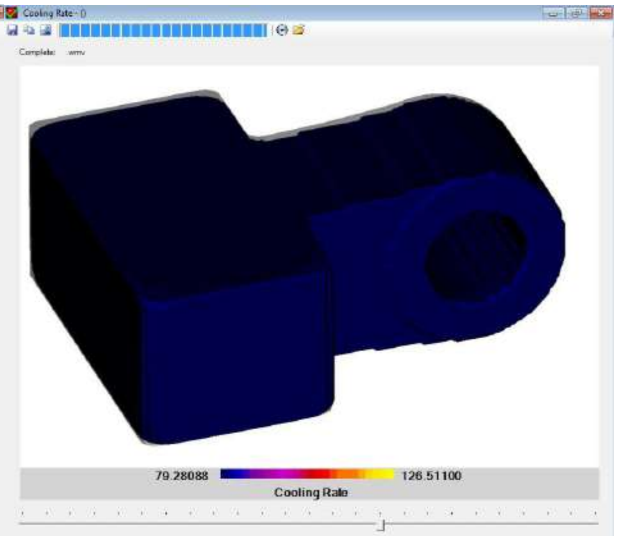


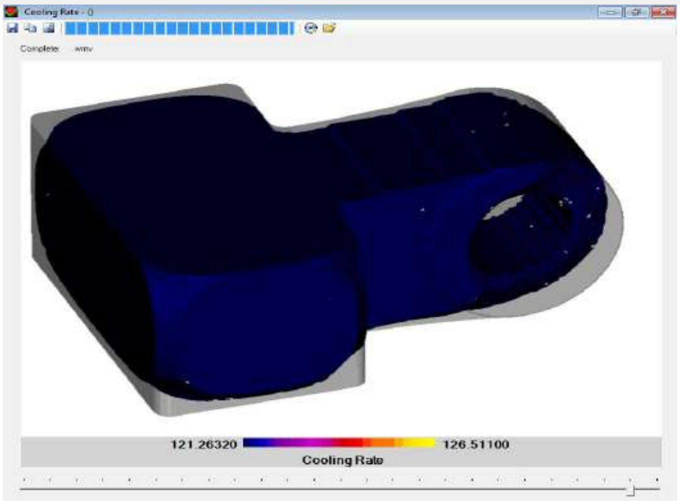


The uniform cooling rates can be achieved by the use of chills.

Analysis in Plot Iso Surface:



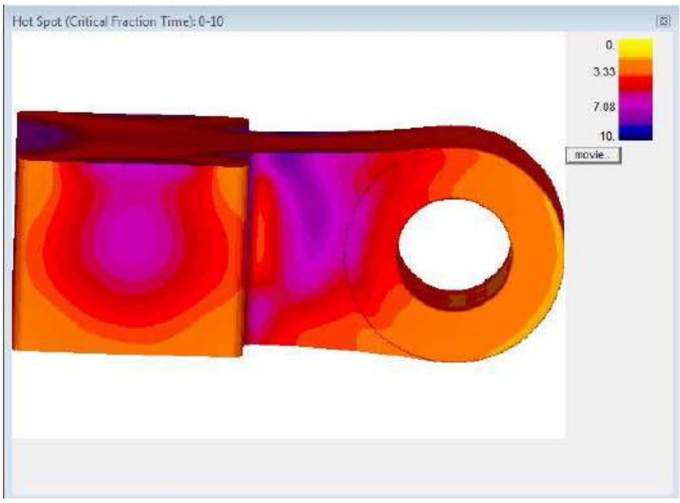




This differential cooling rate produces uneven contraction of parts and gives rise to internal strains in the metal.

