



# **Foundry Technology - II**

## **Students Handbook**

***Class XII***



**CENTRAL BOARD OF SECONDARY EDUCATION**  
2, COMMUNITY CENTRE, PREET VIHAR, DELHI - 110092



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## PREFACE

The Indian Foundry (Metal Casting) Industry is 2nd largest globally. The industry growth in 2010-11 was more than 20% and employs approximately 500,000 people directly and another 1.5 Million indirectly.

Metal castings is the process of melting the metals of different specification and alloys and pouring in cavities (Moulds) to give desired shapes of the final component as per required application. These components are ready to use either as it is or after machining as the case may be. Castings are made in various metallurgies such as grey iron, ductile iron, steel, aluminium and its alloys, zinc, magnesium and copper alloys etc. and then heat treated and machined as required as per use and application of the component.

Government of India has ambitious plans to boost share of manufacturing in the GDP to 25% from present 15-16% , the industry is likely to be driven by huge demand from various industrial sectors which will create an additional demand for 200,000 -250,000 skilled workforce in foundry industry at various levels in next five years. The foundry industry is facing acute shortage of skilled manpower and this shortage is likely to compound in next 5 years.

To address the problem of skilled manpower across various industrial sectors, CBSE has undertaken the ambitious project of introducing competency based Vocational Education in its affiliated schools. Taking cue from this need, a new course on Foundry Technology is being launched in cooperation with the Institute of Indian Foundrymen (IIF); that will help students to join the industry after Class XII or they can pursue higher education in this field.

The Board is grateful to the members of the Committee of Course for their advice, guidance and total commitment towards development of this course. We are indeed indebted to these academic advisors who have lent us the benefit of their rich and insightful experience. I would like to appreciate Vocational EducationCell, CBSE; for coordinating and successfully completing the work.

**Vineet Joshi**  
Chairman, CBSE



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# भारत का संविधान

## उद्देशिका

हम, भारत के लोग, भारत को एक सम्पूर्ण 'प्रभुत्व-संपन्न समाजवादी पंथनिरपेक्ष लोकतंत्रात्मक गणराज्य बनाने के लिए, तथा उसके समस्त नागरिकों को:

सामाजिक, आर्थिक और राजनैतिक न्याय,  
विचार, अभिव्यक्ति, विश्वास, धर्म  
और उपासना की स्वतंत्रता,  
प्रतिष्ठा और अवसर की समता

प्राप्त कराने के लिए

तथा उन सब में व्यक्ति की गरिमा

<sup>2</sup>और राष्ट्र की एकता और अखंडता  
सुनिश्चित करने वाली बधुता बढ़ाने के लिए

दृढ़संकल्प होकर अपनी इस संविधान सभा में आज तारीख 26 नवम्बर, 1949 ई० को एतद्वारा इस संविधान को अंगीकृत, अधिनियमित और आत्मार्पित करते हैं।

1. संविधान ( बयालीसवां संशोधन ) अधिनियम, 1976 की धारा 2 द्वारा ( 3.1.1977 ) से "प्रभुत्व-संपन्न लोकतंत्रात्मक गणराज्य" के स्थान पर प्रतिस्थापित।
2. संविधान ( बयालीसवां संशोधन ) अधिनियम, 1976 की धारा 2 द्वारा ( 3.1.1977 ) से "राष्ट्र की एकता" के स्थान पर प्रतिस्थापित।

## भाग 4 क

### मूल कर्तव्य

51 क. मूल कर्तव्य - भारत के प्रत्येक नागरिक का यह कर्तव्य होगा कि वह -

- (क) संविधान का पालन करे और उसके आदर्शों, संस्थाओं, राष्ट्रधर्वज और राष्ट्रगान का आदर करे;
- (ख) स्वतंत्रता के लिए हमारे राष्ट्रीय आंदोलन को प्रेरित करने वाले उच्च आदर्शों को हृदय में संजोए रखे और उनका पालन करे;
- (ग) भारत की प्रभुता, एकता और अखंडता की रक्षा करे और उसे अक्षण्ण रखें;
- (घ) देश की रक्षा करे और आहवान किए जाने पर राष्ट्र की सेवा करे;
- (ङ) भारत के सभी लोगों में समरसता और समान भ्रातृत्व की भावना का निर्माण करे जो धर्म, भाषा और प्रदेश या वर्ग पर आधारित सभी भेदभाव से परे हों, ऐसी प्रथाओं का त्याग करे जो स्त्रियों के सम्मान के विरुद्ध हैं;
- (च) हमारी सामासिक संस्कृति की गौरवशाली परंपरा का महत्व समझे और उसका परिरक्षण करे;
- (छ) प्राकृतिक पर्यावरण की जिसके अंतर्गत वन, झील, नदी, और वन्य जीव हैं, रक्षा करे और उसका संवर्धन करे तथा प्राणिमात्र के प्रति दयाभाव रखें;
- (ज) वैज्ञानिक दृष्टिकोण, मानववाद और ज्ञानार्जन तथा सुधार की भावना का विकास करे;
- (झ) सार्वजनिक संपत्ति को सुरक्षित रखे और हिंसा से दूर रहें;
- (ञ) व्यक्तिगत और सामूहिक गतिविधियों के सभी क्षेत्रों में उत्कर्ष की ओर बढ़ने का सतत प्रयास करे जिससे राष्ट्र निरंतर बढ़ते हुए प्रयत्न और उपलब्धि की नई उंचाइयों को छू ले;
- '(ट) यदि माता-पिता या संरक्षक है, छह वर्ष से चौदह वर्ष तक की आयु वाले अपने, यथास्थिति, बालक या प्रतिपाल्य के लिये शिक्षा के अवसर प्रदान करे।

1. संविधान ( छ्यासीवां संशोधन ) अधिनियम, 2002 द्वारा प्रतिस्थापित।

# THE CONSTITUTION OF INDIA

## PREAMBLE

**WE, THE PEOPLE OF INDIA**, having solemnly resolved to constitute India into a <sup>1</sup>**SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC** and to secure to all its citizens :

**JUSTICE**, social, economic and political;

**LIBERTY** of thought, expression, belief, faith and worship;

**EQUALITY** of status and of opportunity; and to promote among them all

**FRATERNITY** assuring the dignity of the individual and the<sup>2</sup> unity and integrity of the Nation;

**IN OUR CONSTITUENT ASSEMBLY** this twenty-sixth day of November, 1949, do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

1. Subs, by the Constitution (Forty-Second Amendment) Act. 1976, sec. 2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
2. Subs, by the Constitution (Forty-Second Amendment) Act. 1976, sec. 2, for "unity of the Nation" (w.e.f. 3.1.1977)

# THE CONSTITUTION OF INDIA

## Chapter IV A FUNDAMENTAL DUTIES

### ARTICLE 51A

**Fundamental Duties** - It shall be the duty of every citizen of India-

- (a) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;
- (b) to cherish and follow the noble ideals which inspired our national struggle for freedom;
- (c) to uphold and protect the sovereignty, unity and integrity of India;
- (d) to defend the country and render national service when called upon to do so;
- (e) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities; to renounce practices derogatory to the dignity of women;
- (f) to value and preserve the rich heritage of our composite culture;
- (g) to protect and improve the natural environment including forests, lakes, rivers, wild life and to have compassion for living creatures;
- (h) to develop the scientific temper, humanism and the spirit of inquiry and reform;
- (i) to safeguard public property and to abjure violence;
- (j) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement;
- <sup>1</sup>(k) to provide opportunities for education to his/her child or, as the case may be, ward between age of 6 and 14 years.

1. Subs, by the Constitution (Eighty-Sixth Amendment) Act. 2002.

## GENERAL INSTRUCTIONS TO THE STUDENTS

1. Since the Subject 'Foundry Technology II' is the second and concluding part of Foundry Technology I of Class XI, it is important to revise periodically the basic features of Foundry as discussed in the Guide book for Class XI.
2. It is expected that the student will have the ability to co-relate the topics on Chapter 1 : Special Moulding and Casting processes and Chapter 3: Foundry Practice for ferrous and non-ferrous metals of Class XII Guide Book with the fundamental requirements of pattern design and mould feeding covered in Class XI Guide book.
3. The student should try to gain as much knowledge as possible during visits to Foundries which is part of the sessional assignments. Such visits should act as powerful visual aid to the written text and information learnt from instructors of foundry shop floor should complement the Guide book. Chapter 5 of the Guide Book on Testing can be understood properly only by observations of actual testing procedures.
4. Each student must go through the relevant points on moulding, casting and testing from Guide Book before a factory Visit, so that the mind is already alert and ready to understand the shop floor activities. The student should not hesitate to ask "why" and "how" on the production and quality control activities during factory visits. Such questions and answers should be noted down in pocket note books which shall be the basis of writing more elaborate Reports. Since every one may not observe everything or may not be able to listen to completely the explanations of the Foundry personnel, collaborative Group activity is called for to gain the full benefit of such visits.
5. Proper caution regarding is mandatory during factory visits. All safety requirements must be followed strictly.
6. The student should note down the measures taken in a particular foundry and use of Control charts or Diagrams regarding quality control.

## MODULE OBJECTIVES

S.No.	Unit / Chapter Name	Theory	Key Learning Objectives
1	Special Moulding and Casting processes	25hrs	<ul style="list-style-type: none"> <li>▶ Difference between sand moulding and casting with casting in metal moulds</li> <li>▶ Production in mechanised foundry using metal dies used as moulds</li> <li>▶ Importance of the various casting process with metal moulds rotated with centrifugal force</li> <li>▶ Production of <i>precision castings</i> which has a growing market</li> </ul>
2	Melting and Pouring practice	25hrs	<ul style="list-style-type: none"> <li>▶ Types of melting furnace</li> <li>▶ Logic of selection of furnace</li> <li>▶ Basic concept of furnaces run with different fuels</li> <li>▶ Treatment of melt outside the furnace and pouring practice</li> </ul>
3	Foundry Practice for ferrous and non-ferrous metals	30 hrs	<ul style="list-style-type: none"> <li>▶ Method of production of different types of cast irons</li> <li>▶ Foundry methods to produce steel castings, including alloy steels</li> <li>▶ Special methods to produce non-ferrous alloy castings</li> <li>▶ Differences between casting methods of ferrous and non-ferrous alloys</li> </ul>
4	Cast Metals Technology	20 hrs	<ul style="list-style-type: none"> <li>▶ Basic concepts on the internal structure of metals and the relation of structure and phases with mechanical properties</li> <li>▶ Types of cast irons and their properties</li> <li>▶ Features of cast plain carbon and alloy steels</li> <li>▶ Important cast non-ferrous alloys</li> </ul>
5	Testing and Quality Assurance in Foundry	20 hrs	<ul style="list-style-type: none"> <li>▶ Testing of physical hardness and tensile properties of castings</li> <li>▶ Casting defects – features and remedial measures, which can be co-related with precautions needed in moulding, methoding etc</li> </ul>

# CHAPTER 1: SPECIAL MOULDING AND CASTING PROCESSES

## 1.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource Material
- Duration
- Learning outcomes
- Assessment Plan

### 1.1 Introduction

### 1.2 Gravity Die Casting

### 1.3 Pressure Die Casting

### 1.4 Centrifugal Casting

### 1.5 Shell Mould Casting

### 1.6 Investment Casting

### 1.7 Plaster Mould Casting

### 1.8 Ceramic Mould Casting

### 1.9 Summary

## 1.0 Unit Overview & Description:

### Overview:

This unit will provide the student information about various special moulding and casting processes in the foundry industry. It will help to understand the properties and applications of various productions of castings.

### Knowledge and skill outcomes

- i) Understand of concept of various casting process.
- ii) Know the Properties and Considerations of various casting techniques.
- iii) Observe the advantages and limitations of each casting process used in industries.
- iv) Know the field of applications of various casting process.

### Resource Materials

1. Jain P L, "Principles of Foundry Technology", Tata McGraw Hill Publishing Company Ltd., 2010.
2. <http://www.youtube.com/watch?v=v4i2INpJnVM>
3. [http://www.wiley.com/college/dec/meredith298298/resources/cases/cases\\_s\\_06c.html](http://www.wiley.com/college/dec/meredith298298/resources/cases/cases_s_06c.html)

<b>Duration:</b>	Total Hours 25
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## Learning Outcomes:

Unit-1	Special moulding and casting processes	Outcomes
1.2	Gravity Die Casting	<ul style="list-style-type: none"> <li>• Demonstrate gravity die casting process</li> <li>• Identify gravity die casting process</li> <li>• List advantages, limitations and application of gravity die casting</li> </ul>
1.3	Pressure Die Casting	<ul style="list-style-type: none"> <li>• Identify pressure die casting process</li> <li>• List types of pressure die casting</li> <li>• Demonstrate process description of hot chamber pressure die casting</li> <li>• Demonstrate process description of cold chamber pressure die casting</li> </ul>
1.4	Centrifugal Casting	<ul style="list-style-type: none"> <li>• Understand meaning of centrifugal casting process</li> <li>• List types of centrifugal casting process</li> <li>• Identify various centrifugal casting process</li> <li>• Demonstrate true centrifugal casting</li> <li>• Demonstrate semi centrifugal casting</li> <li>• Demonstrate centrifuge centrifugal casting</li> </ul>
1.5	Shell Mould Casting	<ul style="list-style-type: none"> <li>• Understand shell mould casting process</li> <li>• Demonstrate shell mould casting</li> <li>• List advantages, limitations and application of shell mould casting</li> </ul>
1.6	Investment Casting	<ul style="list-style-type: none"> <li>• Understand meaning of investment casting process</li> <li>• Demonstrate investment Casting</li> <li>• List advantages, limitations and application of investment casting</li> </ul>
1.7	Plaster Mould Casting	<ul style="list-style-type: none"> <li>• Understand meaning of plaster mould casting process</li> <li>• Demonstrate plaster mould Casting</li> <li>• List advantages, limitations and application of plaster mould</li> </ul>
1.8	Ceramic Mould Casting	<ul style="list-style-type: none"> <li>• Identify meaning of ceramic mould casting process</li> <li>• Demonstrate ceramic mould Casting</li> <li>• List advantages, limitations and application of ceramic mould casting</li> </ul>

## Assessment Plan: (For the Teachers)

Unit-1	Topic	Assessment Method	Time Plan	Remarks
1.2	Gravity Die Casting	Exercise: Question & Answer		
1.3	Pressure Die Casting	Exercise: Question & Answer		
1.4	Centrifugal Casting	Exercise: Question & Answer		
1.5	Shell Mould Casting	Exercise: Question & Answer Group Discussion		
1.6	Investment Casting	Exercise: Question & Answer		
1.7	Plaster Mould Casting	Exercise: Question & Answer		
1.8	Ceramic Mould Casting	Exercise: Question & Answer		

## 1.1 Introduction

The traditional method of casting metals is in sand moulds and has been used for millennia. In general the permanent mould casting processes refers to metal mould casting processes which differ from sand casting processes. Although the origins of sand casting date to ancient times, it is still the most prevalent form of casting. Advanced machinery and automated process-control systems have replaced traditional methods of casting. The casting industry is the increasing demand for high-quality casting with close tolerances. This demand is spurring the further development of special moulding and casting processes that produce high quality castings.

Permanent moulds are used repeatedly and are designed in such a way that casting can be easily removed and the moulds can be used for the next casting. Some of the permanent moulding processes are gravity die casting, slush casting, pressure die casting, centrifugal casting, shell moulding, investment casting, continuous casting, slush casting, shot casting and flush casting, etc.

## 1.2 Gravity Die Casting

Basic permanent mould casting is metal casting process that employs reusable moulds ("permanent moulds"), usually made from heat resistant metal. The most common process uses gravity to fill the mould, however gas pressure or a vacuum are also used. This process is known as 'gravity die casting' in England and as 'permanent mould casting' in USA. Here molten metal is poured into the mould

under gravity only, no external pressure is applied. The basic permanent mould casting, sometimes referred to as gravity die casting, a metal mould consisting of two or more parts is repeatedly used for the production of many castings of the same form. The liquid metal enters the mould by gravity. Common casting metals are aluminum, magnesium, and copper alloys. Other materials include tin, zinc, and lead alloys and iron and steel are also cast in graphite moulds. Typical parts include gears, splines, wheels, gear housings, pipe fittings, fuel injection housings, and automotive engine pistons.

### 1.2.1 Moulds for Gravity die casting

Moulds for the casting process consist of two halves. Casting moulds are usually formed from grey cast iron because it has about the best thermal fatigue resistance, but other materials include steel, bronze, and graphite. These metals are chosen because of their resistance to erosion and thermal fatigue.

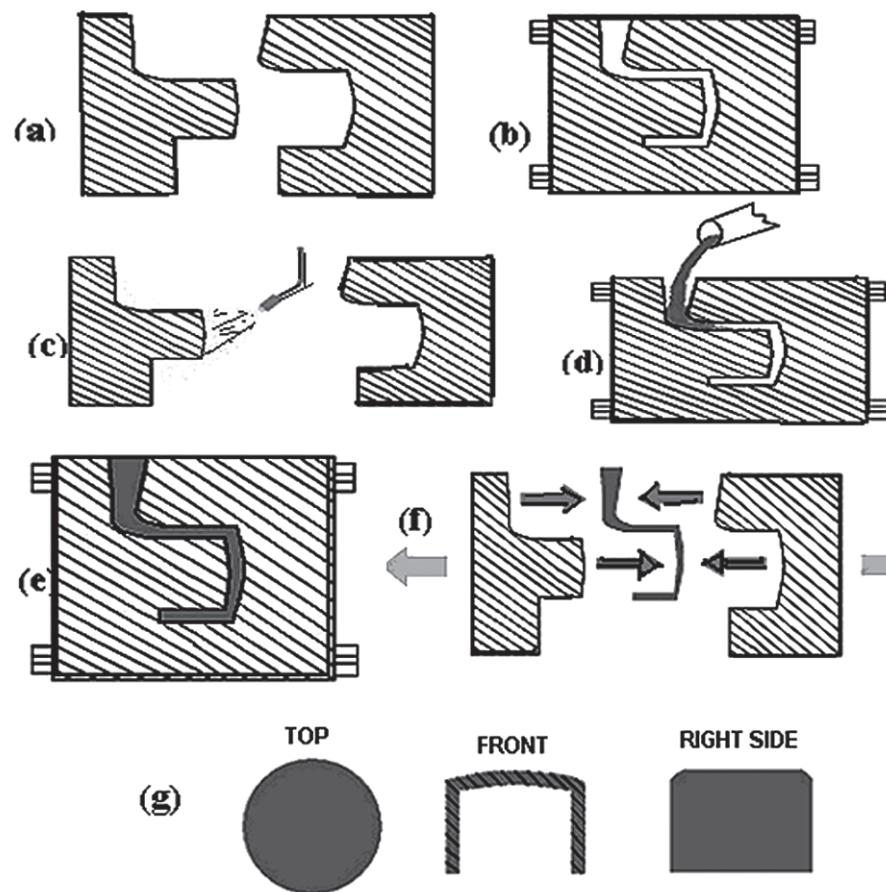
The mould is heated prior to the first casting cycle and then used continuously in order to maintain as uniform a temperature as possible during the cycles. This decreases thermal fatigue, facilitates metal flow, and helps control the cooling rate of the casting metal.

Venting usually occurs through the slight gap between the two mould's halves, but if this is not enough then very small vent holes are used. They are small enough to let the air escape but not the molten metal. A riser must also be included to compensate for shrinkage. This usually limits the yield to less than 60%. Mechanical ejectors in the form of pins are used to remove casts from the moulds. These pins are placed throughout the mould and usually leave small round impressions on the casting.

### 1.2.2 Process Description of Gravity Die Casting

In the permanent mould casting process, two halves of mould is made from materials such as cast iron, steel, bronze, graphite, or refractory metal alloys. The mould cavity and gating system are machined into the mould and thus become an integral part of it. To produce castings with internal cavities, cores made of metal or sand aggregate are placed in the mould prior to casting. Typical core materials are oil bonded or resin-bonded sand, plaster, graphite, grey iron, low-carbon steel, and hot-work die steel. Grey iron is the most commonly used, particularly for large moulds for aluminium and magnesium castings. The schematic sketch of steps of permanent mould casting process is shown in Fig 1.1.

In order to increase the life of permanent moulds, the surfaces of the mould cavity are usually coated with refractory slurry, such as sodium silicate and clay, or sprayed with graphite every few castings. These coating also serve as parting agents and as thermal barriers, controlling the rate of cooling of the casting.



**Fig.1.1 Schematic sketch of steps of basic permanent mould casting process**

(a) Two halves of a permanent mould (cross – sectional), (b) permanent mould assembled, (c) permanent mould being sprayed with refractory slurry before the casting operation, (d) Pouring of permanent mould (gravity fed process), (e) Solidification of casting in permanent mould, (f) permanent mould is opened and solidified casting is ejected and (g) Views of metal casting produced (piston)

Non-ferrous metals are typically used in this process, such as aluminum alloys, magnesium alloys, and copper alloys because of their low melting points. However, irons and steels can also be cast using graphite moulds. Although the permanent-mould casting operation can be performed manually, the process can be automated for large production runs.

### 1.2.3 Advantages

This process produces castings with good surface finish and close tolerances

- Good mechanical properties, and at high production rates.
- Higher production rates than sand casting, but much slower than die casting.
- High dimensional accuracy (+/- 0.010").
- Excellent mechanical properties
- Reduced machining
- Cast-in inserts

- Reduced porosity and inclusions
- Permanent mould castings can be CNC machined, powder coated, anodized and heat treated

### 1.2.4 Limitations

- The casting design must be simple enough and with sufficient draft so that the ejection from the mould is feasible.
- Because of mould cost, the process has limited application.
- Limited to low melting point metals

### 1.2.5 Applications

Manufacturing of carburetor bodies, refrigeration castings, hydraulic brake cylinders, connecting rods, washing machine gears and gear covers, oil pump bodies, typewriter segments, vacuum pump cylinders, small crankshafts and many others.

#### Review questions:

1. What is permanent mould casting?
2. How moulds are prepared in the gravity die casting?
3. Describe processes of making gravity die castings.
4. What are the advantages and limitations of permanent mould casting process?
5. What metals can be cast by this process?

## 1.3 Pressure Die Casting

Die casting is a permanent mould manufacturing process that was developed in the early 1900's. Die casting manufacture is characteristic in that it uses large amounts of pressure to force molten metal through the mould. Since so much pressure is used to ensure the flow of metal through the mould, metal castings with excellent surface finish, faithful reproduction of details, dimensional accuracy, and extremely thin walls can be produced. Wall thickness within castings can be manufactured as small as 0.05 mm. The size of industrial castings using this process vary from extremely small to around 25 kg. Typical parts made in industry by die casting include tools, toys, carburetors, machine components, various housings, and motors. The most common alloys suitable for pressure die casting are Zinc-base alloys and Aluminium-base alloys.

### 1.3.1 Properties and consideration of manufacturing

- Castings with close tolerances, tremendous surface detail, and thin intricate walls can be manufactured using this process.
- Die may have special passages built into them that water is cycled through in order to keep down thermal fluctuations and increase die life.
- The very high initial cost is justified only for long production run or large number of the same item.

- Since the metal mould (dies) is not permeable, adequate vents need to be provided for the elimination of gases during the casting process. These vents are usually placed along the parting line between the die. Even then, gas hole appear frequently within the wall thickness of the castings. So, these are not suitable to bear load.
- Due to the high pressures a thin flash of metal is usually squeezed out at the parting line. This flash has to be trimmed latter from the casting.
- Equipment cost for die casting is generally high.
- Die casting manufacture can be highly automated making labor cost low.

### **1.3.2 Advantages**

- It can form complex shapes.
- Very good surface finish and accuracy.
- High production rate. Extremely economical for large scale production.
- Scrap can be recycled.
- Thin section can be cast

### **1.3.3 Limitations**

- Only certain non-ferrous alloys can be cast economically.
- The maximum size is limited by the size of dies and capacity of the die casting machine.
- Trimming is required
- High tooling and equipment cost
- Limited die life
- Long lead time to start production after getting the order, because machining to make the dies from a drawing , using a strong die alloy takes a long time

### **1.3.4 Types of Die Casting Machines**

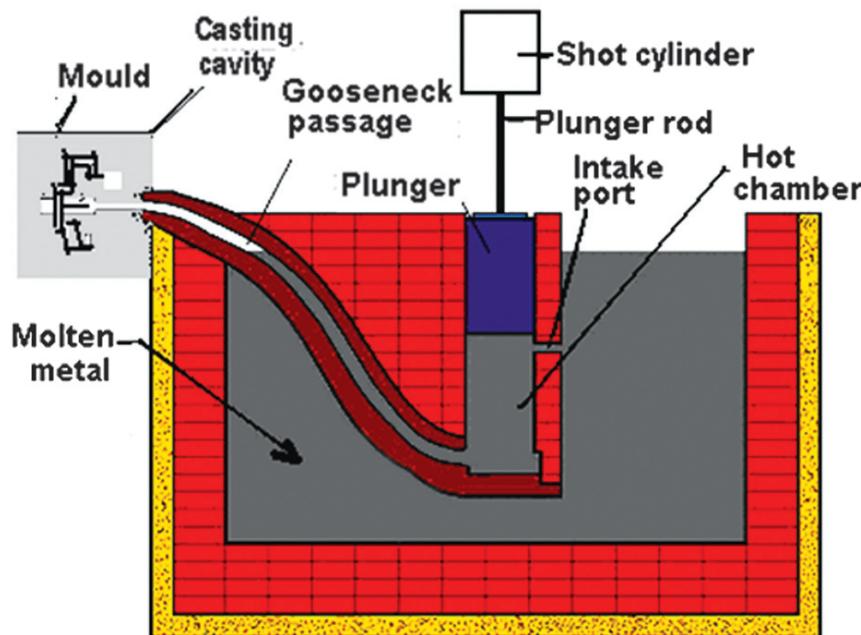
Two principal types of die casting machines are used.