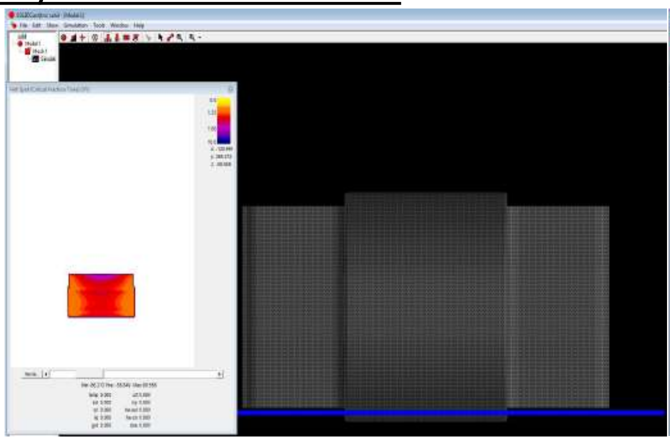
(iii) **Hot Spots (Critical Fraction Time):** Critical fraction solid time is the time for a part of the casting to reach the critical fraction solid point, the point at which the molten metal loses its ability to flow liquid feed metal from the time the pouring ends. It is a better indicator for looking at progressive solidification than solidification time. It also helps find if there are any isolated areas formed in the casting that cannot be fed by risers. It gives a good indication of whether any contraction that forms will be able to be fed