- (i) Hot chamber die casting machine and
- (ii) Cold chamber die casting machine

#### **(i) Hot chamber die casting machine**

A common feature of both the die casting processes is the use of pressure to force molten metal through metal mould called a 'die'. Many of the superior qualities of castings manufactured by die casting, (such as great surface detail), can be attributed to the use of pressure to ensure the flow of metal through the die.

In hot chamber die casting process, the reservoir of molten metal is attached to the die casting machine and is an integral part of the casting apparatus for this manufacturing operation. Hot chamber machines are used for alloys with low melting temperatures, such as zinc, tin, and lead. The temperatures required to melt other alloys would damage the pump, which is in direct contact with the molten metal.



**Fig. 1.2 Hot Chamber die casting process**

The metal is contained in an open holding pot which is placed into a furnace, where it is melted to the necessary temperature. The molten metal then flows into a hot chamber through an inlet (intake port) and a plunger, powered by hydraulic pressure, forces the molten metal through a gooseneck channel and into the die. The schematic sketch of hot chamber die casting is shown in the Fig 1.2. Typical injection pressures for a hot chamber die casting machine are between 1000 and 5000 psi. After the molten metal has been injected into the die cavity, the plunger remains down, holding the pressure while the casting solidifies. After solidification, the hydraulic system retracts the plunger and the part can be ejected by the clamping unit.

In preparation for the next cycle of casting manufacture the plunger travels back upward in the hot chamber exposing the intake ports again and allowing the chamber to refill with molten material.

Hot chamber die casting has the advantage of a very high rate of productivity. During industrial manufacture by this process one of the disadvantages is that the setup requires that critical parts of the mechanical apparatus, (such as the plunger), must be continuously submerged in molten material. Continuous submersion in a high enough temperature material will cause thermal related damage to these components rendering them inoperative. For this reason usually only lower melting point alloys of lead, tin and zinc are used to manufacture castings with the hot chamber die casting process.

## (ii) Cold chamber die casting machine

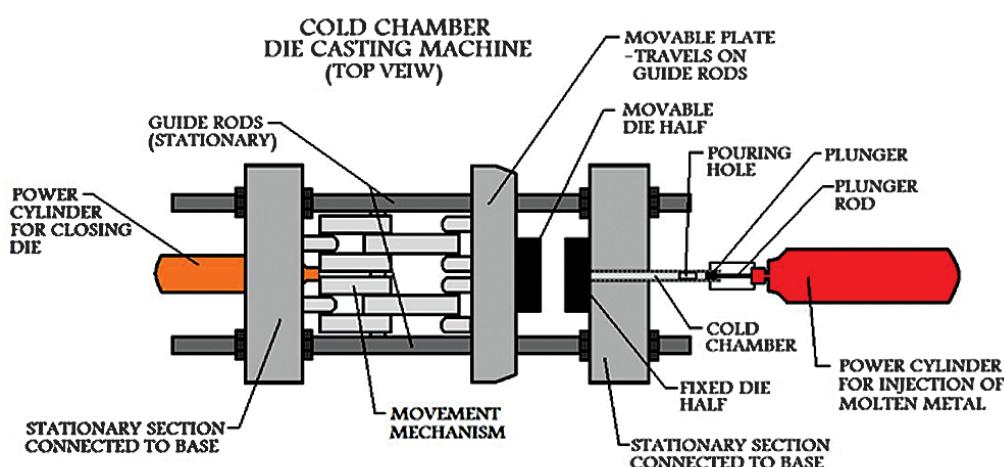
Cold chamber die casting is a permanent mould metal casting process, a reusable mould gating system and all is employed. It is most likely machined precisely from two steel blocks. Large robust machines are used to exert the great clamping force necessary to hold the two halves of the mould together against the tremendous pressures exerted during the manufacturing process.

Cold chamber machines are used for alloys with high melting temperatures that can not be casted in hot chamber machines because they would damage the pumping system. Such alloys include aluminum, brass, and magnesium. The molten metal is still contained in an open holding pot which is placed into a furnace, where it is melted to the necessary temperature. However, this holding pot is kept separate from the die casting machine and the molten metal is ladled from the pot for each casting, rather than being pumped. The metal is poured from the ladle into the shot chamber through a pouring hole. The injection system in a cold chamber machine functions similarly to that of a hot chamber machine; however it is usually oriented horizontally. The schematic sketch of cold chamber die casting machine is shown in the Fig 1.3. A metal shot chamber (cold-chamber) is located at the entrance of the mould. A piston is connected to this chamber which in turn is connected to a power cylinder.

At the start of the manufacturing cycle the correct amount of molten material for a single shot is poured into the shot chamber from an external source holding the material for the metal casting. A plunger, powered by hydraulic pressure, forces the molten metal through the shot chamber and into the injection sleeve in the die. The typical injection pressures for a cold chamber die casting machine are between 2000 and 20000 psi. After the molten metal has been injected into the die cavity, the plunger remains forward, holding the pressure while the casting solidifies. After solidification, the hydraulic system retracts the plunger and the part can be ejected by the clamping unit. The mould is sprayed with lubricant before closing again, and the piston is withdrawn in the shot chamber for the next cycle of production.

Once the mould has been filled with molten metal the pressure is maintained until the casting has solidified. The mould is then opened and the casting is removed. Ejector pins built into the mould assist in the removal of the metal casting.

In most manufacturing operations the internal surfaces of the mould are sprayed with a lubricant before every cycle. The lubricant will assist in cooling down the dies as well as preventing the metal casting from sticking to the mould.



**Fig. 1.3 Cold Chamber Die Casting Machine**

After the casting has been removed and the lubricant applied to the mould surfaces the die are clamped together again then the cycle will repeat itself. Cycle times will differ

depending upon the details of each specific die casting manufacturing technique. In some instances very high rates of production have been achieved using this process.

### 1.3.5 Difference between Hot Chamber and Cold Chamber Die Casting Machine

- The main difference between cold-chamber die casting and hot-chamber die casting manufacture is that in the cold-chamber process the molten metal for the casting is introduced to the shot chamber from an external source, while in the hot chamber process, the source of molten material is attached to the machine.
- Since the liquid metal is brought in from an outside source the die casting machinery is able to stay much cooler in a cold-chamber process. Consequently higher melting point alloys of aluminum, brass, copper, and aluminum-zinc are often cast in manufacturing industry using cold chamber die casting. It is very possible to manufacture castings from lower melting point alloys using the cold-chamber method. When considering industrial metal casting manufacture however the advantages of production by the hot-chamber process usually make it the more suitable choice for lower melting point alloys.
- In the cold chamber die casting process, material must be brought in for every shot or cycle of production. This slows down the production rate for metal casting manufacture, where in the hot chamber process castings can be constantly produced.
- In comparison with the hot die casting process, the cold die casting process requires the application of more pressure of about 20 - 350 MPa. Castings manufactured by cold chamber die casting have all the advantages characteristic of the die casting process, such as intricate detail, thin walls, and superior mechanical properties. The significant initial investment into this manufacturing process makes it suitable for high production applications.

#### Review questions

- What is pressure die casting? What are its process characteristics?
- State the advantages and limitations of pressure die casting.
- List out the types of pressure die casting.
- Explain with sketch the operation and control of hot chamber die casting process.
- Explain with sketch the operation and control of cold chamber die casting process.
- Differentiate between hot chamber die casting process and cold chamber die casting process.

## 1.4 Centrifugal Casting Processes

As its name implies, the centrifugal casting process utilizes the inertial forces caused by rotation to distribute the molten metal into the mould cavities. This method was first suggested in the early 1800s. The manufacturing process of centrifugal casting is a metal casting technique that uses the forces generated by centripetal acceleration to distribute the molten material in the mould. The characteristics of centrifugal casting process are:

- i) The pipe castings are relatively free from defects. Non metallic impurities which segregate toward the bore can be machined off.
- ii) Less loss of metal in tundish compared to that in gating and risering in conventional sand casting.
- iii) Better mechanical properties.
- iv) Production rate is high.
- v) Can be employed to manufacture bimetallic pipes – pipes made up of.

Centrifugal casting has many applications in manufacturing industry today, such as production of pipes for water, gas and sewage; bearing bushes; cylinder liners; piston rings, paper making rollers; clutch plates; pulleys.

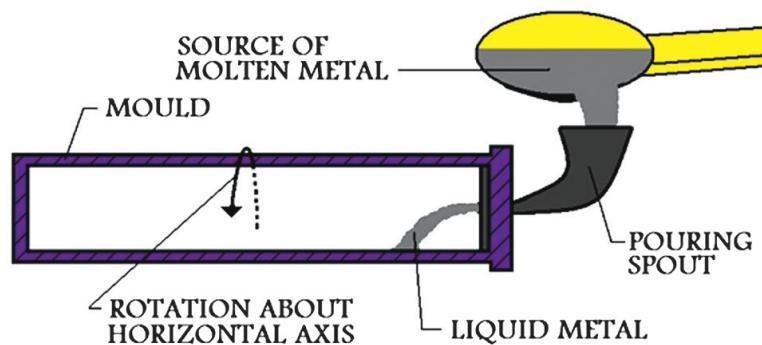
There are three types of centrifugal casting:

- (i) True centrifugal casting
- (ii) Semi-centrifugal casting
- (iii) Centrifuge centrifugal casting.

### 1.4.1 True centrifugal casting

In true centrifugal casting hollow cylindrical parts, such as pipes, gun barrels, and streetlamp posts, are produced by the technique shown in Fig.1.4, in which molten metal is poured into a rotating mould. The rate of pouring is important and is carefully regulated. The molten material for the cast part is introduced to the mould from an external source, by a spout. The liquid metal flows down into the mould, once inside the cavity the centrifugal forces from the spinning mould force the molten material to the outer wall. The axis of rotation is usually horizontal but can be angular or vertical for short work pieces. Moulds are made of steel, iron, or graphite and may be coated with a refractory lining to increase mould life. The mould surfaces can be shaped so that pipes with various outer shapes, including square or polygonal, can be cast. The inner surface of the casting remains cylindrical because the molten metal is uniformly distributed by centrifugal forces. However, because of density differences, lighter elements such as dross, impurities, and pieces of the refractory lining tend to collect on the inner surface of the casting.

Cylindrical parts ranging from 13 mm to 3 m in diameter and 16 m long can be cast centrifugally, with wall thicknesses ranging from 6 mm to 125 m.



**Fig.1.4 Schematic illustration of the True centrifugal casting process**

Thickness of the cast part can be determined by the amount of material poured. Most impurities within the material have a lower density than the metal itself; this causes them to collect in the inner regions of the metal casting closer to the center of the axis of rotation. These impurities can be removed during the casting operation or they can be machined off later.

For a given melt composition, the controlling variables are: i) rate of feeding by the spout (ii) rpm of the machine, which can be adjusted iii) pouring temperature of the melt iv) angle of tilt of the cylinder.

### a) Advantages

- i) Dense and fine grained metal castings are produced by true centrifugal casting
- ii) Clean metal casting is obtained as lighter impurities such as sand, slag, oxides and gas float quickly towards the centre of rotation from where they can be easily machined out.
- iii) No requirement of central core to produce pipe.
- iv) Gating system is not required, this increases yield of the casting as high as 100% in some cases.
- v) Quality castings with good dimensional accuracy can be produced with this process.
- vi) True centrifugal casting is a manufacturing process that is capable of very high rates of productivity.

### b) Limitations

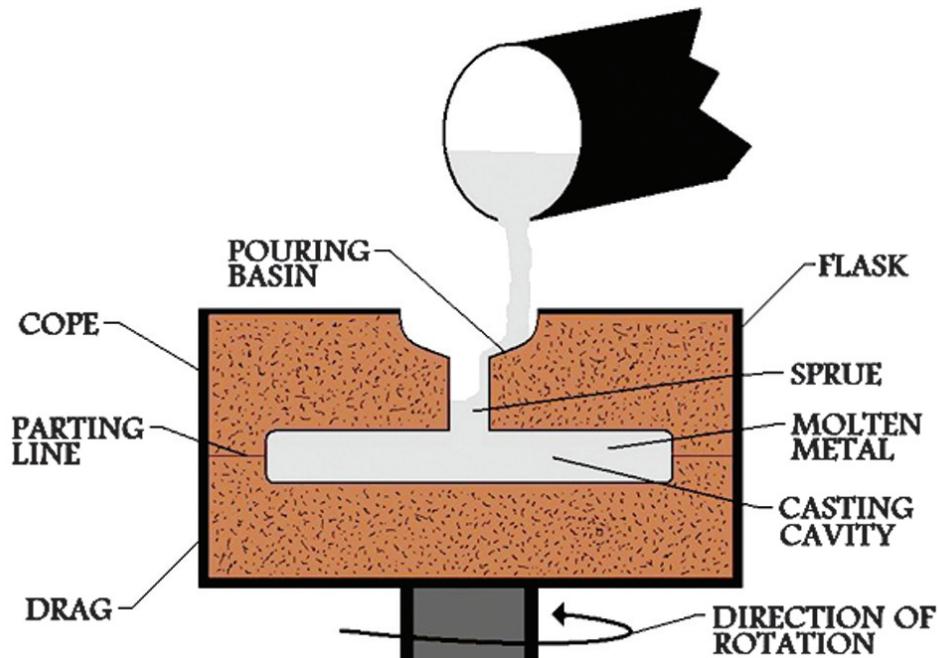
- i) This process is limited to certain shape
- ii) High equipment cost
- iii) Skilled manpower required for operation and maintenance
- c) Applications
- i) Cast iron pipes, alloy steel pipes.
- ii) Bearings for electric motors and machinery.
- iii) Liners for I.C. engines.

## 1.4.2 Semi-centrifugal casting

This method is used to cast parts with rotational symmetry, such as a wheel with spokes. The main difference from true centrifugal casting is that in semi-centrifugal casting the mould is filled completely with molten metal, which is supplied to the casting through a central sprue. Castings manufactured by this process will possess rotational symmetry.

In semi-centrifugal casting, a permanent mould may be employed. However often industrial manufacturing processes will utilize an expendable sand mould. This enables the casting of parts from high temperature materials.

The Fig.1.5 shows schematic sketch of semi – centrifugal casting. The molten material for the metal casting is poured into a pouring basin and is distributed through a central sprue to the areas of the mould.



**Fig. 1.5 Semi-centrifugal casting expendable sand mould used to manufacture a wheel**

The centripetal acceleration generated on the mass of molten metal by a rotating mould is the force that acts to fill the casting with this molten metal. This is also the force that continues to act on the material as the casting solidifies. This material acts to fill vacancies as they form thus avoiding shrinkage areas.

The centripetal forces acting on the casting's material during the manufacturing process of semi-centrifugal casting play a large part in determining the properties of the final cast part. This is also very much the case with cast parts manufactured using the true centrifugal casting process. The forces acting in the true centrifugal process are similar to those that influence the material of a casting being manufactured by semi-centrifugal casting.

The main thing to remember about centripetal forces is that the force will push in a direction that is directly away from the center of the axis of rotation.

#### a) Advantages

- It ensures purity and density at the extremities of a casting such as wheel or pulley.
- Poor structure and impurities can be machined out from the central wheel.

#### b) Limitations

- Limitation over the shape of the casting.
- Lower yield compare to true centrifugal casting.

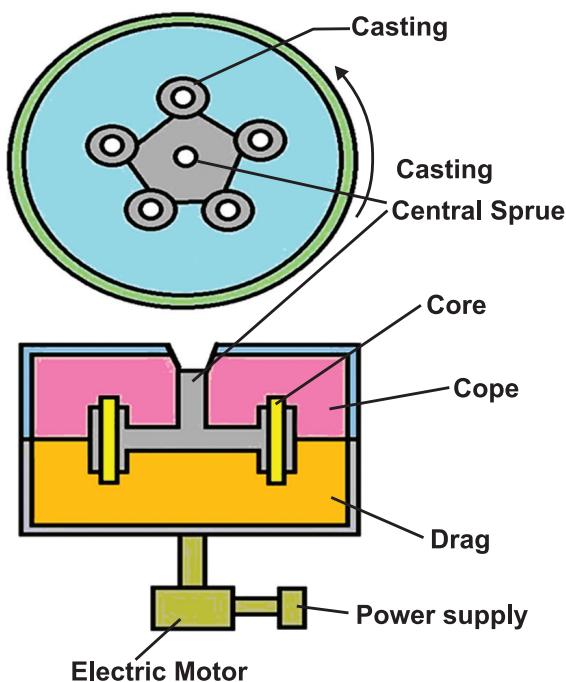
#### c) Applications

- Manufacturing of Cast pulleys and wheels, shaped castings with cores

### 1.4.3 Centrifuge centrifugal casting

Centrifuge centrifugal casting has the widest field of application. In this method, the casting cavities are arranged about the center axis of rotation like the spokes of a wheel, thus permitting the production of multiple castings. Mould cavities of any shape are placed at a certain distance from the axis of rotation. The molten metal is poured from the center sprue and centrifugal force provides the necessary pressure on the molten metal in the same manner as in semi-centrifugal casting. The entire system is rotated about an axis with the central sprue at the center of rotation. This central sprue feeds the metal into the cavities through a number of radial gates. The castings produced are not spun about their axes and the pouring pressure used is not the same for all the castings.

When the correct amount of molten metal to manufacture the casting is poured and distributed completely into the moulds, the apparatus will continue to rotate as solidification is occurring. After the castings have completely solidified the apparatus will stop rotating and the parts can be removed. Fig 1.6 shows the centrifuge centrifugal casting.



*Fig. 1.6 Schematic sketch of centrifuge casting process*

**a) Advantages**

- Denser component can be produced compare to other traditional process.
- Impurities free castings are produced by this method.
- Large numbers of castings are produced using a single mould or multiple moulds.

**b) Disadvantages**

- Only small size of castings can be made.
- Lower yield compare to two other centrifugal casting.

### c) Applications

Valve bodies and bonnets, plugs, yokes, brackets and a wide variety of various industrial castings.

### Review questions

1. What are the characteristics of centrifugal casting process?
2. What are the types of centrifugal casting process?
3. Explain true centrifugal casting process with neat sketch.
4. State the advantages, limitations and application of true centrifugal casting process.
5. Explain semi centrifugal casting process with neat sketch.
6. State the advantages, limitations and application of semi centrifugal casting process.
7. Explain centrifuge centrifugal casting process with neat sketch.
8. State the advantages, limitations and application of centrifuge centrifugal casting process.

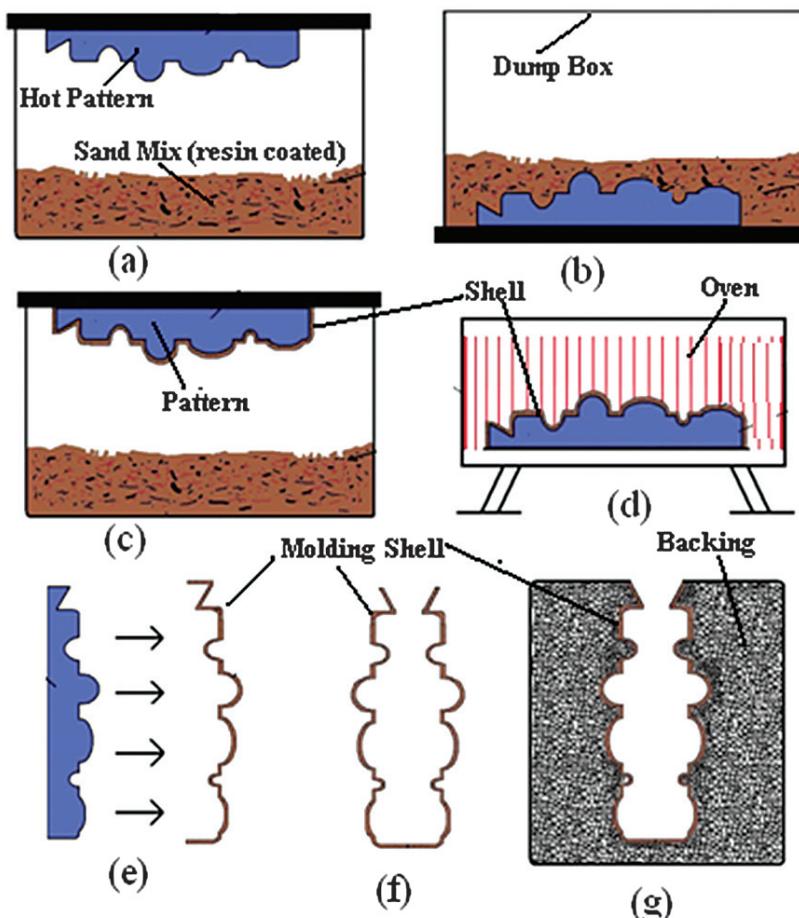
## 1.5 Shell Mould Casting

Shell-mould casting was first developed in the 1940s and has grown significantly because it can produce many types of castings with close tolerances and good surface finishes at a low cost. In the shell process, also referred to as the Croning process, the sand grains are coated with phenolic novolac resins and hexamethylenetetramine. The materials that can be used with this process are cast irons, steels, aluminum and copper alloys.

### 1.5.1 Process description

The first step in the shell mould casting process is to manufacture the shell mould. The sand we use for the shell moulding process is of a much smaller grain size (100 – 150 mesh) than the typical greensand mould. This fine grained sand is mixed with a thermosetting resin binder. A special pattern of a ferrous metal or aluminium is heated to 175- 370°C ( 350- 700° F), coated with a parting agent such as silicone, and clamped to a box or chamber containing a fine sand containing 2.5 to 4.0 percent thermosetting resin binder such as phenol-formaldehyde, which coats the sand particles. The box is either rotated upside down or sand mixture is blown over the pattern, allowing it to coat the pattern. The thickness of the mould can be controlled by the length of time the sand mixture is in contact with the metal casting pattern. The excess "loose" sand is then removed leaving the shell and pattern. The assembly is then placed in an oven for a short period of time to complete the curing of the resin. The shell hardens around the pattern and is removed from the pattern using built-in ejector pins. Two half-shells are made in this manner and are bonded or clamped together in preparation for pouring. The manufacture of the shell mould is now complete and ready for the pouring of the metal casting. In many shell moulding processes the shell mould is supported by sand or metal shot during the casting process. Fig 1.7 shows the sequence of shell moulding process.

The thickness of the shell can be accurately determined by controlling the time that the pattern is in contact with the mould. In this way, the shell can be formed with the required strength and rigidity to hold the weight of the molten liquid. The shells are light and thin, usually 5-10 mm (0.2-0.4 in) and consequently their thermal characteristics are different from those for thicker moulds. Shell sand has a much lower permeability than sand used green-sand moulding, because a sand of much smaller grain size is used for shell moulding. The decomposition of the shell sand binder also produces a high volume of gas. Unless the moulds are properly vented, trapped air and gas can cause serious problems in shell-moulding of ferrous castings.



**Fig. 1.7 Steps in Shell moulding Process**

- (a) Placement of hot pattern over dump box containing resin coated sand mix.
- (b) Resin coated sand mixed dumped over hot pattern
- (c) Shell formed over heated pattern
- (d) Shell curing inside oven
- (e) Shell stripped from pattern
- (f) Two shells joined to form a mould
- (g) Mould is supported in backing material before pouring.

With the use of multiple gating systems, several castings can be made in a single mould. Nearly any metal suited for sand casting may be cast by the shell-mould process. Shell mould casting may be more economical than other casting processes, depending on various factors.

## 1.5.2 Properties and Considerations of Manufacturing

- The internal surface of the shell mould is very smooth and rigid. This allows for an easy flow of the liquid metal through the mould cavity during the pouring of the casting, giving castings very good surface finish. Shell Mould Casting enables the manufacture of complex parts with thin sections and smaller projections than green sand moulds.
- Manufacturing with the shell mould casting process also imparts high dimensional accuracy. Tolerances of 0.010 inches (0.25mm) are possible. Further machining is usually unnecessary when casting by this process.
- Shell sand moulds are less permeable than green sand moulds and binder may produce a large volume of gas as it contacts the molten metal being poured for the casting. For these reasons shell moulds should be well ventilated.
- The expense of shell mould casting is increased by the cost of the thermosetting resin binder, but decreased by the fact that only a small percentage of sand is used compared to other sand casting processes.
- Shell mould casting processes are easily automated
- The special metal patterns needed for shell mould casting are expensive, making it a less desirable process for short runs. However manufacturing by shell casting may be economical for large batch production.

## 1.5.3 Advantages:

- Less sand required for making mould and core
- Good accuracy of dimension and surface finish of  $1.25\mu\text{m}$  to  $3.75\mu\text{m}$ .
- High rate of production with limited floor space
- Moulds and cores can be stored for future use.
- Process can be used for all metals
- Good dimensional tolerance of 0.5%.

## 1.5.4 Limitations:

- Size and weight of castings are limited due to cost and equipment limitation.
- High cost of resin, pattern and equipment.
- Inflexibility in gating and risering

## 1.5.5 Applications:

Typical parts manufactured in industry using the shell mould casting process include cylinder heads, gears, bushings, connecting rods, camshafts and valve bodies.

### Review Questions:

1. What are the characteristics of shell moulding?
2. Explain shell moulding process with neat sketch.
3. State the advantages, limitations and application of shell moulding process.

## 1.6 Investment Casting

Investment casting is also known as the lost wax process. This process is one of the oldest manufacturing processes. The Egyptians used it in the time of the Pharaohs

to make gold jewelry (hence the name Investment) some 5,000 years ago. Intricate shapes can be made with high accuracy. In addition, metals that are hard to machine or fabricate are good candidates for this process. It can be used to make parts that cannot be produced by normal manufacturing techniques, such as turbine blades that have complex shapes, or airplane parts that have to withstand high temperatures.

### 1.6.1 Process Description of Investment Casting

Fig1.8 shows the investment casting process. The first step in investment casting is to manufacture the wax pattern for the process. The pattern for this process may also be made from plastic; however it is often made of wax since it will melt out easily and wax can be reused. Since the pattern is destroyed in the process one will be needed for each casting to be made. When producing parts in any quantity a mould from which to manufacture patterns will be desired. Similar to the mould that may be employed in the expanded polystyrene casting process to produce foam polystyrene patterns; the mould to create wax patterns may be cast or machined. The size of this master die must be carefully calculated. It must take into consideration shrinkage of wax, shrinkage of the ceramic material invested over the wax pattern, and shrinkage of the metal casting. It may take some trial and error to get just the right size; therefore these moulds can be expensive.

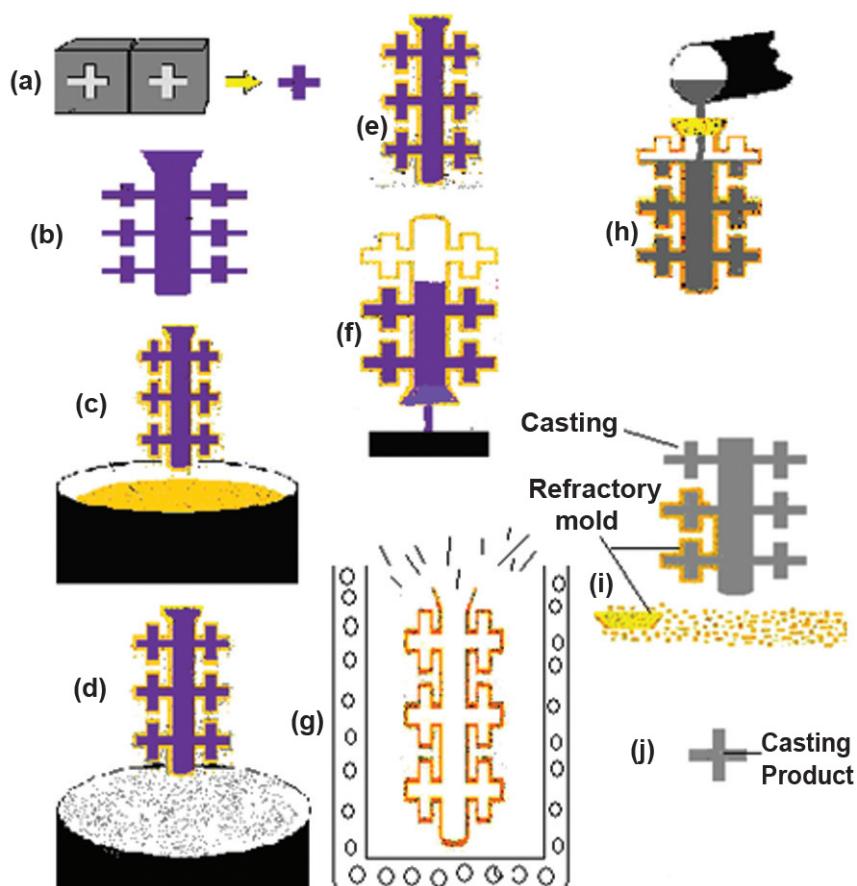
Since the mould does not need to be opened castings of very complex geometry can be manufactured. Several wax patterns may be combined for a single casting or as often the case, many wax patterns may be connected and poured together producing many castings in a single process. This is done by attaching the wax patterns to a wax bar; the bar serves as a central sprue. A ceramic pouring cup is attached to the end of the bar. This arrangement is called a 'tree', because of similarity of casting patterns on the central runner beam to branches on a tree.

The casting pattern is then dipped in ceramic slurry whose composition includes extremely fine grained silica, water, and binders. Investment shell moulds are made by applying a series of ceramic slurry coatings to the pattern clusters. Each coating consists of a fine ceramic layer with coarse ceramic particles embedded in its outer surface.

The fine ceramic layer forms the inner face of the mould and reproduces every detail of the pattern, including its smooth surface. It also contains the bonding agent, which provides strength to the structure. Each coating is allowed to harden or set before the next one is applied. This is accomplished by drying, chemical gelling, or a combination of these. The operations of coating, stuccoing, and hardening are repeated a number of times until the required mould thickness is achieved. The final coat is usually left without dipping into refractory powder in order to avoid the occurrence of loose particles on the mould surface. This final, unstuccoed layer is sometimes referred to as a seal coat.

Once the refractory coat over the pattern is thick enough it is allowed to dry in air in order to harden. The next step in this manufacturing process is the key to investment casting. The hardened ceramic mould is turned upside down and heated to a temperature of

around 90°C-175°C. This causes the wax to flow out of the mould leaving the cavity for the casting.



**Fig. 1.8 Investment Casting Process**

(a) Pattern wax is injected into a metal die to form a pattern (b) Gating patterns are assembled to a sprue to form a tree or cluster (c) Ceramic slurry coating over pattern cluster or tree (d) Stuccoing (e) Ceramic slurry invested over wax pattern drying in air (f) Dewaxing for investment casting (g) Firing (mould for investment casting heated before pouring) (h) Pouring of an investment casting (i) Break up of the mould of investment casting (j) Casting product

The ceramic mould is then heated to around 550°C-1100°C. This will further strengthen the mould, eliminate any leftover wax or contaminants, and drive out water from the mould material. The casting is then poured while the mould is still hot. Pouring the casting while the mould is hot allows the liquid metal to flow easily through the mould cavity filling detailed and thin sections. Pouring the casting in a hot mould also gives better dimensional accuracy since the mould and casting will shrink together as they cool. After pouring of the molten metal into the mould, the casting is allowed to set as the solidification process takes place. The final step in this manufacturing process involves breaking the ceramic mould from the casting and cutting the parts from the tree.

The types of materials that can be cast are Aluminum alloys, Bronzes, tool steels,

stainless steels, Stellite, Hastelloys, and precious metals. Parts made with investment castings often do not require any further machining, because of the close tolerances that can be achieved.

### 1.6.2 Properties and Considerations of Manufacturing

- Investment Casting is a manufacturing process that allows the casting of extremely complex parts, with good surface finish.
- Very thin sections can be produced with this process. Metal castings with sections as narrow as 4 mm have been manufactured using investment casting.
- Investment casting also allows for high dimensional accuracy. Tolerances as low as 0.076 mm have been claimed with this manufacturing process.
- Practically any metal can be investment cast.
- Parts of the investment process may be automated.
- Investment casting is a complicated process and is relatively expensive.

### 1.6.3 Advantages

- Casting made by investment casting route posses excellent details, smoother surface, close tolerance( $\pm 0.003$  mm/mm)
- Machining cost can be eliminated
- Intricate shape can be cast.
- Irregular parts which can not be machined or difficult to machine alloy may be cast.

### 1.6.4 Limitations

- Expensive process compare to other casting processes
- Size limitation of the component part
- Process is relatively slow
- The use of core makes the process more difficult.

### 1.6.5 Applications

- To fabricate difficult to machine and difficult to work alloys into highly complex shapes such as hollow turbine blades.
- Parts of sewing machines, locks, rifles, and burner nozzles.
- Impellers and other pump and valve components
- Jewellery and art castings
- In dentistry and surgical implants
- Fixtures and ratchets
- Machinery components and other parts of complex geometry.
- Gears and cams

## Review Questions:

1. State the various characteristics of investment casting?
2. How patterns are prepared for this process?
3. Explain process description of investment casting with neat sketch.
4. State the advantages and limitations of investment casting process.
5. List the applications of investment casting process.

## 1.7 Plaster Mould Casting

Plaster mould casting is a manufacturing process having a similar technique to sand casting. Plaster of Paris is used to form the mould for the casting, instead of sand. This process and the ceramic-mould and investment casting processes are known as precision casting because of the high dimensional accuracy and good surface finish obtained.

### 1.7.1 Process Description of plaster mould casting

Initially plaster of Paris is mixed with water just like in the first step of the formation of any plaster part. In the next step of the manufacture of a plaster casting mould, the plaster of Paris and water are then mixed with various additives such as talc and silica flour. The additives serve to control the setting time of the plaster and improve its strength. These components are mixed with water, and the resulting slurry is poured over the pattern. After the plaster sets, usually within 15 minutes, the pattern is removed and the mould is dried at 120-260°C to remove the moisture. Higher drying temperature may be used depending on the type of plaster. The mould halves are then assembled to form the mould cavity and preheated to about 120°C. The molten metal is then poured into the mould.

Patterns for plaster moulding are generally made of aluminium alloys, thermosetting plastics, brass, or zinc alloy. Wood pattern are not suitable for making a large number of moulds, because the patterns are repeatedly subjected to the water-based plaster slurry. Since, there is a limit to the maximum temperature that the plaster mould can withstand, generally about 1200°C plaster mould casting is used only for aluminium magnesium, zinc and some copper-base alloys. The castings have fine details with good surface finish. Because plaster moulds have lower thermal conductivity than others, the castings cool slowly, and more uniform grain structure is obtained with less warpage. Wall thickness of parts can be 1-2.5 mm.

### 1.7.2 Properties and Considerations of Manufacturing

- The fluid plaster slurry flows readily over the pattern, making an impression of great detail and surface finish. The qualities of the plaster mould enable the process to manufacture parts with excellent surface finish, thin sections, and produces high geometric accuracy.
- There is a limit to the casting materials that may be used for this type of manufacturing process, due to the fact that a plaster mould will not withstand temperature above 1200°C. Higher melting point materials can not be cast in plaster. This process is typically used in industry to manufacture castings made from aluminum, magnesium, zinc, and copper based alloys.

- Manufacturing production rates for this type of casting process are relatively slow due to the long preparation time for the mould.
- The plaster mould is not permeable which severely limits the escape of gases from the casting.

### 1.7.3 Advantages

- Accurate dimension and excellent surface finish obtained in casting.
- Less machining works require on the casting
- Thin wall casting can be made due to insulating nature of mould material
- For small quantities production plaster moulding may be cheaper than metal mould casting.
- Tolerance of the order of 0.002 to 0.004 mm per mm.

### 1.7.4 Limitations

- This process is not suitable for ferrous casting because the sulphur of gypsum.
- More expensive than sand casting.
- Low strength of casting due to coarse grain.
- Not favorable for large casting due to poor strength of plaster mould.
- Not suitable for high melting metals and alloys(above 2400 F)
- Mould material is non reusable

### 1.7.5 Applications

- Metals cast by this process are mainly yellow brass, manganese and aluminium bronzes, aluminium and magnesium alloys.
- Typical products made in plaster moulds are propeller, core boxes, handles, aluminium pistons, pump and impeller parts, locks, small housings etc.

#### Review Questions:

1. State the various characteristics of plaster moulding?
2. Explain process description of plaster moulding with neat sketch.
3. State the advantages and limitations of plaster moulding process.
4. List the applications of plaster moulding process.

## 1.8 Ceramic Mould Casting

The ceramic mould casting process is similar to the plaster mould process, with exception that it uses refractory mould material suitable for high temperature applications. The process is also called cope-and- drag investment casting.

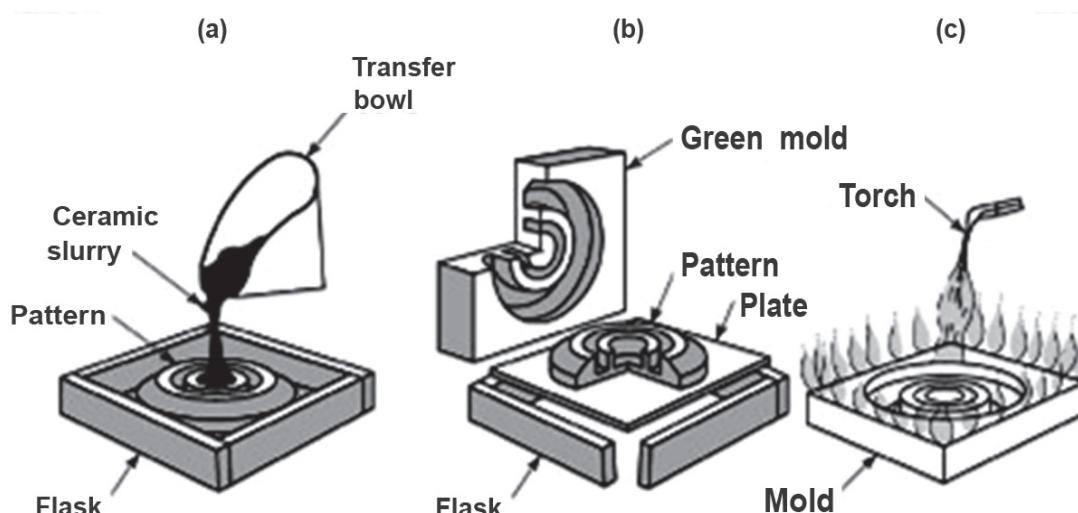
The pattern may be made of wood or metal. The high-temperature resistance of the factory moulding materials allows these moulds to be used in casting ferrous and other high temperature alloys, stainless steels, and tool steels. The castings have

good dimensional accuracy and surface finish over a wide range of sizes and intricate shapes, but the process is somewhat expensive.

### 1.8.1 Process Description of Ceramic Mould Casting

The first step in manufacture by ceramic mould casting is to combine the material for the mould. A mixture of fine grain zircon ( $ZrSiO_4$ ), aluminum oxide, fused silica, bonding agents, and water creates ceramic slurry. This slurry is poured over the casting pattern and let set. The pattern is then removed and the mould is left to dry. The mould is then fired.

The firing will burn off any unwanted material and make the mould hardened and rigid. The mould may also need to be baked in a furnace as well. The firing of the mould produces a network of microscopic cracks in the mould material. These cracks give the ceramic mould both good permeability and collapsibility for the casting process. Fig 1.10 shows the steps of preparation of ceramic mould.



**Fig.1.10 Sequence of operations in making a ceramic mould**

(a) Pouring of slurry (b) stripping of green mould (c) Burn off mould

Once prepared, the two halves of the mould are assembled for the pouring of the casting. The two halves, (cope and drag section), may be backed up with fireclay material for additional mould strength. Often in manufacturing industry the ceramic mould will be preheated prior to pouring the molten metal. The metal casting is poured, and let solidify. In ceramic mould casting, like in other expendable mould processes the ceramic mould is destroyed in the removal of the metal casting.

### 1.8.2 Properties and Considerations of Manufacturing

- Manufacturing by ceramic mould casting is similar to plaster mould in that it can produce parts with thin sections, excellent surface finish, and high dimensional accuracy. Manufacturing tolerances between .002 and .010 inches are possible with this process.
- To be able to cast parts with high dimensional accuracy eliminates the need for machining, and the scrap that would be produced by machining. Therefore

precision metal casting processes like this are efficient to cast precious metals, or materials that would be difficult to machine.

- Unlike the mould material in the plaster metal casting process, the refractory mould material in ceramic casting can withstand extremely elevated temperatures. Due to this heat tolerance the ceramic casting process can be used to manufacture ferrous and other high melting point metal casting materials. Stainless steels and tool steels can be cast with this process.
- Ceramic mould casting is relatively expensive.
- The long preparation time of the mould makes manufacturing production rates for this process slow
- Unlike in plaster mould casting, the ceramic mould has excellent permeability due to the micro cracking, (production of microscopic cracks), that occurs in the firing of the ceramic mould.

### 1.8.3 Advantages

- It can produce parts with thin sections, excellent surface finish, and high dimensional accuracy.
- Eliminates the need for machining.
- Ceramic mould can withstand extremely elevated temperatures
- Large casting may be made by this process.

### 1.8.4 Disadvantages

- Ceramic mould casting is relatively expensive.
- slow rate of production

### 1.8.5 Applications

These casting processes are commonly used to make tooling, especially drop forging dies, but also injection moulding dies, die casting dies, glass moulds, stamping dies, and extrusion dies. This process is expensive, but can eliminate secondary machining operations. Typical parts made from this process include impellers made from stainless steel, bronze, complex cutting tools, plastic mould tooling.

#### Review Questions:

1. What you meant by ceramic mould casting?
2. Explain process description of ceramic mould casting with neat sketch.
3. State the advantages and limitations of ceramic mould casting.
4. List the applications of ceramic mould casting process.

## 1.9 Summary

The unit starts with explanation of various moulding techniques were discussed. Then the makings of moulds in different methods are studies in detail. This is followed by a discussion on the advantages, limitations and application of each process in the foundry industry.

## Exercise Questions-

1. Explain the permanent mould casting techniques with diagram?
2. Describe processes of making gravity die castings.
3. What are the advantages, limitations and application of permanent mould casting process?
4. What are the characteristics of centrifugal casting process?
5. State the types of centrifugal casting process?
6. Discuss true centrifugal casting process with neat sketch.
7. Explain semi centrifugal casting process with neat sketch.
8. Explain centrifuge centrifugal casting process with neat sketch.
9. State the advantages, limitations and application of centrifuge centrifugal casting process.
10. Explain shell moulding process with neat sketch.
11. List out the advantages, limitations and application of shell moulding process.
12. Explain process description of plaster moulding with neat sketch.
13. State the advantages, limitations and applications of plaster moulding process.
14. Explain process description of ceramic mould casting with neat sketch.

# CHAPTER 2: MELTING AND POURING PRACTICE

## 2.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource Material
- Duration
- Learning outcomes
- Assessment Plan

## 2.1 Introduction of Metal Melting Process

### 2.2 Cupola Furnace

### 2.3 Electric Furnaces

### 2.4 Induction Furnace

## 2.5 Influence of Melting and Pouring Practice on Casting Quality

### 2.6 Pouring Ladles

### 2.7 Summary

## 2.0 Unit Overview & Description:

### Overview

This unit will provide the student information about various melting furnaces used in the foundry. It will help to understand the operation procedure of melting and pouring practice for the production of castings in a foundry industry.

### Knowledge and skill outcomes

- i) Understand the various steps involved in melting process.
- ii) Select a furnace for a particular metal effectively based on various criteria.
- iii) Know the influence of melting and pouring practice on casting quality.
- iv) Know various refractory materials.

### Resource Materials:

1. Heine R W, Loper C R and Rosenthal P C, "Principles of Metal Casting", Tata McGraw-Hill Publishing Company Limited, 2010.
2. Manufacturing process, K.Radhakrishna, Sapna Book house, Bangalore
3. [http://infohouse.p2ric.org/ref/01/text/00778/figure3\\_metalcasting.gif](http://infohouse.p2ric.org/ref/01/text/00778/figure3_metalcasting.gif)

<b>Duration:</b>	Total Hours 25
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## Learning Outcomes:

Unit-2	Melting and Pouring practice	Outcomes
2.1	Introduction of metal melting process	<ul style="list-style-type: none"> <li>Identify concept of metal melting process</li> <li>List classification of melting furnace</li> <li>Understand selection of melting furnaces</li> <li>List refractory materials used</li> </ul>
2.2	Cupola melting	<ul style="list-style-type: none"> <li>List different components and zones of cupola</li> <li>Demonstrate charging procedure of cupola</li> <li>Identify operations of cupola</li> </ul>
2.3	Electric Furnaces	<ul style="list-style-type: none"> <li>Understand meaning of electric furnace</li> <li>List construction features of arc furnace</li> <li>Demonstrate process description of arc furnace melting</li> </ul>
2.4	Induction Furnace	<ul style="list-style-type: none"> <li>Understand meaning of induction furnace</li> <li>List construction features of coreless type induction furnace</li> <li>Demonstrate process description of induction furnace melting</li> </ul>
2.5	Influence of Melting and Pouring Practice on Casting Quality	<ul style="list-style-type: none"> <li>Identify influence of melting practice on the cast component quality</li> <li>List influence of pouring practice on the cast component quality</li> </ul>
2.6	Pouring Ladles	<ul style="list-style-type: none"> <li>Identify the purpose of pouring ladles</li> <li>List types of function of ladles</li> </ul>

## Assessment Plan: (For the Teachers)

Unit-1	Topic	Assessment Method	Time Plan	Remarks
2.1	Introduction of Metal Melting Process	Exercise: Fill in the blanks Question & Answer		
2.2	Cupola Furnaces	Exercise: Question & Answer		
2.3	Electric Furnaces	Exercise: Question & Answer		

2.4	Induction Furnace	Exercise: Question & Answer Group Discussion		
2.5	Influence of Melting and Pouring Practice on Casting Quality	Exercise: Fill in the blanks Question & Answer		
2.6	Pouring Ladles	Exercise: Question & Answer		

## 2.1 Introduction of Metal Melting Process

The Melting of any industrial metal used in manufacturing involves the following steps:

- Step 1: Preparing the metal and loading
- Step 2: Melting of metal
- Step 3: Refining and treating molten metal
- Step 4: Holding molten metal
- Step 5: Tapping molten metal
- Step 6: Transporting molten metal

### 2.1.1 Classification of Melting Furnaces

A furnace is a refractory lined chamber in which temperatures as high as 1800°C can be attained with a view to melt a charge. Equipment for lower temperatures is called oven. Furnaces are used in industry for melting purposes. They vary in sizes (capacity), types of fuel used and types of charge to be melted. Given below is the general classification of furnaces used in foundry based on the type of fuel used:

- A) Furnaces using Chemical energy of fuel (Fuel fired furnaces)
- B) Furnaces using Electrical energy (Electric furnaces)

#### A. Fuel-fired furnaces:

##### A.1. Stationery furnaces:

- A. 1.1 Coke fired: Cupola, Pot furnaces, Crucible furnace
- 1.2 Oil/ gas fired: Stationery type – Reverberatory, Movable furnace - Rotary furnace

##### A.2. Electric furnaces:

- A. 2.1 Resistance type: Laboratory muffle furnace, Wire-winding type furnace
- 2.2 Arc Furnaces: i) Direct arc ii) Indirect arc
- 2.3 Induction furnaces: i) Coreless type ii) Core-type Channel furnace

### 2.1.2 Criteria for Selection of Melting Furnaces

While selecting a furnace for the purpose of melting metal, following points must be

considered.

- i) Cost of installation of the furnace
- ii) Fuel type and cost per unit charge to be melt
- iii) Kind of metal or alloy to be melt
- iv) Melting and pouring temperature of the metal to be cast
- v) Quantity of metal to be melt and Quantity of finished product
- vi) Capacity of the furnace
- vii) Running / maintenance cost
- viii) Cost of operation
- ix) Melting efficiency
- x) Pollution problems and control measures to be taken
- xi) Degree of control or purification required

### 2.1.3 Refractory Materials

The word refractory came from the French word réfractaire, meaning “high-melting”. Thus, a refractory material is one that is able to retain its strength at high temperatures. Refractory materials are used in linings for furnaces, kilns, incinerators etc. They are also used to make crucibles.