by liquid feed metal with the risers or feeders. Hot spot plotting is a function in SOLIDCast that locates thermal centers or hot spots within the casting by comparing the solidification times or critical fraction solid times of each metal node to its neighbors. If it froze later than its neighbors, it is an isolated area, or a hot spot.

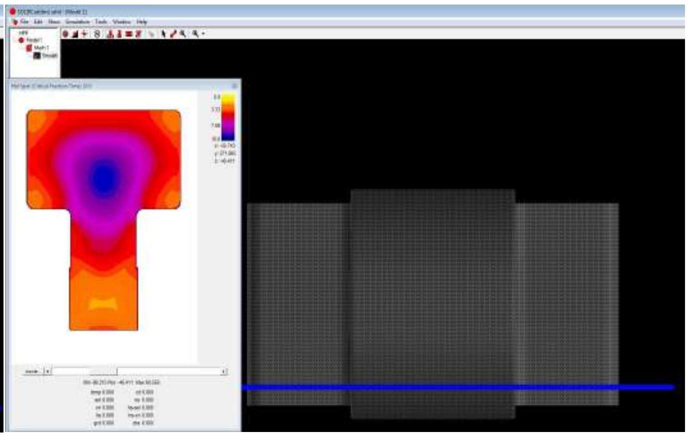
<u>Analysis in CASTPIC Plot:</u>



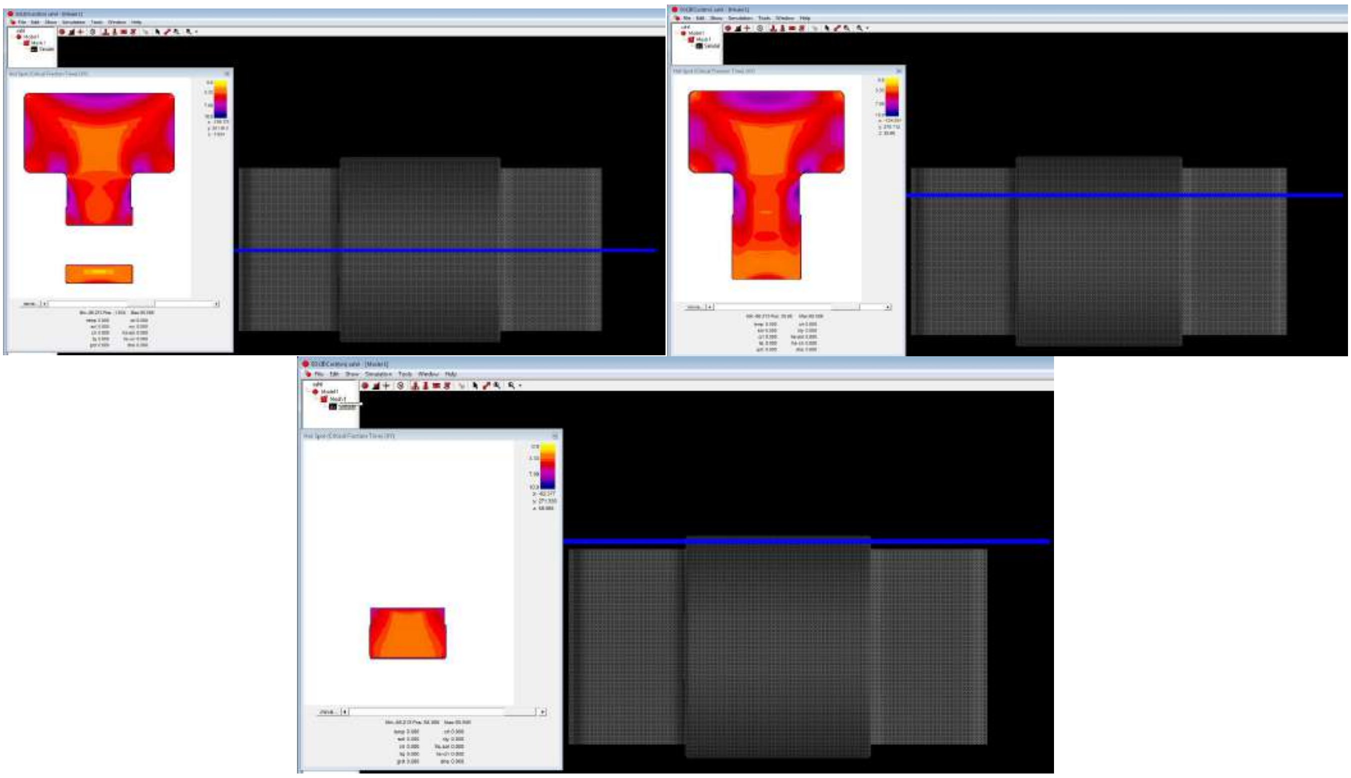
Hot spots are usually indicated by the low values of surface area/volume ratio. The surface area at the bulk is the least shown in blue.