Following are the general properties exhibited by refractory materials:

- (i) High strength (i.e. high value of Young's modulus)
- (ii) High melting point (above 2,200°C)
- (iii) Density ranges from 130 kg/m<sup>3</sup> to 2300 kg/m<sup>3</sup>.
- (iv) Chemically inert (do not react with other components in contact with them in a melting process) and therefore, resistant to corrosion.
- (v) Resistant to thermal shock
- (vi) Both high and low thermal conductivity refractories are available and applied according to the application.
- (vii) Resistant to abrasion

### 2.1.4 Types Refractory materials and their Applications

The most common classification of refractory materials is based on their chemical composition which is described below:

**Acidic Refractories:** Acidic refractories are stable to acidic environment but are attacked by alkalis. The main raw materials for this type of refractories are silica ( $\text{SiO}_2$ ), zirconia ( $\text{ZrO}_2$ ), semi-silica, luminosilicate etc. This group is familiar as  $\text{RO}_2$  group, where R denotes the metallic part of the compound.

**Natural Refractories:** Neutral refractories used in areas where slags and atmosphere may be either acidic or basic. The common examples of these materials are alumina ( $\text{Al}_2\text{O}_3$ ), chromia ( $\text{Cr}_2\text{O}_3$ ) etc. This group of refractories generally referred to as  $\text{R}_2\text{O}_3$  group.

**Basic Refractories:** Basic refractories are used in areas where slags and atmosphere are basic. The main raw materials are magnesia ( $\text{MgO}$ ), dolomite and chrome-

magnesia. This group of refractories generally referred to as RO group.

### Review Questions:

A. Fill up the blanks:

1. Furnaces are used in industries for \_\_\_\_\_ purpose.
2. A refractory material has \_\_\_\_\_ melting point.
3. \_\_\_\_\_ is the non-metallic residual part of the metal melting process.

B. Answer briefly (in three/four sentences):

1. Define furnace. What is the basic difference between a furnace and an oven?
2. Mention the name of two furnaces that are heated by chemical energy.
3. Mention the name of two furnaces that are heated by electrical energy.
4. Name the steps involved in a metal melting process.
5. Mention four important criteria for selection of a melting furnace.
6. Mention four important features of a melting furnace.
7. Give the classification of refractory materials with one example of each.

## 2.2 Cupola Melting

The main purpose of the cupola is to produce heat from solid fuel (hard coke) and transfer it to the charge to be melt. Oxygen is needed to carryout combustion reaction and for this reason air is blast into the interior by means of tuyeres.

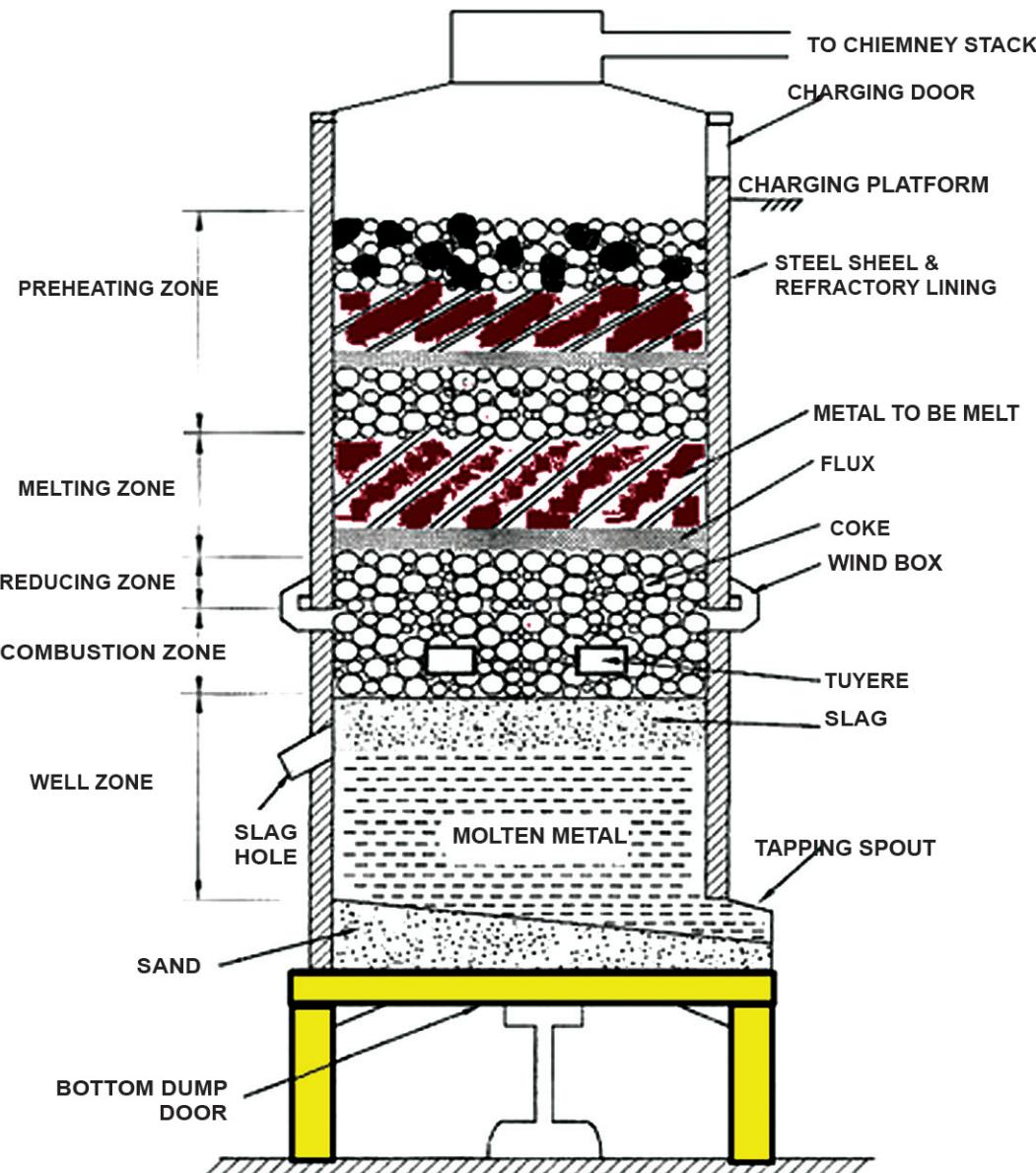
The cupola furnace is used in almost exclusively grey cast iron. In some cases, where large quantities of copper are needed, small furnaces of this type are employed. A cupola is not generally employed for melting of brass (an alloy of copper and zinc) and bronze (an alloy of copper and tin), because the alloying elements zinc and tin undergo excessive oxidation.

### 2.2.1 Different components and zones of cupola

**Cupola steel shell with refractory lining:** The cupola is a steel shell mounted in an upright position on a base plate. The steel shell is usually made of 6 to 10 mm thick plate, depending on the capacity. Fig.2.1 shows the schematic diagram of cupola.

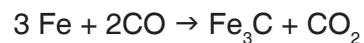
**Charging Platform & charging door:** Through the charging door, charge is introduced into the furnace body. To facilitate pouring operation, a platform is provided thereon.

**Preheating zone:** The preheating zone heats the charge from roomtemperature to about 1090°C. This zone consists of a number of layers of coke, flux and metal as charge. Hot gases from combustion zone moves upward and heat the charge at this zone.

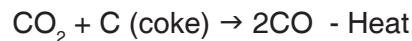


**Fig 2.1: Schematic diagram of a Cupola**

**Melting zone:** The lower layer of metal charge is termed as melting zone of Cupola. The metal charge starts melting in this zone and trickles down through coke bed and gets collected in the well. The molten metal picks up sufficient carbon following the reaction:

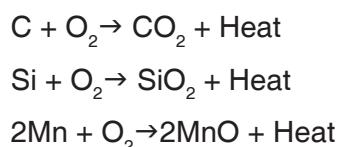


**Reducing zone:** In this zone, an endothermic reaction occurs, in which  $\text{CO}_2$  released in melting zone reaction is changed to CO. The following reaction occurs:



As a result of this, the temperature in the reducing zone falls much below to that of combustion zone. The atmosphere in this zone is reducing in nature (i.e. the zone is a reduction zone) and therefore, the charge is protected against oxidation. For this reason, this zone is also referred to as protective zone.

**Combustion zone:** The combustion zone of Cupola is an oxidizing zone. The total height of this zone ranges between 15 cm and 30 cm. The combustion takes place in this zone with the aid of oxygen supplied by the air blast through the tuyers and an exothermic reaction occurs generating tremendous heat. The heat generated in this zone is sufficient to meet the heat requirements of other zones of cupola. Since this is an oxidising zone, the constituents in the charge get oxidized, all of which are exothermic reactions. Following major reactions occur:



A temperature of about  $1540^{\circ}\text{C}$  to  $1870^{\circ}\text{C}$  is achieved in this zone.

**Well:** The space between the bottom of the tuyeres and the sand bed inside the cylindrical shell of the cupola is called well of the cupola. When melting occurs, the molten metal is collected in this portion before it is tapped out.

**Slag hole:** Slag is the residual part of the metal melting process which is lighter than the melt. As a result, they float on the surface of the melt. The slag is removed from the cupola periodically.

**Wind box:** There is a wind (or blast) box around 1 metre above the base plate. It is usually 600 mm to 1500 mm deep and surrounds the shell. The air is supplied to the wind belt from a blower. The air blast is then conveyed to the interiors of the furnace by the tuyeres.

**Tuyeres:** The fuel is burnt in air which is introduced through tuyeres positioned above the hearth. The hot gases generated in the lower part of the shaft ascend and preheat the descending charge.

**Tapping spout:** It is the place through which molten metal is tapped out of the cupola and is taken into the ladle. The ladle is then conveyed to the vicinity of the moulds and poured onto it.

**Bottom dump door:** The bottom dump door of the cupola is lifted and locked. The sand mixture is placed on the bottom plate and rammed properly. A fire is lit at the working bottom and coke is added in small quantities until it reaches the level of tuyeres. When this coke is well alight, more coke is added to bring the coke bed to its final level. On finding the bed condition satisfactory, charges are put on to fill it to the level of charging hole.

**Stack:** The hollow portion of cupola above the preheating zone is called as stack. It provides the passage for hot gaseous effluents to go to atmosphere from the cupola furnace.

## 2.2.2 Cupola Charge and Operation

Limestone and coke together form a charge, while metal to be melted form another charge. Alternative layers of these charges are filled till the cupola is full.

After the charge is made ready it is alighted and air blast is put on. Around 8 to 10 minutes later, metal is seen passing through the tuyeres level. Within next 10 to 15 minutes, molten metal comes out through the tap hole.

At the end of the melting process, charging is stopped and the air blast is maintained until the entire metal comes out. The blast is then shut off immediately.

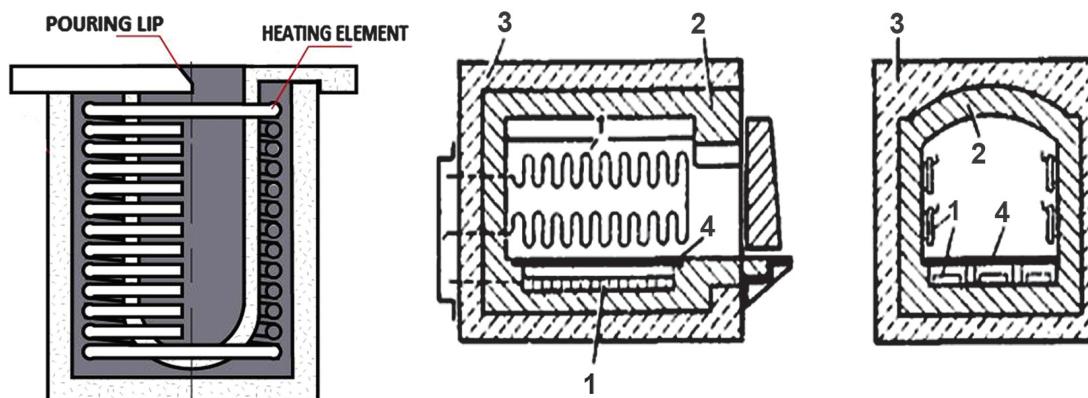
There are mainly two types of cupola furnaces Divided Blast Cupola (DBC) and Cokeless Cupola.

### Review questions

1. What role do the tuyeres of a cupola play in metal melting process?
2. Give the function of preheating zone of a cupola in metal melting process.
3. Give the function of melting zone of a cupola in metal melting process.
4. Give the function of reducing zone of a cupola in metal melting process.
5. Give the function of combustion zone of a cupola in metal melting process.
6. Give the function of tapping spout of a cupola in metal melting process.
7. Name the components that constitute 'charge' for cupola?
8. State the basic principle underlying the working of a Divided Blast Cupola.
9. State the basic principle underlying the working of a Cokeless Cupola.

## 2.3 Electric Furnaces

### 2.3.1 Resistance Furnace



**Fig 2.2 Schematic diagram of Indirect heat resistance furnace**

(1 - heating element, 2 - refractory lining, 3 - heat insulation, 4 - refractory hearth plate)

Resistance furnace is an electric furnace in which heat is developed by the passage of current through distributed resistors (heating units) mounted apart from the charge.

Electric furnaces generally being used in modern foundries are either arc furnaces or induction furnaces. A third type, the resistance furnace, is still used in the production of silicon carbide and electrolytic aluminum. In this type, the furnace charge (i.e., the

material to be heated) serves as the resistance element. Fig 2.2 shows the Schematic diagram of indirect heat resistance furnace.

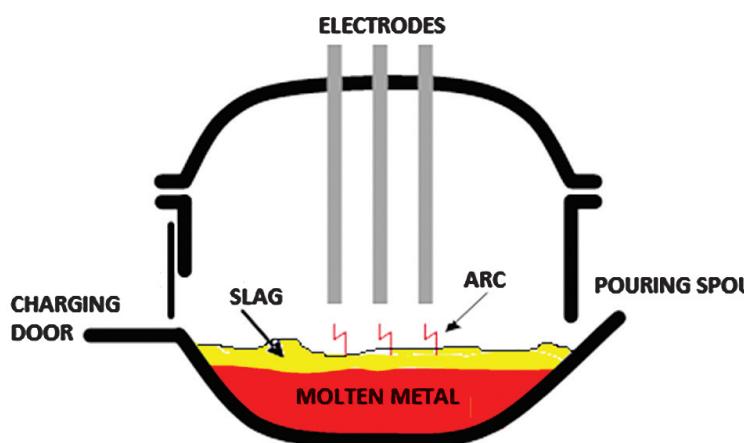
This furnace is heated from outside by resistance alloys such as 80:20 nickel-chromium rod. Most resistance furnaces are of the indirect type. In indirect-heat resistance furnaces, electric energy is converted into heat when a current flows through the heating elements. The heat is transmitted to the charge to be heated by radiation, convection, or conduction. Such a furnace consists of a working chamber formed by a lining composed of a layer of firebrick. The parts and mechanisms that operate in the chamber, as well as the heating elements, are made of heat-resistant steels, refractory steels, or other refractory materials.

Indirect heat resistance furnaces that are used to melt fusible metals, for example, lead, Babbitt metal, aluminum alloys, or manganese alloys are built either as crucible furnaces with a metal crucible and an external heater or as reverberatory furnaces with a bath and, above the bath, heating elements in the roof.

### 2.3.2 Arc Furnace

Arc furnace is an electrical furnace in which the thermal effect of an electric arc is used to melt metals. Arc furnaces are available in small units of approximately one ton capacity which are used in foundries for producing cast iron products. Industrial electric arc furnace temperatures can be raised up to 1,800 °C. In an electric arc furnace, charge material is exposed to an electric arc, and the current in the furnace terminals passes through the charged material. Fig 2.3 shows the Schematic diagram of electric arc furnace.

Electric arc furnaces are used for melting metals and alloys which have high-melting-point. The furnace consists of a saucer-shaped hearth made of refractory material for collecting the molten metal, refractory material lining also extends to the sides and top of the furnace. Two or three carbon electrodes are dipped into the furnace from the roof or the sides. Doors in the side of the furnace allow removal of molten alloys (the products), removal of slag etc. The scrap metal charge is placed on the hearth and melted by the heat from an electric arc formed between the electrodes.



**Fig 2.3 Schematic diagram of Electric Arc Furnace**

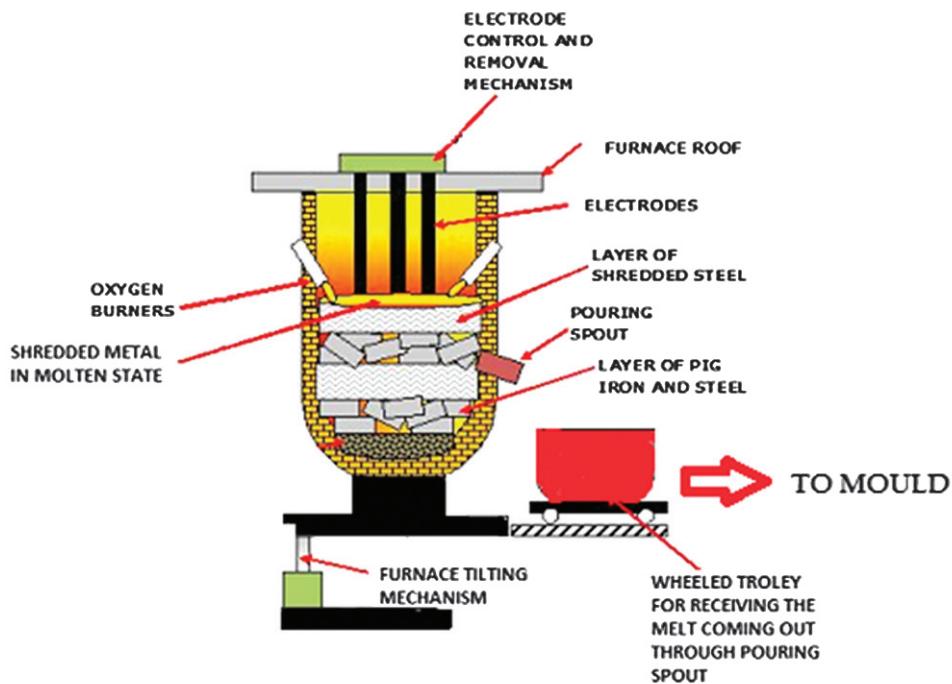
Arc furnaces are classified according to their method of heating as direct and indirect furnaces.

In direct arc furnaces, electric arcs are generated between electrodes and the material to be melted. In such furnaces, the electric arc comes into contact with the metal.

In indirect arc furnaces the arcs are set between electrodes which are placed at a certain distance from the materials being heated, and the heat from the arc is transmitted to them by radiation. In such furnaces the electric arc does not actually touch the metal.

In both the cases, the charge is heated by the heat emitted in the arc and also by the Joule heat developed as the current passes through the charge. Molten metal is drawn off through a spout by tilting the furnace.

The electric power in an arc furnace is supplied from a transformer through copper bars and carbon or, more frequently, graphite electrodes. The electric arc furnace operates as a batch melting process producing batches of molten steel. Modern operations aim for a tap-to-tap time of less than 60 minutes. Some twin shell furnace operations are achieving tap-to-tap times of 35 to 40 minutes. Direct electric-arc furnaces have a very high thermal efficiency - around 70% - and can function at as little as 450-550 kWh/tonne of metal melted. Indirect electric arc furnaces typically achieve closer to 700-1000 kWh/tonne of steel.



**Fig 2.5 Basic layout of an Electric Arc Furnace**

**Electric Arc Furnace Operating Cycle:** Scraps melt in this type of furnace are divided into two grades:

(i) shred (this consists of scraps which have light thicknesses)

(ii) heavy melt (this consists of large slabs and beams)

## Review Questions:

1. State the basic principle underlying the working of an induction furnace.
2. State the basic principle underlying the working of an arc furnace.
3. State the basic principle underlying the working of a resistance furnace.
4. State different stages of tap-to-tap cycle of an electric arc furnace.

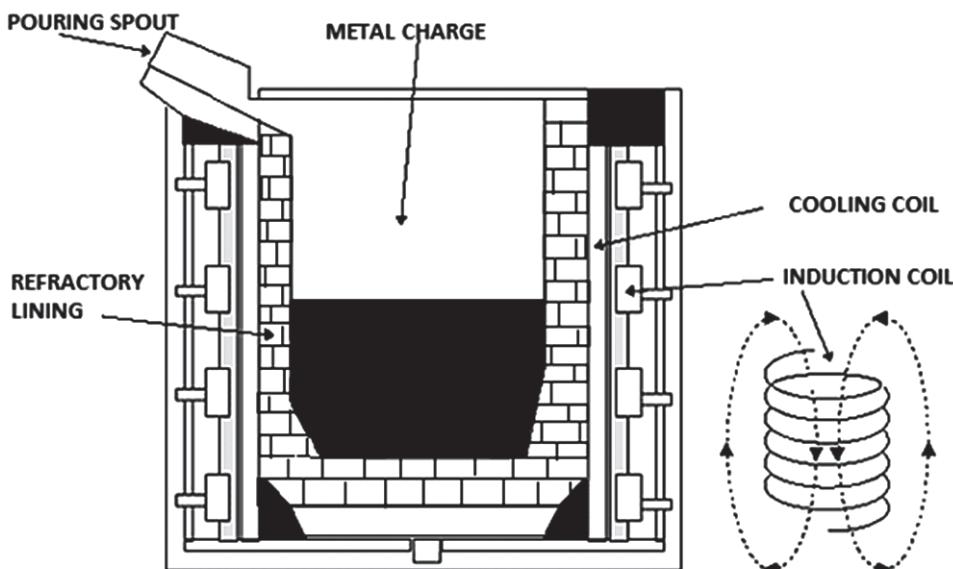
## 2.4 Induction Furnace

An induction furnace is operated by the principle of electromagnetic induction. Heat is produced by alternating current solenoid coil. When an electric current flows through a conductor, a magnetic field is created around the conductor. The opposite of this phenomenon is known as electromagnetic induction, in which, a current is induced in a conductor by changing magnetic field. If a magnet is moved towards the conductor, a current is created in a certain direction. When the magnet is moved away from the conducting wire, current is induced in opposite direction. However, no current is induced if the magnet remains stationary with respect to the conducting wire.

When a magnet is moved in one direction toward the conducting wire, current will be induced in one direction only. This unidirectional current is known as direct current (DC). However, when the magnet is moved toward and away from the conducting wire in a periodic manner, alternating current (AC) is induced. The electric energy obtained in this manner is then converted to heat energy and is used to melt the metal.

### 2.4.1 Coreless type Induction Furnace

Coreless type induction furnace (as shown in Fig 2.4) consists of a cylindrical crucible with refractory lining. It has copper coils that are protected by a shield and kept cool by water circulating through a cooling coil. A layer of refractory material is placed above the coils.



**Fig 2.4 Schematic diagram of Coreless Induction Furnace**

The crucible, which is a melting pot made of heat resistant material, is located above the refractory lining. The metal to be melt is placed inside the crucible. Primary winding of the transformer is wound around a crucible. The metal to be melt acts as a short circuited secondary of the transformer. The furnace is generally operated by high frequency alternating current. The primary is connected to an A.C. supply of frequency in the range of 500 to 600 Hz. The magnetic flux produced by primary sets up eddy current in the metal to be melt. This heat is used to melt the metal. The electromagnetic forces produced helps in stirring the bath of molten metal.

### **Review Questions:**

1. Give the classification of induction furnace.
2. What is the basic difference between coreless and channel induction furnace?
3. Describe the working principle of coreless induction furnace.

## **2.5 Influence of Melting and Pouring Practice on Casting Quality**

Melting is performed in a furnace. A casting defect is more likely to occur if due to improper melting and pouring practices. Any sort of irregularity in the metal casting process is not undesirable. Some defects can be tolerated while others can be repaired otherwise they must be eliminated. Pouring metal defects include misruns, cold shuts, and inclusions. A misrun occurs when the liquid metal does not completely fill the mould cavity, thereby, leaving an unfilled portion. Cold shuts occur when two fronts of liquid metal do not fuse properly in the mould cavity, leaving a weak spot. If the fluidity of the molten metal lacks or there are narrow cross-sections in the mould, mis-runs and cold shuts are likely to occur. By changing the chemical composition of the metal or by increasing the pouring temperature, the fluidity of the molten metal pool can be increased. Back pressure from improperly vented mould cavities may also be held responsible for such defects.

### **Review Questions:**

#### **A. Fill up the blanks:**

1. \_\_\_\_\_ usually consists of metal oxides which floats on the surface of the molten metal.
2. During \_\_\_\_\_ process, a metal is transformed from liquid to solid phase.
3. The process of formation of the first stable tiny particle is called \_\_\_\_\_.
4. The crystallization process consists of two major events, \_\_\_\_\_ and \_\_\_\_\_.

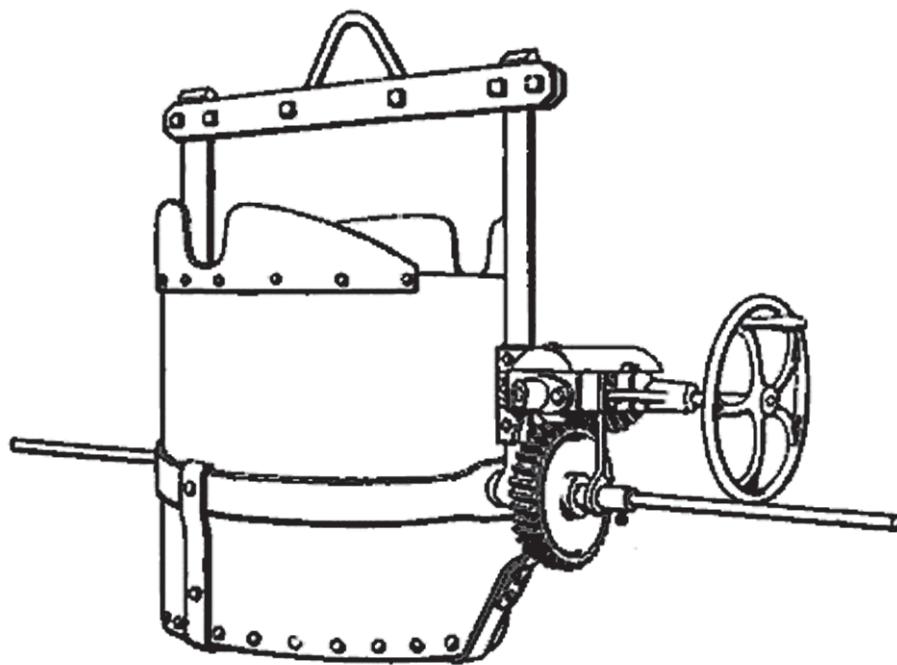
**B. Answer briefly (in three/four sentences):**

1. Mention the names of shop floor tests generally carried out in foundries for on spot quality control. Give the details of any one of such tests.
2. How the melting and pouring practice are influenced on casting quality?

## 2.6 Pouring Ladles

The vessels used to carry the molten metal from furnace to the mould are known as pouring ladles as shown in Fig 2.5. Generally, the molten metal is temporarily stored in large holding ladles from which metal can be tapped off as and when required. These holding ladles are constructed of steel shell lined with refractory bricks. These ladles are generally designed to receive metal from the furnace simultaneously with the pouring off of metal from them into smaller ladles known as pouring ladles.

Ladles range in size from small hand carried vessels that resemble a kitchen ladle and hold 20 kilograms or to large steel mill ladles that hold up to 300 tonnes. Many non-ferrous foundries also use ceramic crucibles for transporting and pouring molten metal and will also refer to these as ladles. Depending on the size, pouring ladles may be either crane operated or hand operated.



**Geared Ladle.**

**Fig 2.5 Schematic diagram of Ladles**

Unless the ladle is to be used with alloys that have very low temperature melting point, the ladle is also fitted with a refractory lining. It is the refractory lining that stops the steel vessel from suffering damage when the ladle is used to transport metals with high melting temperatures that, if the molten metal came in direct contact with the ladle shell, would rapidly melt through the shell. Refractory lining materials come in many

forms and the right choice very much depends on each foundry's working practices. Traditionally ladles used to be lined using pre-cast firebricks however refractory concretes have tended to supersede these in many countries.

Foundry ladles are normally rated by their working capacity rather than by their physical size. Hand-held ladles are typically known as handshank ladles and are fitted with a long handle to keep the heat of the metal away from the person holding it. Their capacity is limited to what a man can safely handle. Larger ladles are usually referred to as geared crane ladles. Their capacity is usually determined by the ladle function. Small hand-held ladles might also be crucibles that are fitted with carrying devices. However, in most foundries, the foundry ladle refers to a steel vessel that has a lifting bail fitted so that the vessel can be carried by an overhead crane or monorail system and is also fitted with a mechanical means for rotating the vessel, usually in the form of a gearbox. The gearbox can either be manually operated or powered operation.

For the transportation of very large volumes of molten metal, such as in steel mills, the ladle can run on wheels, a purpose-built ladle transfer car or be slung from an overhead crane and will be tilted using a second overhead lifting device.

The most common shape for a ladle is a vertical cone, but other shapes are possible. Having a tapered cone as the shell adds strength and rigidity to the shell. Having the taper also helps when it comes time to remove the refractory lining. However straight sided shells are also fabricated as are other shapes.

The most common of these other shapes is known as a drum ladle and is shaped as a horizontal cylinder suspended between two bogies. Large versions, often having capacities in excess of 100 tonnes are used in steel mills are often referred to as torpedo ladles. Torpedo ladles are commonly used to transport liquid iron from a blast furnace to another part of the steel mill. Some versions are even adapted so that they can be carried on special bogies that can be transported by either road or rail.

## 2.6.1 Types of Ladles

Ladles can be "lip pour" design, "teapot spout" design, "lip-axis design" or "bottom pour" design:

- For lip pour design the ladle is tilted and the molten metal pours out of the ladle like water from a pitcher.
- The teapot spout design, like a teapot, takes liquid from the base of the ladle and pours it out via a lip-pour spout. Any impurities in the molten metal will form on the top of the metal so by taking the metal from the base of the ladle, the impurities are not poured into the mould. The same idea is behind the bottom pour process.
- Lip-axis ladles have the pivot point of the vessel as close to the tip of the pouring spout as can be practicable. Therefore as the ladle is rotated the actual pouring point has very little movement. Lip-axis pouring is often used on molten metal pouring systems where there is a need to automate the process as much as possible and the operator controls the pouring operation at a remote distance.
- For bottom pour ladles, a stopper rod is inserted into a tapping hole in the bottom of the ladle. To pour metal the stopper is raised vertically to allow the metal to flow out the bottom of the ladle. To stop pouring the stopper rod is inserted back into the drain hole. Large ladles in the steelmaking industry may use slide gates below the taphole.

Ladles can be either open-topped or covered. Covered ladles have a (sometimes removable) dome-shaped lid to contain radiant heat; they lose heat slower than open-topped ladles. Small ladles do not commonly have covers, although a ceramic blanket may be used instead (where available).

Medium and large ladles which are suspended from a crane have a bail which holds the ladle on shafts, called trunnions. To tilt the ladle a gearbox is used and this is typically a worm gear. The gear mechanism may be hand operated with a large wheel or may be operated by an electric motor or pneumatic motor. Powered rotation allows the ladle operator to be moved to a safe distance and control the rotation of the ladle via a pendant or radio remote control. Powered rotation also allows the ladle to have a number of rotation speeds which may be beneficial to the overall casting process. Powered rotation obviously also reduces the effort required by the ladle operator and allows high volumes of molten metal to be transferred and poured for long periods without operator fatigue. Where the ladle is fitted with a manually operated gearbox, the type of gearbox most commonly used is the worm and wheel design because in most practical circumstances, and when correctly maintained it can be considered as "self-locking" and doesn't need an internal friction brake to regulate the tilting speed of the ladle. Other types of gear system can be also be used but they have to be fitted with an additional braking system that can hold the ladle if the operator takes his hand off the hand-wheel.

Lip-axis ladles may also use hydraulic rams to tilt the ladle. The largest ladles are un-geared and are typically poured using a special, two-winches crane, where the main winch carries the ladle while the second winch engages a lug at the bottom of the ladle. Raising the second winch then rotates the ladle on its trunnions.

Ladles are often designed for special purposes such as adding alloys to the molten metal. Ladles may also have porous plugs inserted into the base, so inert gases can be bubbled through the ladle to enhance alloying or metallic treatment practices.

### Review questions

1. What is the purpose of ladles?
2. What are the types of ladles?
3. Draw the different types of ladles.
4. Discuss the ladles preparation.

## 2.7 Summary

The unit starts with concept of melting furnace and ladles used in the foundry industry. The selection of furnace and refractory materials used in the melting furnace are discussed. The students are studied the operation procedure of cupola furnace, electric arc furnace, induction furnace and ladles.

## Exercise Questions-

1. What is melting furnace? What are the types of melting furnaces?
2. State the various sources of heat.
3. Draw the flow chart for the steps involved in a metal melting process.
4. Mention the important criteria for selection of a melting furnace.
5. Mention the important features of a melting furnace.
6. Give the classification of refractory materials with one example of each.
7. Discuss the influence of the following in cupola melting:
  8. Coke bed height, (ii) iron coke ratio, (iii) Air flow rate
9. Explain the principle underlying the working of a Divided Blast Cupola with neat sketch
10. State the basic working principle of a cokeless cupola with neat diagram.
11. What are the main difficulties encountered in cupola operation? Suggest their remedies
12. Explain the basic principle of an induction furnace of a coreless type Induction furnace.
13. Explain the construction features of electric arc furnace
14. What are the different types of Refractories?
15. List the names of shop floor tests generally carried out in foundries for on spot quality control.
16. How the melting and pouring practice are influenced on casting quality?
17. Define ladles. What are the types of ladles?
18. Explain any two types of ladles with neat sketches.

# CHAPTER 3: PRODUCTION PRACTICE FOR FERROUS AND NON FERROUS CASTINGS

## 3.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource Material
- Duration
- Learning outcomes
- Assessment Plan

### 3.1 Introduction

### 3.2 Production Practice for Cast Iron Castings

### 3.3 Production Practice for Steel Castings

### 3.4 Production Practice for Non Ferrous Castings

### 3.5 Summary

## 3.0 Unit Overview & Description:

### Overview

This unit will provide the student knowledge about the production methods of different types of cast iron castings, steels castings and non ferrous castings in the foundry. It will help to understand the production of practice of various ferrous and non ferrous castings.

### Knowledge and skill outcomes

After completing this chapter the students would be able to:

- i) Understand the various properties essential for melting a metal.
- ii) Select the suitable method for casting of cast irons and its alloys.
- iii) Knowledge about the various types of cast irons and their special properties.
- iv) Understand the various production practices used for steels and its alloys.
- v) Select the suitable casting techniques for copper and aluminum alloys.

### Resource Materials:

1. Heine R W, Loper C R and Rosenthal P C, "Principles of Metal Casting", Tata McGraw-Hill Publishing Company Limited, 2010.
2. Dharmendra Kumar and Jain S K, "Foundry Technology", CBS Publishers & Distributors, 2007.
3. [http://web.iitd.ac.in/~suniljha/MEL120/L5\\_Metal\\_Casting2012.pdf](http://web.iitd.ac.in/~suniljha/MEL120/L5_Metal_Casting2012.pdf)
4. <http://www.themetalcasting.com/casting-pattern-design.html>

<b>Duration:</b>	Total Hours 30
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## Learning Outcomes:

Unit-3	Production Practice For Ferrous And Non Ferrous Castings	Outcomes
3.1	Introduction	<ul style="list-style-type: none"> <li>Understand concept of castability of metal and alloy</li> <li>List effect on chemical composition</li> <li>Demonstrate carbon equivalent</li> </ul>
3.2	Production Practice for Cast Iron Castings	<ul style="list-style-type: none"> <li>List production methods for grey iron castings</li> <li>Identify production practice for malleable iron castings</li> <li>Demonstrate production practice of S.G. iron castings</li> <li>Demonstrate moulding methods of cast iron production</li> </ul>
3.3	Production Practice for Steel Castings	<ul style="list-style-type: none"> <li>List production practice of Steel castings</li> <li>Demonstrate moulding methods of cast iron classification of steels</li> <li>Identify castability of steel castings</li> </ul>
3.4	Production Practice for Non Ferrous Castings	<ul style="list-style-type: none"> <li>List general characteristics of non ferrous metals</li> <li>Demonstrate production practice of copper alloy castings</li> <li>Identify production practice of Aluminum alloy castings</li> </ul>

## Assessment Plan: (For the Teachers)

Unit-1	Topic	Assessment Method	Time Plan	Remarks
3.1	Introduction	Exercise: Question & Answer		
3.2	Production Practice for Cast Iron Castings	Exercise: Question & Answer		
3.3	Production Practice for Steel Castings	Exercise: Question & Answer		
3.4	Production Practice for Non Ferrous Castings	Exercise: Question & Answer		

## 3.1 Introduction

For beginners, the term ‘Production Practice in foundries’ covers the essential points

of moulding practice, melting methods including treatment of melts , properties of the as-cast materials in that group and typical applications. For example, for non-ferrous alloys, this Chapter would only point out which of the moulding and casting methods are usually adopted, what type of melting furnaces are used and what are the alloys for specific applications. The moulding or casting methods referred here shall not be elaborated, but the student should prepare those specific methods for examination purpose.

### 3.1.1 Castability of a Metal and Alloy

In order to produce a casting of a given metal or alloy, the foundry technologist is concerned about a property, known as castability. It is somewhat subjective term and can be considered to involve the following factors:

**Fluidity of the molten metal:** Fluidity in foundry terms is not the reverse of viscosity, but is a more generalized and practical term. Fluidity is measured in a special mould called ‘fluidity spiral’ and the length traversed by a molten metal before it freezes completely is a measure of fluidity. Surface tension, presence of dissolved gas or slag in the melt, composition etc are factors that influence fluidity. Grey cast irons are known for their excellent fluidity, while this property of steel and some non-ferrous alloys is not that good. Proper and special care is required to fill the mould without shrinkage and other defects in the solidified casting.

**Solidification shrinkage:** This volume shrinkage is very small for grey cast irons but quite large for steels and non-ferrous alloys. The size of the feeders (Risers) has to be large enough. As a result, yield of the casting (actual weight of the casting / weight of the metal poured in the mould) can be quite low – 50 % or even less.

**Melting and pouring temperature:** Melting temperature is directly linked with cost of melting, in terms of energy cost and cost of wear and loss of refractories in the furnace. There are indirect factors of (i) chance of gas absorption at high temperatures (ii) need to have superior mould properties if pouring temperature is high – as for steel or alloyed cast irons.

### 3.1.2 Chemical Composition – Effect on Structure and Properties

Cast iron is a multicomponent alloy of iron with carbon and other elements and solidifies as heterogeneous alloy with more than one constituent in the microstructure. Because of the presence of high carbon and silicon in cast irons, usually 1-3%, they possess lower melting temperature, better fluidity and lesser reactivity with moulding materials as compared to steel. Owing to the formation of low density graphite during solidification, liquid to solid volumes shrinkage is reduced and production of complex castings is facilitated.

Various types of cast irons are generally designated on the basis of mechanical properties rather than chemical composition. Because of similarities between different types, other important factors which are vital for successful production of different types of cast irons are:

- (a) Inoculants which act as nucleating agents in the production of grey iron to

control the size and type of graphite.

- (b) Trace amounts of minor elements, e.g. use of bismuth and tellurium in the production of malleable cast iron and presence of residual magnesium which causes the formation of nodular graphite in S.G. iron.
- (c) Adjustment of composition required for the production of same grade of small castings and large casting.

High alloy iron castings have a very wide range in base composition and also contain major amounts of other alloying elements and are used in applications demanding extreme abrasive wear, heat or corrosion resistance, besides other specific properties. As these property requirements are often difficult to establish and verify, high alloy irons are usually specified by their chemical composition.

### 3.1.3 Carbon Equivalent

Iron-carbon alloys have a eutectic at 4.3 % carbon but owing to the presence of silicon, the carbon content of eutectic is decreased. This is a linear relation and it is convenient to express the combined effect of carbon and silicon as carbon equivalent (C.E.)

$$C.E = \%C + \frac{1}{3} \% Si$$

In presence of appreciable amount of phosphorus, the phosphorus content of the iron is also included in carbon equivalent

$$C.E = \frac{\%C + \%Si + \%P}{3}$$

The carbon equivalent establishes the solidification temperature of alloys as also their foundry characteristics and properties. However, it is noteworthy that irons of constant carbon equivalents but with appreciably different carbon and silicon contents will have different casting properties, e.g. carbon is more than twice as effective in reducing solidification shrinkage and silicon is more effective in preventing thin section from becoming hard and this is not adequately represented by the carbon equivalent equation.

**Silicon:** It is invariably present in all cast irons, decreases the solubility of carbon in liquid and solid solutions and encourages graphitization. With an increase in carbon equivalent the amount and size of graphite inclusions increase and the proportion of pearlite and its degree of dispersion decrease resulting in impairing the mechanical properties.

**Manganese:** It combines with sulphur to form manganese sulphide which occurs as randomly distributed particles in the microstructure. In the absence of Manganese, iron combines to form a low melting eutectic (m.p.985°C) at the grain boundaries during solidification and this impairs the mechanical properties. For effective neutralization of harmful effect of sulphur, the manganese to sulphur ratio should be 4 to 5. Manganese in excess of this amount aids in the formation of final structure as pearlite and increases strength and hardness.

**Sulphur:** Sulphur can dissolve in unlimited quantity in liquid iron but has insignificant solubility in solid iron. With an increase in sulphur content of iron to about 0.12 pct. or more, fluidity of liquid iron decreases sharply and hard spots appear in the castings.

This is due to higher amount of cementite and pearlite in the structure resulting from reduced solution of carbon and silicon in iron and slower disintegration of cementite.

**Phosphorus:** It reduces the temperature of eutectic transformation, affects eutectic composition and promotes metal fluidity, therefore high phosphorus content (1 pct and above) is preferred to produce thin sections and highly detailed grey cast iron castings. It reduces the solubility of carbon in iron and has insignificant effect on graphitization. It is soluble in iron upto 0.3 pct. but in larger amounts forms a separate phosphide eutectic,  $\text{Fe}_3\text{P} - \text{Fe}_3\text{C}-\text{Fe}$  (steadite) which melts at 950°C. With phosphorus content of 2 pct, or less does not have any measurable adverse effect on the properties of grey iron because of good dispersion of small phosphide particles in the structure. For some specific applications, high phosphorus grey irons provided satisfactory wear resisting and non glazing surface.

**Other Major and Alloying Elements:** Additions of alloying elements over 0.1% and up to 3% are generally made to modify or enhance the properties of base iron, whereas alloy contents from 3 to 30 pct. are used to produce irons with entirely different properties. The latter class are designated as high alloy cast irons and have unusual properties.

### Review questions

1. Name two elements that promote graphite formation in cast irons.
2. Write the formula for Carbon equivalent.
3. Write down the castability of metals and alloys.
4. List the various alloying elements and their effect on the production of castings.

## 3.2 Production Practice for Cast Iron Castings

### 3.2.1 Production Practice for Grey Iron Castings

Grey car iron possesses excellent casting characteristics, availability and favourable cost. The production of Grey iron castings is a large industry that twice as much Grey iron is cast annually as all other cast metal combined. Much of the engineering and mechanization which developed in foundry was the result of improvements in order to meet the production demands for Grey iron castings.

#### Moulding Practice

For the production of Grey cast iron castings, several moulding processes such as green sand moulding, dry sand moulding, shell moulding,  $\text{CO}_2$  process moulding, High pressure sand moulding and permanent moulds are used, but the greatest tonnage of castings is produced by green sand moulding.

#### Characteristics of Moulding sand mixtures:

- High green compressive and shear strength
- Sufficient clay to absorb expansion

- Sufficient moisture to activate clay
- Sufficient permeability

### **Patterns for Green sand moulding:**

- Small scale production: a simple wood pattern on a follow board will do.
- Medium scale production: A match plate pattern
- Mass scale production: cope and drag pattern
- Pattern shrinkage allowance 2.5 to 4 mm per 300 mm

### **Cores:**

Different types of cores used for making cavities etc. in Grey castings are

#### **Oil sand cores**

- Hot box core
- CO<sub>2</sub> Core
- Cold set core

### **Pouring temperature**

- From Cupola, molten iron is poured in the ladle at about 2850°F whereas this temperature is about 2700°F in case of an induction furnace.
- Fluidity of molten iron depends upon
  - i. Its temperature
  - ii. Inoculants, and
  - iii. Alloying elements in it.
- Higher temperatures are preferred for casting thin sections and vice versa.
- Too high a pouring temperature results in very hard casting or scabbing of the casting
- Too low a pouring temperature leads to misruns, etc.

### **Gating and feeding system**

- A good gating and feeding system
  - i. Fills mould cavity rapidly but without turbulence
  - ii. Prevents introduction of air and mould gases into the metal stream
  - iii. Stops slag, dross or sand tec., from entering the mould along with the molten metal
  - iv. Aids in promoting progressive solidification of the castings
  - v. Maintain a high casting yield
- Gating and feeding practice is less critical for grey iron than for other metals, because during solidification graphite precipitates and the expansion of graphite balances solidification shrinkage of Grey iron
- Gates for Grey iron castings are about 50 to 80% smaller than those required for comparable bronze, aluminium or steel castings
- Gates should be designed such that they will break off cleanly and would not require (much) grinding, sawing or chipping
- Two types of gating systems are employed for production Grey iron castings, namely

- a) A non pressurized system with a restriction near the base of the sprue.

	Sprue :	Runner	:	All gates	
Cross-sectional area	1	:	4	:	3

- b) A non-pressure gating system helps displacing non-metallic inclusions into the runner extension, floating slag and minimizing spouting of the metal from the gate into the mould cavity.

- i. A pressurized system restricts the rate of metal flow into the mould cavity and provides an opportunity for the slag to float at the top of the sprue or in the pouring basin

	Sprue :	Runner	:	All gates	
Cross-sectional area	10	:	9	:	8

- Gates should be located in such a way that directional solidification is promoted
- Risers should be placed at regions of the casting last to solidify.

### Machining Allowances

Castings			
		Small	Large
1.	For surfaces in the cope side of a casting	6 mm	25 mm
2.	For surfaces in the drag side of a casting	3 mm	12.5 mm
3.	For single bore cylinders:	Bore diameter (mm)	Allowance (mm)
		100	3 to 5
		100 to 200	3 to 6
		200 to 300	5 to 8
		300 to 500	6 to 10

### Quality Control

The control of quality in Grey iron castings necessitates periodic measurement of hardness and tensile properties of the castings. Statistical methods (sampling and control charts, etc.) may be employed for evaluating the quality of the castings.

### 3.2.2 Production Practice for Malleable Irons Castings

In malleable iron the major portion of its carbon appears in the microstructure as nodules of temper carbon. For the purpose of casting into moulds, the composition of molten metal is suitably adjusted particularly in regard to carbon and silicon content so as to produce white iron castings completely free from primary graphite. The white cast iron castings are then heat treated at a temperature above 950°C for an appropriate period to dissociate the iron carbide in the matrix as temper carbon, because it is forming in the solid state during heat treatment.

Commercially two types of malleable iron are known as white heart and black heart basically derived from the colour of the fracture of the annealed material. Alloyed malleable irons or special malleable irons are modifications of the above two types and are known as pearlitic grade. These irons are most important in various engineering applications and are of comparatively recent development. Rapid solidifications required to form white iron in the as cast condition, limits the thickness for a malleable casting to about 75 mm. A part from other factors, the practical section thickness limitation has been a major factor in the growing popularity of ductile iron over malleable iron castings.

As compared to grey iron, malleable iron is stronger, ductile and possesses greater toughness and fatigue strength. Its machining characteristics are comparable to grey iron. It can be surface hardened to develop good wear resistance. Automotive components, agricultural equipment and rail road industry are major users of malleable iron castings.

For the production of white heart malleable iron castings, the base metal generally has relatively high carbon content (3 percent and above) and a low silicon content (around 0.5 to 0.6 %) which on solidification essentially produces a white cast iron structure. The castings are annealed in a decarburizing atmosphere in order to eliminate as much carbon as possible from the surface of the casting by oxidation, thereby producing a soft and ductile skin merging into a high carbon centre consisting of nodules in a pearlite matrix. Owing to non-uniformity of structure throughout the casting, this material is not considered as pearlitic malleable cast iron.

The decarburization in the heat treatment process is brought about at about 1000°C by packing the castings in contact with hematite iron ore. The carbon at the surface of the castings is oxidized and is lost as CO<sub>2</sub> there by leading to the diffusion of more carbon outwards from the interior and its oxidation. The final structure of thin section may be completely ferritic which on fracturing appears steel white and hence the name white iron.

The age old packed decarburization process has been replaced by gaseous decarburization process in which air as well as saturated steam are circulated in the heat treatment furnace leading to the formation of the reaction gas containing approximately 0.02 percent carbon so that a slightly reducing atmosphere is produced to avoid oxidation of iron.

### **Moulding Practice**

As malleable iron is mainly employed for castings produced on an mass scale, moulds are generally made by machine moulding. In view of greater shrinkage of white iron as compared to grey iron, the gating system is designed to enable progressive solidification of the casting, by running hot white iron first in thick members of the casting ( the reverse is true for grey iron). Risers should be set up at the places where the iron enters thick section and about one-third of the height of the riser should lie in that well. Owing to lower fluidity of white iron, a larger cross section of gates is required and the relation between the cross sections of gate, runner, and the sprue are different than those used for grey iron castings. The above ratio may be 1:1:1.5 and could be suitably modified to suit the requirement of individual casting design.