<u>Analysis in Plot Cut Plane:</u>

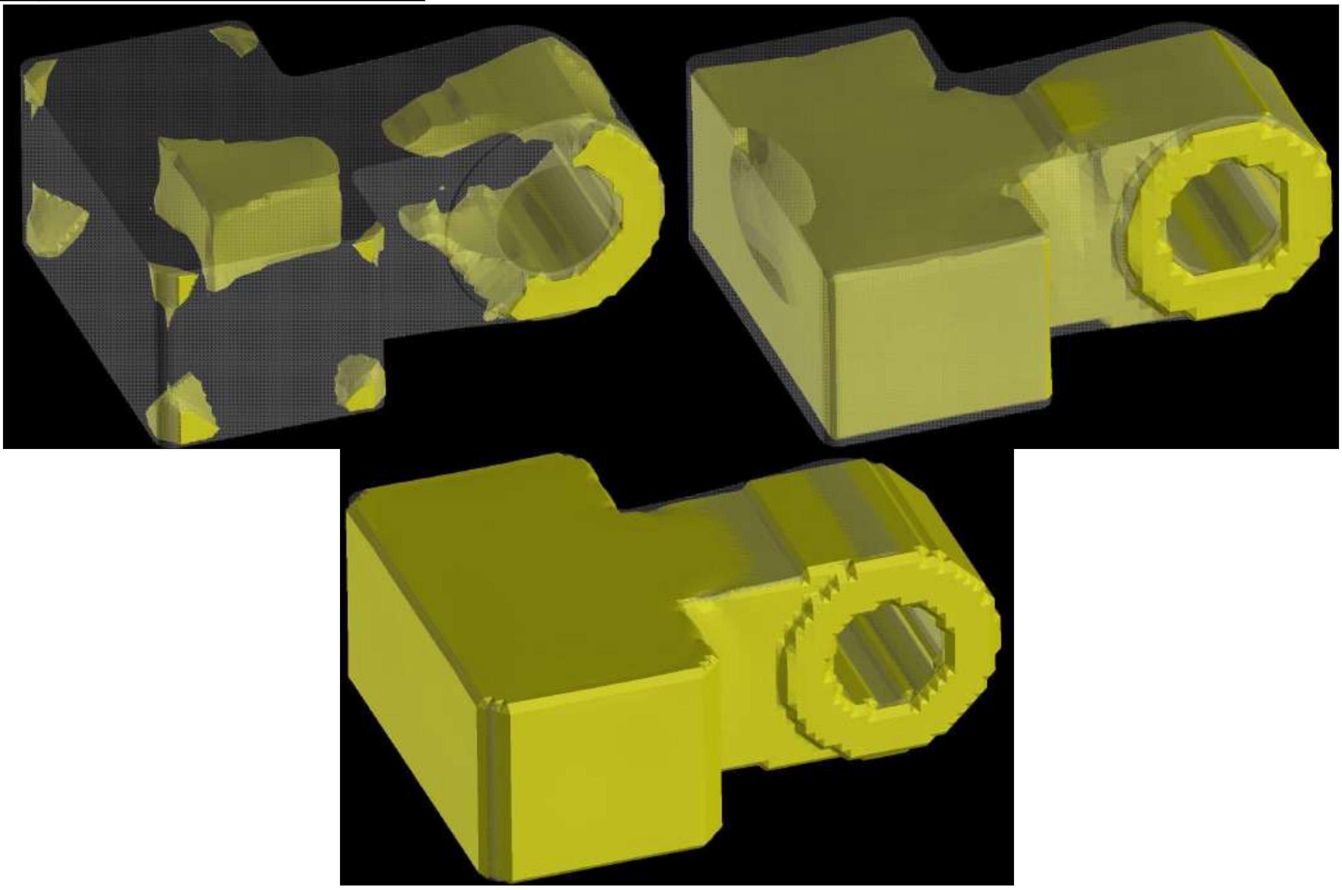




The various methods used for preventing hot spots include adequate provision of gates and risers, and proper manipulation of metal temperatures and pouring speeds.



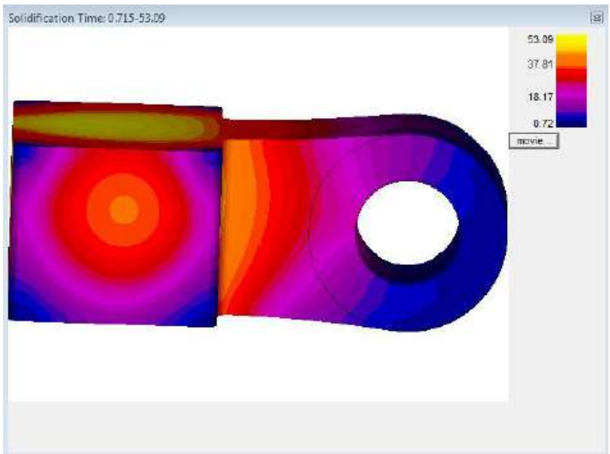
Analysis in Plot Iso Surface:



The nodes have solidified over time.