The technology of moulding and the moulding processes employed, i.e. sand moulding, shell moulding,  $\text{CO}_2$  moulding, and core making are in general similar to those employed in foundry producing grey iron casings in similar sizes and quantities. The properties of malleable iron are dependent on the carbon content, a marked reduction in strength and ductility occurs as the carbon content is increased to the range of 3 %. At low carbon levels when optimum properties are achieved, problems of high melting point, high solidification shrinkage and more expensive processing are encountered. To have better strength and hardness, pearlitic malleable irons have become more popular instead of malleable irons having a ferritic matrix.

Pearlitic malleable irons are used where higher strength and resistance to mechanical wear are the prime requirement in the service and comparatively less resistance to shock is involved. The composition of malleable irons is closely controlled because the requirements for producing a white iron casting with high carbide stability are the opposite to those for rapid annealing where strong graphitizing tendency is desired. In many foundries castings are classified according to section thickness, i.e., 6 mm, 12 mm, 18 mm etc. and the composition is suitably adjusted for the above section thickness to achieve the optimum annealing cycle. For very thin castings which cool faster, higher carbon and silicon content can be used and these can be annealed in appreciably shorter period of time. None of the carbide forming elements which stabilize the carbide structure can be tolerated, e.g. the presence of 0.5 percent of Cr may prolong the annealing cycle to make it uneconomical. For this reason, majority of malleable castings are made with an average section thickness of 12 mm or less. It has been found that such elements as Te, Bi and B used in small quantities promote carbide formation during solidification, but do not suitable carbide stability which is detrimental to annealing cycle of a reasonable period. It has thus become possible to increase the thickness of malleable iron castings to about 75 mm by using these special elements. However, such castings constitute a comparatively minor part in the commercial production of malleable iron.

### **3.2.3 Production Technique of Spheroidal Graphite Cast Iron**

Ductile iron therefore possesses the optimum combination of the product advantages of steel and the process advantages of grey cast iron.

**Uses:** The automotive, agriculture implement industries and pipe and pipe fittings are major uses of ductile iron castings. It has been estimated that automotive applications such as crank shaft, rocker arms, spacer blocks, spindles, cam shafts, connecting rods account for approximately 55 percent of the total ductile iron castings production.

Owing to the requirements of composition control of base iron, melting of charge material for the production of S.G. iron is generally carried out in electric induction melting furnaces. Air furnaces either reverberatory or rotary type are unsuitable as the oxidizing flame leads to high carbon loss. Basic lined direct arc furnaces can give base iron of very low sulphur content but are not commonly used. Indirect arc and electric resistance furnaces are not commercially viable owing to poor melting economy. Acid lined hot blast cupolas are also unsuitable as the high carbon percentage required cannot be obtained using the high steel scrap charges. Basic lined or lineless hot blast

cupolas with basic slag practice may be used for the production of S.G. Iron, since the sulphur content can be reduced to the desired level and sufficiently high carbon in the melt can be obtained.

The molten cast iron of suitable chemical composition is then treated with magnesium (some times with cerium), to obtain nodular form after inoculation with multicomponent ferrosilicon. After magnesium treatment, only a small quantity of residual magnesium is left in the metal. For getting the proper spherodisation, it is necessary to control the physical and chemical conditions of the base iron.

Graphite nodules can be obtained by a large number of processes and techniques which can be broadly classified into following two categories:

- (a) Processes which use magnesium master alloys.
- (b) Processes which use pure magnesium

### **Moulding and Casting Practice**

The moulding practice is similar to that of grey iron with the exception that allowance has to be made for slightly different shrinkage characteristics of nodular iron. Some modification to the gating system is also necessary because of the dross forming tendency of nodular iron. The pattern shrinkage is 13 mm per meter with substantially pearlitic matrix and on annealing to completely ferritic structure, the pattern shrinkage is recommended to about 4 mm per meter.

To counteract the deleterious effect of the dross forming tendency of the metal, the gating system is designed to retain the slag and dirt in the gating system ahead of the mould cavity, the metal is introduced into the mould with minimum turbulence possible and the rate of entry of the metal into the mould cavity is controlled. For reducing the turbulence possible and the rate of entry of the metal into the mould cavity is controlled. For reducing the turbulence of metal, the gates are generally positioned at the bottom of the casting and the ingates are taken from the bottom of the runner sections. To trap the dross in the runner and prevent its entry into the casting cavity, the runner cross section should be twice to four times that of the minimum sprue cross section.

The cost of normalizing or annealing is usually 10 to 25 pct. of the total cost and therefore, efforts should be made to produce every single type or grade of ductile iron without any heat treatment. As cast delivery presents the most significant saving potential in the overall economy of S.G. iron castings.

### **Review questions**

1. Why grey iron very brittle, but spheroidal graphite iron is is not?
2. What is fluidity in foundry terms? Name one method of its measurement
3. How does malleable iron differ from grey cast iron?
4. Can you use the same mould materials for steel casting as well as for grey cast iron
5. What are the special properties that a ductile iron has but white iron does not
6. Describe the production practice for grey cast iron casting
7. What are the moulding practices for malleable iron casting production?
8. Explain the moulding and casting of SG iron casting production.

## 3.3 Production Practice for Steel Castings

### 3.3.1 Classification of steels

- A. Carbon steels - i) low carbon ii) medium carbon and iii) High carbon steels. Such steels served useful purpose earlier, but for many versatile applications, these are not replaced by alloy steels, requiring smaller section thickness, hence less weight.
- B. Low alloy steels - with alloy content limited to about 5 per cent. Alloying elements are selected for the purpose of improving certain properties, depending on the nature of the alloying elements and their mutual affinity to produce desirable phases.
- C. High alloy steels - There are a few very useful steels with alloy content being more than 5 wt %. (i)Stainless steels may have 18-30% Cr and up to about 10% Ni, (ii)Hadfieldhigh manganese steels , with 11-12% Mn and about 1.2% C are also alloy steels used only in cast form for wear resistance property. From the applications point of view, the high alloy steels can be classified as: a) corrosion – resistant grades b) wear-resistant grades and (c) heat-resistant grades.

#### **Corrosion-resistant high-alloy cast steels, cast stainless steels**

Cast stainless steels, have grown steadily in technological and commercial importance during the past 40 years. The principal applications for these steels are for chemical-processing and power-generating equipment involving corrosion service in aqueous or liquid-vapor environments at temperatures normally below 315°C. These alloys are also used for special services at temperatures up to 650°C.

Cast stainless steels are defined as ferrous alloys that contain a minimum of 12% Cr for corrosion resistance. Chromium is the element that confers resistance to tarnishing or reaction under oxidising condition or oxidation elevated temperature. A passive barrier film of chromium oxide on the surface protects the component from oxidation and also against attack by oxidising chemicals, including nitric acid. Higher chromium content stainless steels (26-28 %) are magnetic and are specified for applications in corrosive media.

Most cast stainless steels are of course considerably more complex alloy. Nickel is an essential element in non-magnetic varieties of austenitic stainless steels. Presence of nickel imparts ductility of stainless steel.

#### **Wear-Resistant Steels ('Hadfield' manganese steel)**

Cast wear-resistant steels are used in wear applications such as earth-moving equipment, in steel plants to transport hard coke, ore, lime stone etc and scrap metal. Wear-resistant alloys can be either manganese steels or heat treated low-alloy steels. The non-magnetic high-manganese high carbon steels are commonly known as Hadfield steels – after the name of its inventor. Typically, the % Mn is about 11-14% and % C about 1.1-1.3%.

This steel is used extensively primarily in the equipment used in ore crushing, grinding; teeth of excavator, mining, quarrying, oil well drilling, steelmaking, dredging, and in the manufacture of cement. One common item is the ‘points’ in railway crossings which have to experience tremendous friction against the wheels of rail bogies and wagons.

### **Foundry control of Hadfield Steel:**

- i) For castings with heavy sections, carbon and silicon should be on the lower side, silicon not more than 0.6%.
- ii) Instead of silica sand, olivine sand or chromite sand should be used or zircon sand as facing sand should be used to avoid reaction with the mould or sand fusion defect.
- iii) Pouring temperature should be as low as permissible
- iv) During ‘fettling’ to remove risers by flame cutting, carbides may form if cooling is slow. A fast cooling under water jet is recommended.
- v) During heat treatment of as-cast components before use, initial heating to above 1000°C should not be more than 120°C per minute. Castings should not be introduced when the furnace is hot, otherwise castings may crack.
- vi) If temperature is not controlled during heat treatment and exceeds 1300°C, grain boundaries may soften and fuse. On cooling, grain boundary area remains weak and prone to cracking.

### **Applications:**

- Due to work hardening, and ability to develop high hardness and excellent abrasion resistance, hadfield steels find use as the crushing surface in industrial crushers, and as liners (hard inside surface) of mineral crushing and grinding equipment.
- In India, a major application of this steel is in railway tracks at crossing points; Hadfield castings can withstand the fluctuating load of the wheels as they roll over repeatedly the crossing points.

**Strength and Hardness:** Depending on alloy choice and heat treatment, ultimate tensile strength levels from 400 to 1700 MPa can be achieved with cast carbon and low-alloy steels. For carbon steels, the hardness and strength values are largely determined by carbon and alloy content and the heat treatment.

Special features of foundry practice for steel castings:

Although both cast irons and steel castings belong to ‘ferrous’ group, there are a few major differences in foundry practice. These differences arise basically from the fact that melting point and melting range of steel, including alloy steels, are much higher than those for cast iron castings.

- i) Special melting furnace, like 3-phase Electric Arc furnace (EAF) or Induction furnace, that can generate high temperature, are used.
- ii) Since the mould material has to withstand high temperature, special care is taken to select sand with higher ‘refractoriness’ (high fusion range, and having ability to withstand high temperature) than that required for cast irons. Around the pattern, Facing sand of higher quality is used, supported by ordinary quality ‘backing’ sand to fill up the mould box.

- iii) Again, because of high pouring temperature, there is chance of more hydrogen and nitrogen getting dissolved in the melt. In addition, according to gas laws in physics, the gases in the mould (from moisture, from mould or core coatings, core-making organic compounds etc) expand to larger volume. As a result, there is the critical requirement of permeability of mould and core. So the moisture level is more restricted and controlled.
- iv) For alloy steels, costlier zircon sand or olivine sand , which are superior to silica sand on two points (i) they have higher melting point ( higher refractoriness) than silica sand, and (ii) silica sand undergoes some expansion at around 800°C, but these zircon sand or olivine sand do not expand and are stable even at high temperatures.
- v) All steel castings are heat treated and alloy steels are usually treated by multi-step heat treatment like solutionising, quenching and tempering.

Thus, steel castings are much costlier than cast iron castings.

### 3.3.2 Castability of steel castings

The common principles of gating and risering are applicable for steel castings also. It should be noted that proper feeding of castings depend on

- the design of runner, gates and risers
- proper location of ingates and risers
- temperature and fluidity of the melt
- shrinkage of the casting

The ability of the melt to fill up the mould – large or small, simple or complex – depends on several factors:

- a) **Fluidity** - Steel melt has moderate fluidity and fluidity decreases rapidly with temperature. Alloy steels have lower fluidity than plain steels, high – Cr steels have lower fluidity than other steels. Higher the carbon level, lower is the melting point and higher is the fluidity.
- b) **Shrinkage** - Since volume shrinkage of steel castings in general is significant, adequate riser volume and proper riser location is critical.

**Common defects for steel castings due to moulding:** Apart from hot tearing, other common casting defects typical for steel casting are:

- a) Metal penetration and burn-on: When the steel melt penetrates to some distance in the mould or core, a thin layer of sand hardens on the casting. Combination of factors such as high pouring temperature, high momentum of the stream, coarse sand grain size, presence of oxide and slag inclusions in the melt are the factors that promote this defect. Good quality mould coating, a facing layer of zircon sand can prevent this defect.
- b) Mould erosion, sand drop: The factors causing these defects are high temperature, improper gate design with ingate facing a mould wall at short distance, and improper mould strength with inadequate ramming. When the momentum of the metal stream dislodges some sand from mould wall, that area would contain extra metal. In addition, the dislodged sand can cause another defect at some other location as sand fusion on the surface.

Furnace	Mode of heating
Electric arc furnace or EAF, (three-phase)	Electric arc between graphite electrode and the metal charge produces heat. Heat is transferred mainly by radiation
Induction furnace (Coreless) – usually medium frequency	Inductive heating the copper coil embedded in the lining and the metal charge in the crucible

### 3.3.3 Specific Characteristics of Casting of Steels

The physical and metallurgical characteristic call for special consideration in the moulding and casting of steels are detailed below:

- i. In view of the higher melting point of steels as compared to cast iron, higher pouring temperatures are involved. This requires sands of greater refractoriness such as high silica sand bonded with refractory clays.
- ii. Molten steel on cooling from the pouring temperature to the solidification temperature contract about 1.6 pct. per  $1000^{\circ}\text{C}$ , then it undergoes solidification contraction of 3 pct during freezing and finally a further contraction of 7.2 pct. when the solidified metal cools to room temperature. Therefore when casting steels, it is important to provide an ample supply of molten metal from risers to compensate for the decrease in volume to avoid shrinkage cavities. In case of cast iron this is somewhat less critical because of relatively low solidification shrinkage.
- iii. No carbonaceous material or washes can be used on the mould faces because of the tendency of molten steel to dissolve carbon.
- iv. The design of the steel castings should ensure progressive solidification and adequate feeding of the casting. In such directional solidification, the metal starts solidifying at places farthest from the risers and proceeds progressively towards the risers, the latter being last to solidity. The casting walls should be as uniform in thickness as possible and there should not be abrupt variation in thickness as large accumulation of metal at the junction of the walls is undesirable.
- v. Directional solidification can also be achieved by the use of external or internal type of chills, by using mould materials having varying thermal properties in different portions of the mould, thereby ensuring the desired change in the rate of heat loss and setting up favorable temperature gradients in the metal and the use of exothermic compound in the mould to have differential cooling.
- vi. In order to produce sound castings, molten steel should be roughly deoxidized before pouring into the mould otherwise dissolved oxygen will lead to boiling in the ladle and result in defects such as blow holes, gas porosity, and sponginess.
- vii. Steel castings should have larger machining allowance as compared to cast iron and nonferrous castings because of higher shrinkage and deeper penetration into the sand by molten steel.
- viii. To prevent erosion of mould walls by the stream of molten steel, it is necessary that moulds for steel casting must be compacted more strongly as compared to moulds for iron castings.

- ix. The high shrinkage of steel can also cause substantial stresses and cracks in the casting, this being particularly in case of intricately shaped castings. To eliminate the formation of cracks owing to non uniform shrinkage, the moulding sands should possess good deformability.
- x. Casting ribs which are subsequently removed in machining are also helpful in eliminating the formation of hot cracks. The thickness of these ribs reaches 10-20 percent of the thickness of casting walls.

### 3.3.4 Melting Practice

For the production of castings involving different shapes and section thickness, the higher tapping temperature is used to attain better fluidity of molten steel. For the production of steel ingot for rolling, the requirement is not so critical because mould filling is simpler in ingot mould. The basic features of making steel in a foundry including the melting furnace used are except that for the production of castings, the melting furnaces are smaller in size. Another salient difference is that steel ingots may be made as rimming, semi-killed or killed steels, whereas for foundry products only thoroughly killed (fully deoxidized) steel is used.

Now a days overwhelming majority of steel foundries use either electric arc or electric induction type of furnaces because of better metallurgical control which results in cleaner steel with superior properties. The requirement of stringent specifications in various grades of steel castings particularly for the production of alloy steel castings has encouraged the use of electric furnaces. In the electric arc furnaces, it is possible to refine the metal to achieve low sulphur and phosphorus contents even when using inferior grade scrap as melting stock. In electric induction furnaces, generally more refining is attempted because the stirring action of the bath makes it difficult to maintain a slag cover on the metal. The melting stock therefore consists of selected grade pedigree scrap. The induction furnace possesses the advantages of flexibility in operation and is particularly suitable for the production of low carbon steels because there is no carbon pick up as may occur in an electric arc furnace from the electrodes. Small lots of alloy steel castings and special steel castings are generally produced using induction melting.

Other melting units such as open hearth furnace and other processes involving the use of oxygen steel making are comparatively not popularly used for the production of steel castings owing to their large production capacity. To ensure low hydrogen content in steel as also to reduce non metallic inclusions to minimum, vacuum degassing of molten steel may be used for making special purpose castings to meet stringent service requirements.

### 3.3.5 Moulding Practice

#### (i) Green Sand Moulding

Because of versatility and favorable economics, small steel castings are produced in green sand mouldings than by other methods. Owing to higher pouring temperature, only synthetic sands are used in mould mixtures for steel and the binder used is generally restricted to bentonite. Mould coatings of a refractory type consisting of silica flour, zircon flour, or chromite flour are used to obtain better finish on the casting including smoother surfaces, decreased scabbing and buckling and less metal penetration.

## (ii) Dry Sand Moulding

Dry sand moulding is commonly used for producing large steel castings weighing from 1 tonne to well over 100 tonnes because of its superiority over green sand moulds for large castings. Dry sand moulds are stronger, permit closer dimensional tolerances and withstand more handling. This being particularly important when core setting may take 3-4 days. Dry sand moulds are similar to green sand moulds except that silica flour is generally added for enhanced rammed density of the mould and a thermosetting resin may also be incorporated in the mix. Moulding is usually done with a sand slinger and after coating with a mould wash, drying is done at 320-360° C for 10-40 hours depending on the size of the mould.

For very large castings which cannot be accommodated in flasks or extremely heavy section castings which might break out of flask because of high ferrostatic pressure are generally produced by pit moulding which is a variant of dry sand moulding.

## (iii) Shell Mould

Shell moulding is used for producing castings in carbon or low alloy steels of the section thickness in the range of 6 mm to 50 mm and weighing upto about 150 kg. Investment casting is used for steels of various compositions to produce intricate shapes, usually range not more than 5 kg. Ceramic moulding has proved specially, useful for casting intricate shapes for making cast to shape tools and dies from tool steels, because of the advantage of good dimensional accuracy and smooth surfaces, steel cannot be cast into plaster moulds because of the destruction of plaster caused by high pouring temperature of steel.

Fine grained silica, zircon, chromite or olivine sand is used for core making in steel foundries because of its ability to withstand liquid steel temperature up to 1630° C, Cores may be produced by oil binding, resin binding, carbon dioxide process, or by using chemically setting core binders. Oil bonded or resin bonded cores require a schedule for production at least 3 days prior to moulding. For carbon dioxide process cores the lead time is shortest of all core making methods being only 2-4 hours prior to mould production. Shell cores possess best dimensional tolerance ( $\pm 0.008$  cm/cm) compared to 0.020 for CO<sub>2</sub> process and  $\pm 0.031$  for baked oil sand cores. Another advantage of shell cores over cores bonded with other binders is better collapsibility as little resistance is offered to solidification contraction of steel by the shell core. Thus, for the production of thin walled castings where core restriction is a problem, shell cores are generally employed. With shell cores, it is possible to produce casting sections as thin as 4 mm as compared to other types of cores where the usual minimum casting section is 6.5 mm. Shell cores also give considerably better casting surface smoothness than is possible with other sand cores. Shell cores are generally avoided in the production of low carbon steel castings (<0.15 pct C) because of carbon pick up at the surface from resin unless the core surface is to be removed by machining. Chemically setting core binders are used for the production of medium and large cores as the need for core reinforcement is greatly reduced and both these binder systems require no ramming. Although the cores may be removed from core boxes in 1 hour to 8 hours depending upon the cross sectional area of the cores and the binder system used, core finishing operations for medium and large cores require a minimum lead time of 2-3 days before moulding.

### 3.3.6 Pouring Practice

Optimum pouring temperature is very important for proper quality of steel castings and molten steel is generally teemed from the ladle into the moulds at a temperature of 1450 to 1550°C. The ladles used for pouring into moulds include the bottom poured ladle, tea pot ladle, and lip pour ladles depending upon the size of casting and other considerations. For the production of large castings, bottom pouring is preferred because it is difficult to control the stream of molten steel by filtering a large ladle. Bottom pouring also greatly reduces the risk of non-metallic particles such as pieces of ladle lining, slag etc, close to the top of the ladle, thereby, delivering cleaner metal to the mould. However, bottom poured ladles generally are unsuitable for pouring into smaller sand moulds. The molten steel is delivered too fast because of the pressure head and the sand mould is not strong enough to withstand the impact of molten stream. Also frequent opening and closing of the stopper leads to leaking of the ladle. Tea pot ladles in various sizes cover the entire range of casting sizes for which the bottom poured ladle is unsuitable. As the metal flows from the bottom of the ladles up the spout and over the lip, it is free of slag and eroded refractory. Lip poured ladles are generally not popular for pouring steel castings because the hot metal is not taken from the bottom of the ladle, thereby considerably increasing the risk of inhomogeneity in chemical compositions as also abundance of nonmetallic inclusions from slag and other extraneous matter which flows unchecked.

Before tapping steel from the furnace it is necessary to preheat ladle linings to 800 - 1050°C using oil fired or gas fired burners. This reduces the thermal shock to the lining when the molten steel comes in contact, thereby prolonging the life of the ladle lining. Preheating also reduces the formation of skull owing to fast freezing of molten steel specially with casting of low carbon steels. The ladles are lined with firebricks or by monolithic lining depending upon the capacity of the ladle. Monolithic lining is commonly used for small ladles generally below 400 kg capacity for prevention of erosion of the lining which reduces its life as also increase dirt in steel, it is necessary to pay proper attention to the quality of the refractory material used as also its maintenance.

Ideally the optimum pouring time should be established taking into consideration the temperature of molten steel, its solidification characteristics, heat transfer characteristics and thermal stability of mould as also the size, shape and mass of the casting. From practical consideration, however, control on pouring time is difficult because generally it is necessary to pour many different castings from one ladle. An attempt is made to control the speed at which molten steel enters the mould cavity by suitable design of the gating system. The design of gating system and risers for steel castings calls for special care in view of low fluidity, large volume shrinkage, tendency to form hot cracks and absorption of gases. Rules for gating of steel castings include the following:

- i. The length of gates should be as small as possible to enable better filling of the mould. Usually round gates and runners are preferred to square cross-sections because the former cause less surface friction and allow more metal to flow per unit time.
- ii. During pouring the mould, gate should be filled completely with metal to exclude air and gases from the mould which may dissolve in the metal or form cavities in the casting.

- iii. Whenever possible, the gates should form a part of the main casting pattern as these are less susceptible to erosion as compared to cut gates.
- iv. To promote directional solidification, the metal should enter the mould cavity at the places which solidify last. The metal should enter the mould cavity at as many points as possible to minimize hot spots.
- v. To eliminate the possibility of pulling a place out of the casting during solidification, it is necessary that the cross sectional area of the gate must be smaller than that of the casting at their junction.
- vi. The gating system for pouring steel unlike that for cast iron calls for setting up large risers to supply feed metal to compensate for shrinkage in the casting. The mass of gating system and risers may account for 25-50 pct. of the casting. The importance of decreasing the amount required for gates and risers by proper designing is quite obvious.
- vii. An effective gating system for pouring steel should provide for filling the mould as rapidly as possible without excessive turbulence. If the metal does not rise rapidly to provide the necessary support, the mould can collapse owing to the destruction of the binder in the moulding sand because of the radiated heat of the molten metal.
- viii. In view of the tendency of large flat surfaces to develop rat tails, the gated end of the mould should be low so that the metal runs up a slight inclined. The same also concerns thin walls of the cavity. It is a common practice to use high pouring rates for light sections.

### 3.3.7 Risering Practice

In view of the high shrinkage, risering of steel castings deserves special attention as detailed below:

- i. Risers are usually placed over thick section of the casting. A thicker section of the casting acts as a reservoir for feeding the thinner sections which solidify first and thicker sections are fed by the risers. Because feeding from the risers depends upon gravity they are usually located at the top of the mould. Such open risers also serve as collectors for nonmetallic inclusions which float up to the surface apart from feeding the casting to compensate for the shrinkage.
- ii. Most risers are cylindrical in shape with their height approximately equal to their diameter; this configuration delays the solidification of steel owing to surface area to volume ratio.
- iii. Exothermic sleeves made of antipiping compound which mainly consists of thermit formulation are used to maintain the metal in the liquid condition in the riser. However, for large castings, the use of such exothermic sleeves is ineffective because sleeves burn out before the riser stops feeding the casting.
- iv. Where the use of open risers may entail a large requirement of metal, blind risers may be used.

### Review Questions:

1. What is the main alloying element in stainless steel to make it stainless?
2. What is the role of nickel in stainless steel?
3. List the classification of steels.
4. Write shore notes on castability of steels castings.
5. Describe the melting and moulding practice of steel castings.
6. Can you use the same mould materials for steel casting as well as for grey cast iron
7. Discuss the pouring and risering practice steel production.

## 3.4 Production Practice for Non Ferrous Castings

Except iron and steel, all metals are non-ferrous. In this chapter however, the discussion will be restricted to a few common casting alloys based on the following non ferrous metals – copper, zinc, aluminium and magnesium.

The non-ferrous metals vary widely in physical and chemical properties. But one important property is common for them – each one of them can form a number of solid solutions with other non-ferrous metal, forming a series of alloys with different sets of properties.

The family of cast non-ferrous cast metals consists of numerous members, with extremely wide range of properties. The foundry characteristics, i.e. melting, pouring etc, depend on

- The typical physical properties of melting point, density, atomic weight
- Chemical nature, affinity to oxygen, reactivity , tendency to dissolve gases like H<sub>2</sub>, N<sub>2</sub>
- metallurgical nature- tendency of alloying with other metallic elements

**Table 3.4 Physical properties of a few non-ferrous metal**

Metal and symbol	Density (g/cm <sup>3</sup> )	Melting Temp. (°C)	Atomic No. (weight)	Typical Properties
Magnesium, Mg	1.74	651	12 (24)	Light weight, good high temperature mechanical strength
Aluminium, Al	2.7	663	13 ( 27)	High strength-to weight ratio. resistance to oxidation
Titanium, Ti	4.50	1668	22(47.9)	Excellent strength-to weight ratio, fatigue strength and corrosion resistance; high melting point

Zinc, Zn	7.1	419	30 (65.38)	Good stiffness, moderate mechanical strength, low corrosion resistance – utilized in galvanizing
Copper, Cu	8.94	1083	29 (63.54)	Good thermal and electrical conductivity, excellent wear and corrosion resistance

### 3.4.1 Properties and features of non-ferrous metals relevant to casting:

- Compared to steel, melting points are lower. It means that small foundries can employ electric resistance furnaces which are clean, almost pollution free and metal loss is low.
- Compared to iron or steel, densities of Al and Mg and their alloys are much lower, but in non-ferrous alloys, there can be wide variation in density of alloying elements
- Fluidity of most non-ferrous alloys (except Al-Si alloys) is less than that of cast irons and steels, in other words, castability is not good
- Volume shrinkage is significant – similar to that of steel, but risers are less effective due to low density of the melt
- These metals are quickly form a film of oxide even for very brief exposure to air. This film, known as dross, hinders flow in the mould and tends to produce many surface defects. Apart from dross, the tendency to form ‘inclusions’ (non-metallic impurities) is also high.
- These metals tend to absorb hydrogen gas from humid air, from moist refractory, from fuel gases etc. Proper degassing methods are required to minimise hydrogen, otherwise typical pin-hole defects due to hydrogen can cause rejection of castings.
- In melting brass (Cu-Zn), there is some loss of zinc as white vapour since boiling point of zinc is low (910°C)- this is known as zinc flaring. So extra zinc is to be added.
- Many non-ferrous alloys freeze over a long range of temperatures. So feeding thick sections require special attention.
- Non-ferrous melts react with oxygen of air and tend to have many non-metallic inclusions of oxides, sulphides etc, which do not float easily. So, melting is done keeping the melt surface under proper cover of a suitable flux. The flux should absorb inclusions and act as barrier to prevent reaction of the melt with atmosphere.
- Pressure Die casting is applied for Zn-based and Mg-based alloys. Gravity die casting (‘Permanent mould casting’) is suitable for Al and Cu-base alloys.

### 3.4.2 Copper Base Cast Alloys

Copper in the cast form, discovered accidentally while lighting charcoal fire over copper oxide ore, was the first metal to be used by mankind.

### A. Moulding for copper castings:

All the common moulding and casting methods are applicable for copper:

- i) Sand casting
- ii) CO<sub>2</sub> process
- iii) Shell mould casting
- iv) Gravity Die-casting - Not all copper base alloys are suitable for die-casting. The principal alloys which are die-cast are aluminum-bronzes, certain brasses and high tensile brass. Relatively simple shapes are cast by this method.
- v) Centrifugal casting
- vi) Continuous casting

Normal moulding practice with necessary quality control of moulding sand, cores and ramming is required for making moulds ready for casting.

### B. Melting and casting Non-ferrous alloys - important points:

- i) Pure copper is difficult to cast as it has low fluidity and tends to cause cracks at section joints
- ii) Molten copper quickly absorbs gases, particularly hydrogen, which can cause porosity problems. The casting characteristics of copper can be improved by the addition of small amounts of elements like beryllium, silicon, nickel, tin etc. The melt should be under proper flux cover.
- iii) Since the melt absorbs gases, pouring should be done at as low temperature as possible, without causing misrun or cold shut defects.
- iv) Pouring - The lip of the ladle should be as close as possible to the sprue opening, ensuring an uninterrupted stream, to minimise reactions with air and gas absorption.
- v) In melting Yellow Brasses, containing large percentage of zinc, white flare forms as zinc is lost due to vaporization during melting. One good effect of zinc flaring is that dissolved gases, mainly hydrogen, are also removed by zinc vapour. Aluminum is added to increase fluidity of the melt and to keep zinc vaporization to a minimum. Extra zinc is to be added to make up for the loss in flaring.

### C. Recommended Foundry Practices for Copper Alloy Castings – A Summary

- i) Melt rapidly under oxidizing atmosphere; do not hold in furnace longer than necessary
- ii) Metal not to be heated more than 80°C above melting temperature
- iii) Add zinc where required to make up for zinc loss by oxidation, preferably with appropriate amount of Phosphor Copper
- iv) Skim the melt carefully and avoid vigorous stirring
- v) Take accurate temperature readings
- vi) Pour at the lowest temperature that will protect against misruns and internal shrinkage

- vii) Keep sprue full of melt at all times
- viii) Provide adequate gates and risers; enhance feeding by placing chills, using exothermic padding of risers and exothermic compounds.
- ix) Maintain sand properties by rigorous sand testing
- x) Use clean scrap of known composition; never add oily or painted scrap

### 3.4.3 Aluminium Base Cast Alloys

Aluminum castings have played an integral role in the growth of the aluminum industry since its inception in the late 19th century. The first commercial aluminum products were castings, such as cooking utensils and decorative parts. Further understanding of the metallurgy non-ferrous metals and heat treatment resulted in development and use of many grades of aluminium alloys. Its low density was once thought to be a limitation, as aluminium could be dented easily. With more knowledge gained on the behaviour of the metal to form alloys, it has been possible to develop strong aluminium alloys. So, the important engineering property of ‘specific strength’ or ‘strength-to-weight ratio’ for aluminium alloys has become quite large, which makes them very attractive materials for making components for all types of aerospace or aircraft components.

Classification of cast aluminum alloys is developed by the Aluminum Association of the United States. Each cast alloy is designated by a four digit number with a decimal point separating the third and the forth digits.

Table 3.5 Aluminium cast alloy designations

Alloy designation	Main alloying elements
1xx.x	aluminum, 99.0% minimum; no alloying
2xx.x	copper (4%...4.6%);
3xx.x	silicon with added copper and/or magnesium
4xx.x	silicon only
5xx.x	magnesium (4%...10%);
6xx.x	Unused at present
7xx.x	zinc is the main alloying element, with Cu, Mg, etc
8xx.x	Tin
9xx.x	Unused at present

- The first digit indicates the alloy group according to the major alloying element:
- The second two digits identify aluminum alloy or indicate the alloy purity. In the alloys of the 1xx.x series the second two digits indicate the level of purity of the alloy – they are the same as the two digits to the right of the decimal point in the minimum concentration of aluminum (in percents): 150.0 means minimum 99.50% of aluminum in the alloy, 120.1 means minimum 99.20% of aluminum in the alloy. In all other groups of aluminum alloys (2xx.x through 9xx.x) the second two digits signify different alloys in the group.
- The last digit indicates the product form: casting (designated by “0”) or ingot (designated by “1” or “2” depending on chemical composition limits.)

A modification of the original alloy or impurity limits is indicated by a serial letter before the numerical designation. The serial letters are assigned in alphabetical order starting with A but omitting I, O, Q, and X (the letter "X" is reserved for experimental alloys).

Among non-ferrous alloys, three families of castings can be classified as **light metals group – Al-base, Mg-base and Ti-base**. Their common features are:

- Low density
- Low strength in pure form but can form a number of alloys giving a wide range of strength. High strength is obtained in Al-Cu system by a heat treatment mechanism known as 'Age-hardening' or precipitation hardening'. Other alloys can provide special properties.
- These alloys can form oxides very rapidly. A film of oxide causes casting problems like low flowability, surface impurities due to trapped oxides, poor strength etc.
- They can dissolve hydrogen gas; increasing brittleness- can give pin-hole porosity.

### **Aluminium alloy moulding and casting – special features**

**Moulding** - Like copper alloys, aluminum alloy castings are produced in hundreds of compositions by all commercial casting processes, including green sand, dry sand, composite mould, plaster mould, investment casting, permanent mould, , and pressure die casting. Common moulding procedures and precautions have to be adopted.

**Gating ratio** - Because the aluminium alloys can be oxidized readily if the metal stream in the mould has high flow velocity and is turbulent then there is more risk of oxidation and dross formation. So the gating system is designed in such a way that the gating ratio is non-pressurized, which means the cross sections of sprue base area: total runner cross section area : total ingate area is 1: 3 : 3 for example. Greater area of gates means that the flow velocity metal stream will slow down after the sprue and will fill the mould cavity quietly, without turbulence.

**Cosworth process** - Special mention must be made of the special casting methods such as Cosworth process. This process has been developed especially to produce defect-free high quality aluminium alloy castings for aero-space applications. As mentioned earlier (3.3.1), aluminium alloy melts are has a strong tendency to react with air to produce films of aluminium oxide.The Cosworth process, has a special feature – the aluminium melt is not allowed to come in contact with air (oxygen) during feeding the mould. This is achieved by sealing the mould assembly and keeping it full of inert gas. The mould is placed above the melt reservoir. Molten aluminium alloy is lifted up by special electromagnetic pump to deliver the melt slowly to fill the mould from the bottom. The mould is also specially made with zircon sand and organic binder.

### **Aluminium melting and Melt treatment**

**Melting Furnaces** - Aluminium and its alloys have relatively low melting temperature. So there are many options, depending on the amount of melt required.

- a) Gas or oil-Fired Furnaces
- b) Electric resistance heated Crucible Furnace for small batches

- c) Coke – fired crucible furnace
- d) Induction Furnace.

**Charge** - Production of high quality castings based on aluminum depends on quality of raw materials, especially master-alloys which are used for alloying. Proper analysis should be carried out so that the alloys are used in proper proportion, considering possible losses. In addition, care should be taken to make sure that undesirable elements are not introduced through the charge . For example, excess Fe, Mn etc can come from bad or wrong scrap in Cu or Al-base alloys.

#### **Melting loss, dross formation and gas absorption in melting Aluminium alloys -**

Al – alloys can easily absorb harmful quantities of hydrogen gas and consequently give rise to gas or pinholes or gas porosity. It is essential to pour a clean and de-gassed melt in the moulds. Proper care is required to avoid contact of the melt with moisture. All runners, risers etc must be thoroughly dried.

**Dross formation** is the formation of aluminium oxide and other oxides which collect on the surface of molten metal. It is a typical problem of aluminium melting, causing surface and internal defects in castings. Drossformation and gas absorption depends on the type of melting unit. Electric resistance furnaces and induction furnaces produce the cleanest melt, lowest risk of dross formation and gas (hydrogen) absorption. For aluminium castings used for critical components, such as for aircraft or components, very sound castings without internal flaw are required. Normal casting methods cannot prevent the formation of a surface film of oxide which becomes entrapped in the melt. So, special casting methods have been developed to counter this typical defect of aluminium alloys.

**Fluxing and Flushing (degassing)** - These are very important steps in the casting of all light metals, particularly aluminium and magnesium.

**Fluxing** means adding suitable agents (i) to react with the dross so that it can float up and (ii) to prevent reaction of the melt of aluminium with atmosphere by acting as a barrier and (iii) to absorb impurities in the melt. This is also called Cover flux. All aluminium alloys, in general, are melted under flux cover of halide salts. These fluxes contain salt mixtures that are liquid at normal aluminum melting temperatures. Typical fluxes are: a) 47.5% sodium chloride, 47.5% potassium chloride, and 5% sodium aluminum fluoride or b) 45% KCl, 45 % NaCl and 10 % NaF. Other cover flux combinations include aluminium and zinc chlorides. Some manufacturers of cover flux recommend that the flux should be stirred in the melt to be effective, so that the dross can be easily separated from the metal.

**Flushing or degassing** is the step to remove dissolved gas, mainly hydrogen, by causing bubbling of another harmless gas or gas mixture through the melt. A good side effect of such gas flushing is that suspended impurities and dross can float up to be absorbed in the flux cover. Neutral or inert gas like argon (Ar) can be passed through the melt, but this gas is costly. Use of N<sub>2</sub>, and / or Cl<sub>2</sub> gas is common. Cl<sub>2</sub> gas is reactive and some aluminium is lost as aluminium chloride, but is very effective as a degasser.

### 3.4.4 Magnesium Base Cast Alloys

Magnesium is a special engineering material because, having a specific gravity of only 1.74. Its importance has increased rapidly in recent decades because it forms alloys with aluminium (specific gravity 2.7) and lithium (specific gravity 0.53) which have the lowest density combined with reasonable strength. So, high performance components with extremely high specific strength or strength -to- weight ratio can be produced from these alloys. When molten, proper precautions have to be taken, as mentioned earlier. These alloys can be welded with suitable electrode. However, magnesium is not an easy metal to cast; being extremely reactive and does not form a protective oxide film like aluminium to prevent further reaction.

**Foundry characteristics:** special care in moulding - Being very reactive, in a sand mould, molten magnesium will readily react with the moisture in the mould.

**Sand Moulding of Mg alloys – special ingredients (Inhibitors)** - Many Mg-Alloy castings are made in sand moulds i.e. synthetic sand which consists of silica, binder and water. In sand moulds, molten Mg will react with the moisture rapidly, forming MgO and hydrogen. To avoid this reaction, special ingredients, also known as **Inhibitor**, are used in the sand mix. Any of the following two Inhibitors can be used:

- Boric acid in combination with sulphur, or
- Ammonium bi-fluoride, about 0.2 %

**Melting of magnesium:** Pure Magnesium melts at about 650°C. Melting is carried out under flux cover. If refractory-lined furnace is used, neutral high alumina refractory is required. However, magnesium is easily melted in a clean iron crucible.

Potassium and magnesium Chloride ( $KCl + MgCl_2$ ) is an effective flux cover to protect from reaction with atmosphere and also to absorb dross and impurities. Sulphur powder is sprinkled on the melt during pouring to prevent oxidation.

Grain refinement is done by adding charcoal on the melt. Degassing or flushing operations are similar to those of aluminium melt.

#### Alloying:

- a) Mg-Al-Zn alloys, with about 9% Al, up to 0. 7% Zn are widely used as die casting alloys. Strength can be increased by heat treatment. About 0.2% Mn is used with these alloys to improve strength and corrosion resistance.
- b) Mg- 5% Al – 0.3 Mn alloys also have been widely used as die- cast components for car parts such as steering wheel, seat frame, and other components, aircraft component .
- c) An important group of Mg- Zn casting alloys (without aluminium) With zinc within 2 – 5%, 0.7%, Zr.

### 3.4.5 Zinc Base Cast Alloys

Zinc- based alloy castings, usually Zn- Al alloys or ZA alloys, are manufactured almost always by Pressure Die casting process. Aluminium level in zinc is 3.5- 4.5 % in the common grade, and about 0.25 % copper is also present in a popular grade. The most common grades of pressure die cast zinc alloys are known by brand names Zamak 3, Zamak 5 etc. Both of contain about 4 % Al, and 0.25 % Cu (Zamak 3) and 1.0 % Cu (Zamak 5).

There are also high aluminium grades with about 8%, 12% and 27% Al, alloyed with small amounts of Cu and Mg, which can be sand cast or cast by Gravity die casting. These alloys have much higher tensile strength than Zamak alloys. But these sand cast alloys exhibit significant shrinkage. This problem can be overcome by adequate chilling.

Aluminium improves fluidity of the melt, minimizes the risk of reaction between zinc and the die and increases strength. Magnesium, in small amounts, (0.02-0.03%), reduces the harmful effects of impurities like lead, tin etc. A small amount of copper, about 0.25% also has a role similar to that of Mg. Cu also increases strength.

Under normal clean air and water, die cast zinc alloys have good corrosion resistance. This property can be improved further by coating or anodizing.

### **Harmful impurities:**

- i) Lead, iron, cadmium (Cd) and tin (Sn) , even in small concentrations, makes the component prone to cracking, distortion or corrosion. These effects may be visible after one year. So, careful control of melting charge is required.
- ii) Content of iron, manganese, chromium etc also should be restricted as various defects may arise, machinability is reduced sharply .

### **Moulding:**

Although zinc alloys are mainly used for pressure die casting and gravity die (Permanent mould) casting, alloys with 12% Al can be cast in sand moulding and also in gravity die casting with graphite mould, which is much cheaper than metal dies, has good thermal conductivity and so can be cooled rapidly.

### **Method of casting:**

- a) About 4% Al – Hot chamber pressure die casting
- b) 8% Al- both Hot chamber and Cold chamber pressure die casting.

### **Applications:**

Auto sector is the largest customer for zinc alloy die casting components. Parts of carburetor, fuel pump, windshield wipers, steering wheel, radiator, instrument panel cover, handle etc. Other sectors of use are toys, electrical and electronic appliances, office equipment etc.

### **Review questions**

1. Write briefly on the typical precautions required for non-ferrous castings.
2. Why degassing and fluxing steps are so important for non-ferrous castings?
3. Discuss the Production practice of copper alloy castings
4. Explain the Production practice of Aluminum alloy castings

## **3.5 Summary**

The unit starts with explanation of the castability of various metals and alloys used in the production of castings. The chemical composition and alloying elements of ferrous and non ferrous metals are discussed. Then the production of casting such as grey

iron, malleable iron, SG iron, steel castings, aluminum alloy and copper alloy castings are studied in details.

## Exercise Questions-

1. Name the various elements that promote graphite formation in cast irons.
2. Define the castability of metals and alloys.
3. Discuss the various alloying elements and their effect on the production of castings.
4. Why grey iron very brittle, but S.G iron is not?
5. What is fluidity?
6. Describe any two methods for fluidity measurement with neat diagram.
7. What are the properties and application of ductile iron?
8. Describe the production practice for grey cast iron casting
9. What are the moulding practices for malleable iron casting production?
10. Explain the moulding and casting of SG iron casting production.
11. State the various alloying elements in stainless steel.
12. List the classification of steels.
13. Describe the melting and moulding practice of steel castings.
14. Discuss the pouring and risering practice steel production.
15. Why degassing and fluxing steps is are so important for non-ferrous castings?
16. Discuss the production practice of copper alloy castings
17. Explain the production practice of aluminum alloy castings

# CHAPTER 4: CAST METALS TECHNOLOGY

## 4.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource Material
- Duration
- Learning outcomes
- Assessment Plan

## 4.1 Introduction and Characteristics of Metals

## 4.2 Cast Iron Technology

## 4.3 Cast Steel Technology

## 4.4 Non Ferrous Cast Alloys

## 4.5 Summary

## 4.0 Unit Overview & Description:

### Overview

This unit will provide the students, knowledge about the various cooling curves for pure metals and alloys. And then various mechanical properties of metals are discussed. It's provides the importance of alloy elements and their control and application of cast non ferrous metals.

### Knowledge and skill outcomes

After completing this chapter the learners would be able to:

- i) Observe the various cooling curves for pure metal and alloys.
- ii) Know about various hardness and tensile properties of metals
- iii) Briefly understand the various classifications of cast irons; study their properties.
- iv) Know the various properties enhanced by individual alloying element.
- v) Observe the various fields of applications of cast copper alloys, cast aluminium alloys and cast magnesium alloys.

### Resource Materials:

1. Raghavan V, "Physical Metallurgy Principles and Practice", Prentice Hall of India Pvt. Ltd., 2010.
2. Chakrabarti A K, " Casting Technology and Cast Alloys", Prentice Hall of India, 2009.
3. [http://web.iitd.ac.in/~suniljha/MEL120/L5\\_Metal\\_Casting2012.pdf](http://web.iitd.ac.in/~suniljha/MEL120/L5_Metal_Casting2012.pdf)

<b>Duration:</b>	Total Hours 20
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## Learning Outcomes:

Unit-4	Cast Metals Technology	Outcomes
4.1	Introduction and Characteristics of Metals	<ul style="list-style-type: none"> <li>• List characteristics of metals</li> <li>• Demonstrate solidification of metals</li> <li>• Understand cooling curves of alloys</li> <li>• Identify nucleation</li> </ul>
4.2	Cast Iron Technology	<ul style="list-style-type: none"> <li>• Identify classification of cast iron</li> <li>• Types of graphite</li> <li>• List chemical composition and structure of grey cast iron</li> <li>• List chemical composition and structure of white cast iron</li> <li>• List chemical composition and structure of malleable iron</li> <li>• Identify chemical composition and structure of S.G. cast iron</li> </ul>
4.3	Cast Steel Technology	<ul style="list-style-type: none"> <li>• List classification of cast steels</li> <li>• Identify alloying elements of cast steels</li> <li>• Classify high alloy steels</li> <li>• Demonstrate production practice of Steel castings</li> </ul>
4.4	Non Ferrous Cast Alloys	<ul style="list-style-type: none"> <li>• List general characteristics of non ferrous metals</li> <li>• Identify chemical composition and application of copper and their alloys</li> <li>• List chemical composition and application of aluminum and their alloys</li> <li>• Identify chemical composition and application of magnesium and their alloys</li> </ul>

## Assessment Plan: (For the Teacher)

Unit-1	Topic	Assessment Method	Time Plan	Remarks
4.1	Introduction and Characteristics of Metals	Exercise: Question & Answer		
4.2	Cast Iron Technology	Exercise: Question & Answer		

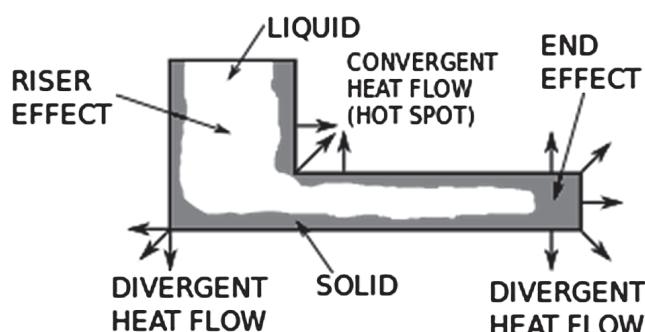
4.3	Cast Steel Technology	Exercise: Question & Answer		
4.4	Non Ferrous Cast Alloys	Exercise: Question & Answer		

## 4.1 Introduction and Characteristics of Metals

Metals account for about two thirds of all the elements and about 24% of the mass of the planet. Metals have useful properties including strength, ductility, high melting points, thermal and electrical conductivity, and toughness. A few of the common characteristics of metals are presented below.

- Ability to alloy
- Ability to deform easily (malleability / ductility)
- Electrical Conductivity
- Crystalline nature
- Heat treatable

Most metals and alloys shrink as the material changes from a liquid state to a solid state. Therefore, if liquid material is not available to compensate for this shrinkage a shrinkage defect forms. When progressive solidification dominates over directional solidification a shrinkage defect will form. (As shown in Fig 4.1)



**Fig 4.1 Solidification process**

The geometrical shape of the mould cavity has direct effect on progressive and directional solidification. At the end of tunnel type geometries divergent heat flow occurs, which causes that area of the casting to cool faster than surrounding areas; this is called an end effect. Large cavities do not cool as quickly as surrounding areas because there is less heat flow; this is called a riser effect. Also note that corners can create divergent or convergent (also known as hot spots) heat flow areas.

In order to induce directional solidification chills, risers, insulating sleeves, control of pouring rate, and pouring temperature can be utilized.

Directional solidification can be used as a purification process. Since most impurities will be more soluble in the liquid than in the solid phase during solidification, impurities will be "pushed" by the solidification front, causing much of the finished casting to have

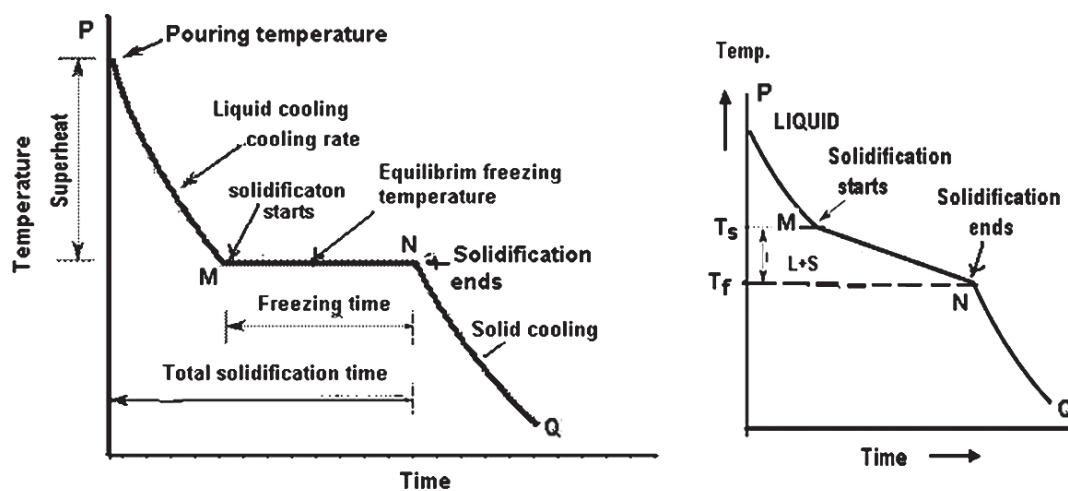
a lower concentration of impurities than the feedstock material, while the last solidified metal will be enriched with impurities. This last part of the metal can be scrapped or recycled. The suitability of directional solidification in removing a specific impurity from a certain metal depends on the partition coefficient of the impurity in the metal in question, as described by the Scheil equation. Directional solidification is frequently employed as a purification step in the production of multicrystalline silicon for solar cells.