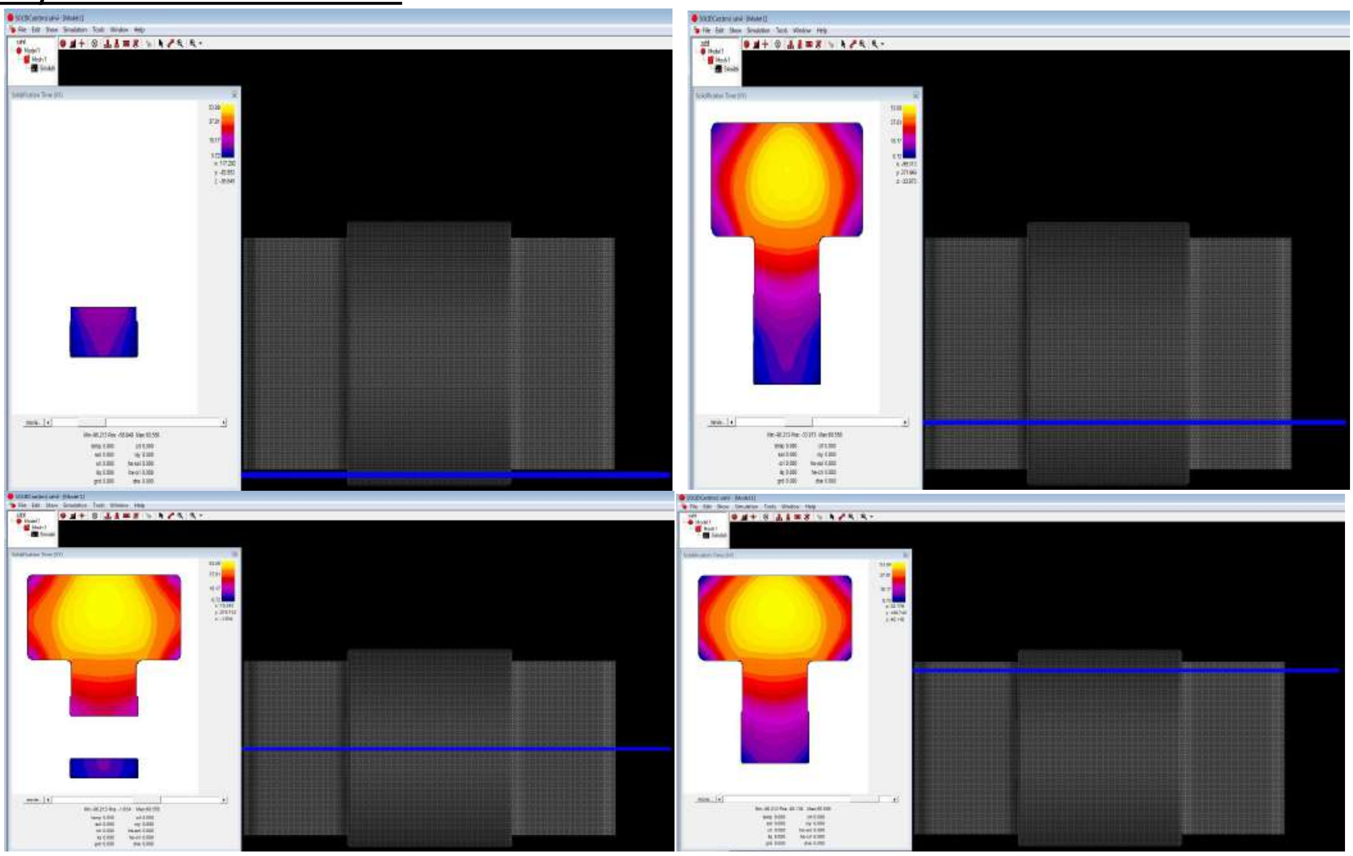
(iv) **Solidification Time**: It shows the time for each part of the casting to become completely solid, i.e., to cool to the Solidus Point. This can help to locate isolated areas of the molten metal within the casting and to get a general idea of progressive solidification in various areas of the casting. The isolated area is the area that is prone to shrinkage.

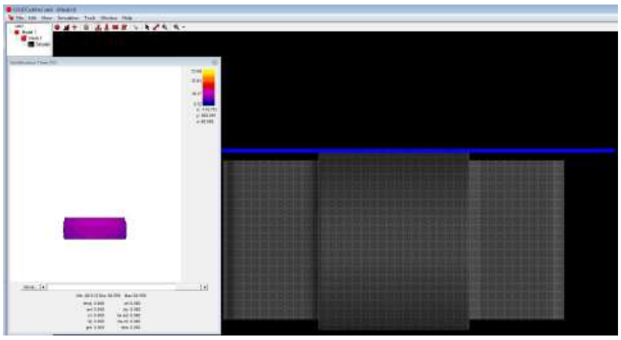
<u>Analysis in CASTPIC Plot:</u>



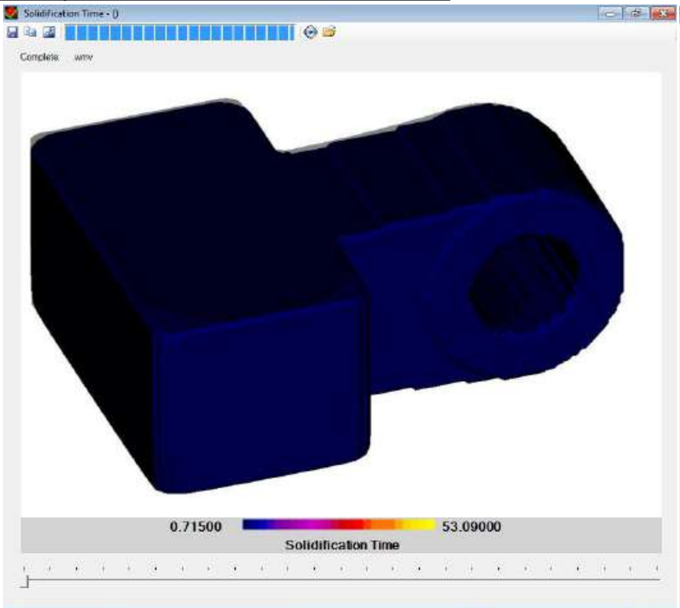
The solidification time at nodes can be observed. The bright yellow spot takes the longest time to solidify and the region is also called the hotspot.

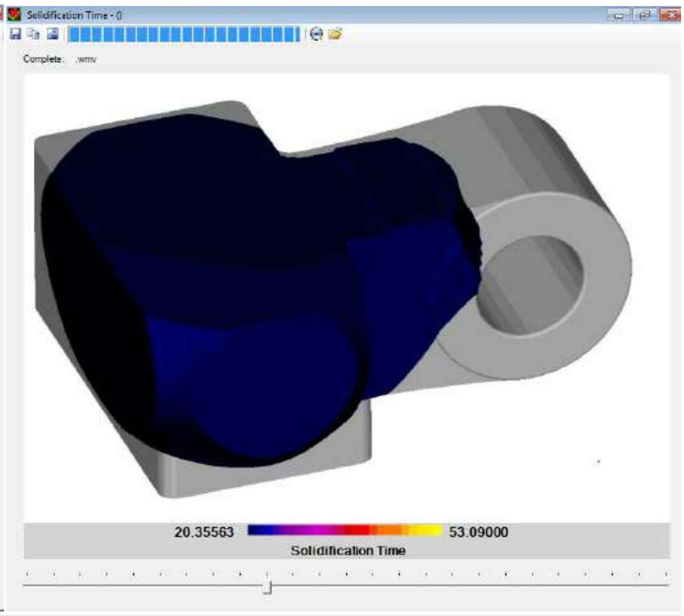
<u>Analysis in Plot Cut Plane:</u>

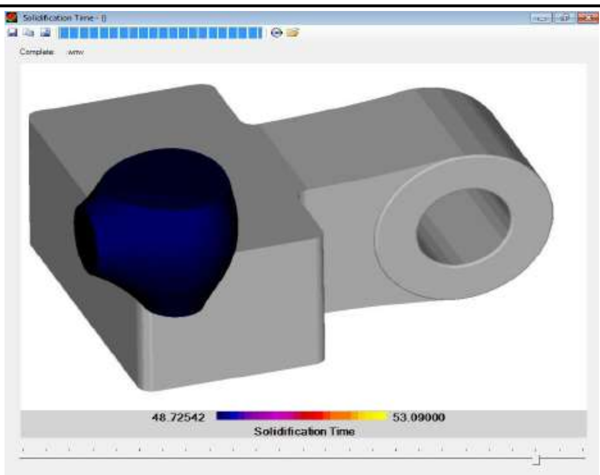




Analysis in Plot Iso Surface:







The metal solidifies over different instance of time

Conclusion

I, hereby conclude that, have learnt lot regarding sand casting and metallography of metals during this internship period.

Various testing described in the report ensure the quality and reliability of the final product, thus playing a crucial role in certifying the integrity and soundness of the casting.

Numerical simulations and optimization techniques can help foster the success and viability of the foundry industry for many years to come. The more capability and accuracy that is built into our simulation tools, the better and more efficient casting can be produced.

This internship provided me to observe and hands-on experience in the real industry. I had a taste of the real atmosphere in the workplace, as well as, a good relationship of mutual help and cooperation during my internship.

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