#### 4.1.1 Solidification of a Pure Metal and its Structure on Solidification

**Cooling curve of a pure metal:** A pure metal has one unique melting or solidification temperature. So, if gradually cool 100 gm of molten copper from 1250°C and continuously measure the temperature of the melt every minute, we expect to find that:

- From 1250°C to the melting / solidification temperature of 1083°C, there shall be progressive drop in temperature with time
- At the solidification temperature, the temperature should remain constant (M-N) with respect to time till all the copper has solidified completely
- After all the copper is solidified at 1083°C, the solid metal will cool gradually in air.

The time-temperature plot thus obtained is known as Cooling curve for a pure metal as shown in Fig. 4.2. From P, liquid temperature drops with time as the melt cools, till M. The horizontal part MN indicates the melting point  $T_M$ , at which temperature remains constant till solidification is complete. Solidification is an exothermic reaction. So the heat evolved during solidification of a pure metal makes up for the heat lost during cooling in air. After complete freezing at N, cooling of the solid metal is shown by the line NQ. Freezing time and total time for solidification from molten state are obtained from such cooling curves.



**Fig. 4.2 (left) Cooling curve of a pure metal , showing a ‘temperature arrest’ at  $T_M$ , the theoretical melting temperature and (right) cooling curve of copper-nickel alloy, showing that solidification takes place over a range of temperature.**

**Cooling curves of alloys:** An alloy consists of more than one metallic element, each with its own melting points. Many types of alloys can form in metal systems between common metals. When two elements form an alloy system, Copper and nickel for example, or copper and zinc as brass, the alloy is called a '**binary alloy**'. Details of all alloy systems are beyond the scope of this Course. But at this point, one point should be noted: except one special case, alloys solidify over a range of temperatures whereas a pure metal solidify at a constant temperature, which is its melting or freezing point.

Thus, as shown schematically in Fig. 4.2, the cooling curve of a pure metal shows that as the molten pure A gradually cools to its freezing point  $T_M$ , the temperature drop is arrested till all the liquid solidifies. In contrast, in an alloy, at a certain temperature, solidification will start at temperature  $T_s$  corresponding point M in the cooling curve. But since there is no unique freezing temperature, solidification will continue as temperature drops continuously till N. This point, corresponding to temperature  $T_F$  marks the finish of solidification process.

This feature has great impact in metal casting practice, when molten alloy is poured and cooled in a mould. For a considerable period of time, solid and liquid metal co-exist, not only in the mould cavity but also in the feeder channel – in the ingates and risers. When the liquid metal contains a proportion of solid crystals, the fluidity and flowability is reduced sharply. Feeding the solidifying casting in the mould thus becomes difficult. Special measures in design of feeding system and moulding are required for casting certain alloys.

### 4.1.2 Crystalline solids

Crystalline solids are typically formed by cooling and solidification from the molten (or liquid) state. According to the Ehrenfest classification of first-order phase transitions, there is a discontinuous change in volume (and thus a discontinuity in the slope or first derivative with respect to temperature,  $dV/dT$ ) at the melting point. Within this context, the crystal and melt are distinct phases with an interfacial discontinuity having a surface of tension with a positive surface energy. Thus, a metastable parent phase is always stable with respect to the nucleation of small embryos or droplets from a daughter phase, provided it has a positive surface of tension. Such first-order transitions must proceed by the advancement of an interfacial region whose structure and properties vary discontinuously from the parent phase.

The process of nucleation and growth generally occurs in two different stages. In the first nucleation stage, a small nucleus containing the newly forming crystal is created. Nucleation occurs relatively slowly as the initial crystal components must impinge on each other in the correct orientation and placement for them to adhere and form the crystal. After crystal nucleation, the second stage of growth rapidly ensues. Crystal growth spreads outwards from the nucleating site. In this faster process, the elements which form the motif add to the growing crystal in a prearranged system, the crystal lattice, started in crystal nucleation. As first pointed out by Frank, perfect crystals would only grow exceedingly slowly. Real crystals grow comparatively rapidly because they contain dislocations (and other defects), which provide the necessary growth points, thus providing the necessary catalyst for structural transformation and long-range order formation.

### 4.1.3 Nucleation

Nucleation can be either homogeneous, without the influence of foreign particles, or heterogeneous, with the influence of foreign particles. Generally, heterogeneous nucleation takes place more quickly since the foreign particles act as a scaffold for the crystal to grow on, thus eliminating the necessity of creating a new surface and the incipient surface energy requirements.

Heterogeneous nucleation can take place by several methods. Some of the most typical are small inclusions, or cuts, in the container the crystal is being grown on. This includes scratches on the sides and bottom of glassware. A common practice in crystal growing is to add a foreign substance, such as a string or a rock, to the solution, thereby providing nucleation sites for facilitating crystal growth and reducing the time to fully crystallize.

The number of nucleating sites can also be controlled in this manner. If a brand-new piece of glassware or a plastic container is used, crystals may not form because the container surface is too smooth to allow heterogeneous nucleation. On the other hand, a badly scratched container will result in many lines of small crystals. To achieve a moderate number of medium sized crystals, a container which has a few scratches works best. Likewise, adding small previously made crystals, or seed crystals, to a crystal growing project will provide nucleating sites to the solution. The addition of only one seed crystal should result in a larger single crystal.

Some important features during growth are the arrangement, the origin of growth, the interface form (important for the driving force), and the final size. When origin of growth is only in one direction for all the crystals, it can result in the material becoming very anisotropic (different properties in different directions). The interface form determines the additional free energy for each volume of crystal growth.

Lattice arrangement in metals often takes the structure of body centered cubic, face centered cubic, or hexagonal close packed. The final size of the crystal is important for mechanical properties of materials. (For example, in metals it is widely acknowledged that large crystals can stretch further due to the longer deformation path and thus lower internal stresses.).

### 4.1.4 Mechanisms of Growth

An example of the cubic crystals typical of the rock-salt structure. Time-lapse of growth of a citric acid crystal. The video covers an area of 2.0 by 1.5 mm and was captured over 7.2 min. The interface between a crystal and its vapor can be molecularly sharp at temperatures well below the melting point. An ideal crystalline surface grows by the spreading of single layers, or equivalently, by the lateral advance of the growth steps bounding the layers. For perceptible growth rates, this mechanism requires a finite driving force (or degree of supercooling) in order to lower the nucleation barrier sufficiently for nucleation to occur by means of thermal fluctuations.[6] In the theory of crystal growth from the melt, Burton and Cabrera have distinguished between two major mechanisms.

**Non-uniform lateral growth:** The surface advances by the lateral motion of steps which are one interplanar spacing in height (or some integral multiple thereof). An element of surface undergoes no change and does not advance normal to itself except

during the passage of a step, and then it advances by the step height. It is useful to consider the step as the transition between two adjacent regions of a surface which are parallel to each other and thus identical in configuration — displaced from each other by an integral number of lattice planes. Note here the distinct possibility of a step in a diffuse surface, even though the step height would be much smaller than the thickness of the diffuse surface.

**Uniform normal growth:** The surface advances normal to itself without the necessity of a stepwise growth mechanism. This means that in the presence of a sufficient thermodynamic driving force, every element of surface is capable of a continuous change contributing to the advancement of the interface. For a sharp or discontinuous surface, this continuous change may be more or less uniform over large areas each successive new layer. For a more diffuse surface, a continuous growth mechanism may require change over several successive layers simultaneously.

Non-uniform lateral growth is a geometrical motion of steps — as opposed to motion of the entire surface normal to itself. Alternatively, uniform normal growth is based on the time sequence of an element of surface. In this mode, there is no motion or change except when a step passes via a continual change. The prediction of which mechanism will be operative under any set of given conditions is fundamental to the understanding of crystal growth. Two criteria have been used to make this prediction:

- Whether or not the surface is **diffuse**. A diffuse surface is one in which the change from one phase to another is continuous, occurring over several atomic planes. This is in contrast to a sharp surface for which the major change in property (e.g. density or composition) is discontinuous, and is generally confined to a depth of one interplanar distance.
- Whether or not the surface is **singular**. A singular surface is one in which the surface tension as a function of orientation has a pointed minimum. Growth of singular surfaces is known to require steps, whereas it is generally held that non-singular surfaces can continuously advance normal to themselves.

### Review questions:

1. Outline briefly any four characteristics of metals.
2. Explain why alloys and not pure metals are used to manufacture components for industrial applications
3. Discuss the solidification process in the metals
4. Describe the nucleation and mechanism of growth.

## 4.2 Cast Irons Technology

Cast iron usually refers to a family of iron -carbon alloys, with more than 2 weight per cent carbon. The colour of a fractured surface can be used to identify an alloy.

**White cast iron** is named after its white surface when fractured, due to its brittle carbide impurities which allow cracks to pass straight through.

**Grey cast iron** is named after its grey fractured surface, which occurs because the graphitic flakes deflect a passing crack and initiate countless new cracks as the material breaks

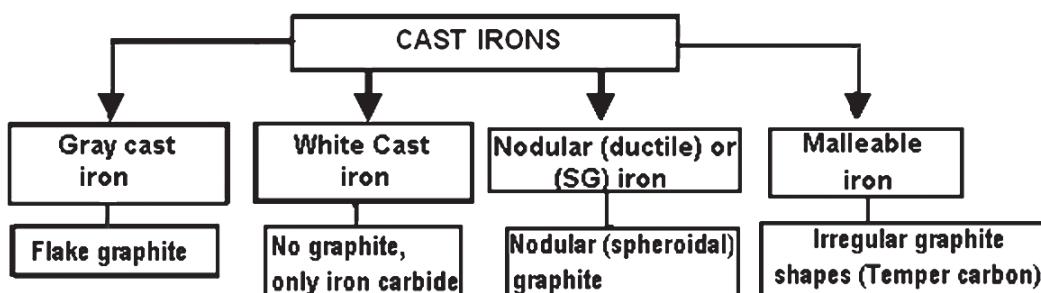
Cast irons may often be used in place of steel at considerable cost savings. The design and production advantages of cast iron include:

- Low tooling and production cost compared to steel castings
- Excellent fluidity of the melt, can be cast into complex shapes
- Good machinability
- Excellent wear resistance and high hardness of white cast irons
- High inherent damping capabilities of grey cast iron- used as machine base
- Spheroidised Graphite (SG) iron or ductile irons can have properties close to those of steel, at much lower cost.
- For some varieties of cast irons, a range of properties can be obtained to suit the needs of various users

The properties of the cast iron and graphite shape and size are affected by the following factors:

- ▶ Chemical composition of the iron; effects of alloying elements
- ▶ Rate of cooling of the casting in the mould (which depends on the section thickness in the casting and the mould material)
- ▶ Type , size and distribution ('morphology') of the graphite formed
- ▶ Effect of harmful impurities

The various types of cast iron are shown in the Fig 4.3.



*Fig. 4.3 Different types of cast irons and their typical graphite shapes*

#### 4.2.1 Types of graphite

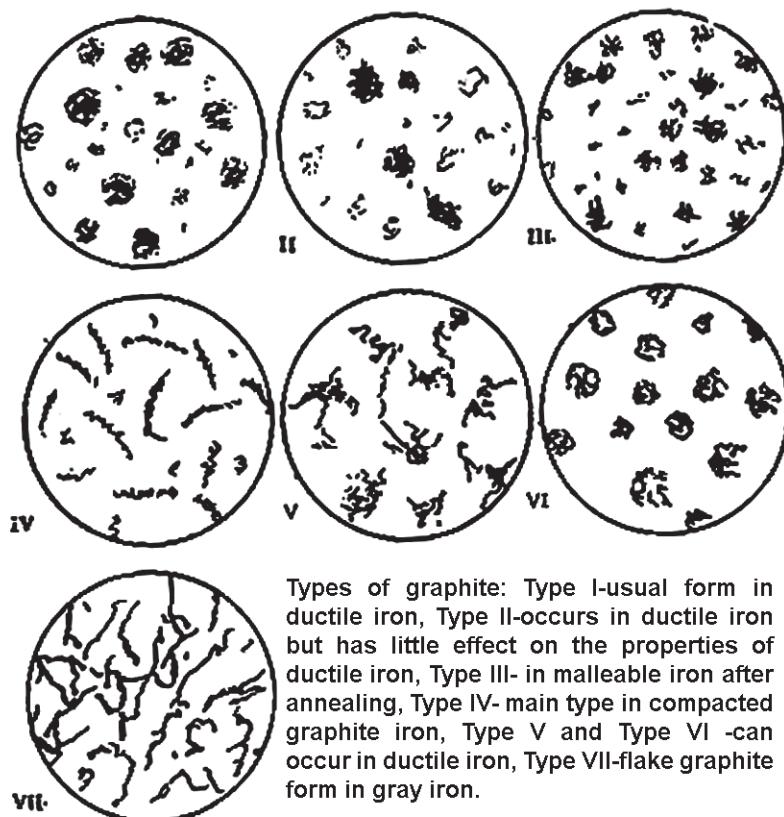
The shape, size and distribution of graphite in the structure exert a pronounced influence on the properties of cast irons. ASTM (A-247) has classified seven basic types of graphite (Fig. 4.4) which occur in cast irons. Flake graphite form has been further classified into five types from A through E (Fig 4.5)

**Graphite Size:** In addition to the form and type a standard for evaluating the size of flakes and nodular forms of graphite has been provided by ASTM specifications (A-247). These sizes increase geometrically from 1 mm in length or diameter at 100 magnification for size 8 to 128 mm for size 1.

The properties of different cast irons are established by the following factors:

- a) The form in which the major portion of carbon occurs, i.e, as carbide or in some shape of graphite.

- b) The structure of the matrix (ferrite, pearlite, bainite martensite or austenite) in which the iron carbide or graphite occurs.



**Types of graphite:** Type I - usual form in ductile iron, Type II - occurs in ductile iron but has little effect on the properties of ductile iron, Type III - in malleable iron after annealing, Type IV - main type in compacted graphite iron, Type V and Type VI - can occur in ductile iron, Type VII - flake graphite form in gray iron.

*Fig 4.4 Seven basic types of graphite*

Microstructure	Description
	Type A flake graphite has a uniform distribution and an apparent random orientation. Commonly preferred in mechanical applications.
	Type B is in the form of rosette groupings with random orientation. This occurs in irons of near eutectic composition.
	Type C (called high graphite) occurs in hyper-eutectic (high C) irons where graphite is formed in liquid iron before eutectic solidification begins. This form of coarse graphite is desirable in ingot moulds involving high heat transfer. Its presence reduces tensile properties and modulus of elasticity and results in pitted machined surface.



Type D graphite occurs in an inter dendritic segregation and with a random orientation of the individual flakes. This type occurs in rapidly cooled irons (permanent mould grey cast iron) but having sufficient silicon content to prevent the retention of iron carbide. Irons with this type of graphite have higher tensile properties. However it is difficult to obtain an entirely pearlitic matrix.



Type E occurs in low total carbon irons (strongly hypereutectic) with a dominant primary structure of austenitic and a normal eutectic solidification. The graphite formation is confined to the interstices between the austenite dendrites so that the graphite is classified as interdendritic with preferred orientation.

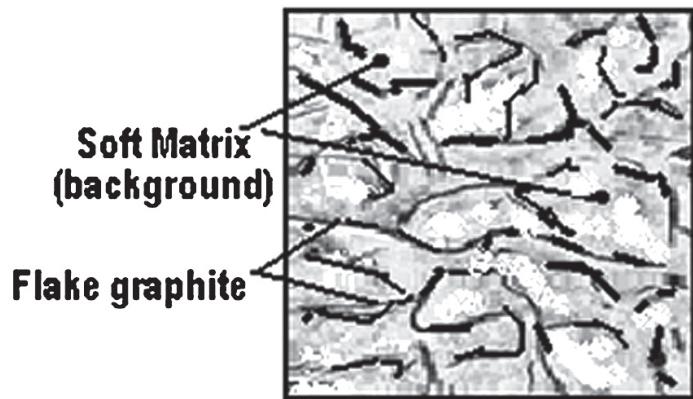
*Fig 4.5 Various graphite forms*

#### 4.2.2 Grey Cast Iron (GCI)

**Introduction:** Grey cast iron is by far the oldest and most common form of cast iron. As a result, it is assumed by many to be the only form of cast iron and the terms "cast iron (CI)" and "grey iron" are used interchangeably. All cast irons are not grey irons. Grey irons are quite brittle, but all cast irons are not so brittle, while white cast iron is even more brittle. Grey iron is named so because its fracture has a grey appearance. A large part or all of the carbon is in the form of flakes of graphite. This graphite forms during slow cooling. The matrix consists of ferrite, pearlite or a mixture of the two. The flake-like shape of graphite in Grey iron exerts major influence on its mechanical properties. The graphite flakes act as stress raisers which may cause localized fracture. As a result, Grey iron exhibits poor or very little elongation as measured in tensile test. But again, graphite flake in grey cast iron allows a cast iron machine base to absorb vibrations – a property known as 'damping capacity'. The presence of graphite flakes also gives Grey Iron excellent machinability and self-lubricating properties (Fig 4.6).

**Melting, cooling and Casting of grey cast iron** - Cast iron melting is carried out in either cupola furnace or in electric induction furnace. Both (1) Composition control and (2) cooling rate in the mould are influential factors to determine the structure and properties.

**Composition** - Presence of silicon, 1-2.5 %, favours graphite formation. In two dimensions, as polished surface will appear under a microscope, the graphite flakes appear as curved lines.



**Fig. 4.6 Typical structure of grey cast iron showing black graphite flakes on a light coloured background (matrix) indicating softer 'ferrite'; deep grey areas in the matrix indicate strong 'pearlite'**

It is preferred to have well distributed flakes, not too thick and not in clusters.

The **carbon equivalent (CE)** of a cast iron helps to distinguish the grey irons which cool into a microstructure containing graphite and the white irons where the carbon is present mainly as cementite. The carbon equivalent is defined as:

$$\text{CE(wt\%)} = \frac{\text{C} + \text{Si} + \text{P}}{3}$$

A high cooling rate and a low carbon equivalent favours the formation of white cast iron whereas a low cooling rate or a high carbon equivalent promotes grey cast iron.

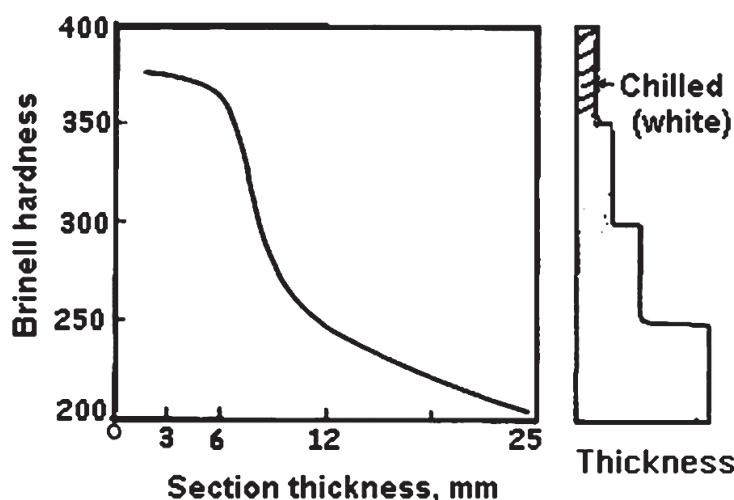
### Factors influencing structure of Grey cast iron

- When cooling rate is slow, as in sand mould, the most important factor is the composition of the cast iron melt, and carbon equivalent (CE) in particular.
- Higher CE, more graphite, thicker flakes; lower CE, chance of hard iron carbide formation
- Faster cooling and low CE increase the risk of iron carbide formation only, particularly in thin sections that cool faster. Proper control of composition is required for castings of thin and thick sections
- The matrix or background on which graphite flakes determine the strength properties. Mainly soft Ferrite matrix indicates a cast iron of less tensile strength, but tougher; more of pearlite indicates higher tensile strength.
- Manganese has the opposite effect of silicon – it promotes carbide (pearlite) formation and opposes graphite formation during cooling. Thin sections can show very brittle white fracture, which proves carbide formation. This is not desirable by the customer.

### 4.2.3 White Cast Iron

White cast iron is unique in that it is the only member of the cast iron family in which graphite formation is not wanted and all the carbon is present only as carbide. Due to

the absence of graphite, its fracture has a light white appearance. The presence of different carbides, depending on the alloy content, makes white cast irons extremely hard and abrasion resistant but very brittle. The effect of section thickness of a cast iron melt is shown in Fig. 4.7.



**Fig. 4.7 Effect of section thickness on the tendency to form carbide, particularly if Carbon equivalent is not adequate**

**Chilled Cast Iron:** When localized area of a grey cast iron is cooled very rapidly from the melt, as cooling in contact with metallic surface, very hard phases form there to result in white cast iron structure. This type of white cast iron is called Chilled cast iron. A chilled iron casting can be produced by adjusting the carbon composition of the white cast iron so that the normal cooling rate at the surface is just fast enough to produce white cast iron while the slower cooling rate below the surface will produce grey iron. The depth of chill decreases and the hardness of the chilled zone increases with increasing carbon content.

**Special features of white cast iron and its applications:** The melt for white cast iron should have lower carbon equivalent compared to grey cast iron. Per cent Mn is also higher and depending on use, alloying elements can be added. The applications of cast white iron are:

- i) Unalloyed White iron is the starting material for producing malleable iron by a special long heat treatment, called **malleabilising**.
- ii) The hardness of white cast iron is utilized, usually after alloying, to produce very hard **alloy white cast irons**.

#### Role of alloying elements in white iron

The object of alloying is to:

- i) Increase hardness by using those elements that have a strong affinity towards carbon to form hard carbides. To obtain high hardness, pearlite should be avoided.
- ii) To alter the cooling characteristics in such a manner that carbides can form while cooling easily, without requiring too fast cooling rate, and avoiding pearlite

at the same time.

- iii) The concentration of alloying elements for a given casting can be varied to a limited extent for a given grade to take into account the section thickness. If thicker pieces of white iron require high hardness, then there is a limit on cooling rate. Too high a cooling rate can cause casting defects like cracking, distortion (warping) etc. In such case, the aim would be to modify the alloying so that through-thickness hardening can take place with moderate cooling rate, without risk of casting damage.

### **Role of Chromium**

- Chromium is used in small amounts to control chill depth by promoting martensite formation. Some amount of nickel is always associated in this case so that martensite formation becomes easier. Martensite is not carbide, but is a phase supersaturated with carbon. Chromium is used in amount of 1 to 4 percent in chilled iron to increase hardness and improve abrasion resistance.
- It also suppresses the formation of graphite in heavy sections.
- When added in amounts of 12 to 35 percent, chromium will impart resistance to corrosion and oxidation at elevated temperatures.

A common rule is that fast cooling of a casting from molten state prevents graphite and pearlite formation. How fast the rate should be depends not only on the composition or alloy content, but also on the

### **Classification of alloy cast irons:**

1. **Nickel-chromium white irons**, or **Ni-hard cast iron** which are **low-chromium alloys** containing usually 3 to 5% Ni and 1.5 to 4% Cr, 2.9 – 3.6% C in the common grades (ASTM A 532, type I to III). In one grade, the range of Cr is 7 to 11% Cr. Ni-hard irons are primarily used for abrasion-resistant applications and are readily cast into the parts needed in machinery for crushing, grinding, and handling of abrasive materials. When abrasion resistance is the main requirement, carbon level is on the higher side within this range 2.9 – 3.6 %. When service condition repeated impact, lower level of 2.9 % carbon is specified. The as- cast hardness in sand casting will be typically about 550 HB (Brinell).
2. **Acid-resistant high Chromium-molybdenum (Co-Mo) irons** containing 11 to 23% Cr, up to 3% Mo , carbon 1 – 2 %, and often additionally alloyed with nickel or copper. When the chromium levels exceed 20% , high-chromium cast irons exhibit good resistance to oxidizing acids, particularly nitric acid (HNO<sub>3</sub>). High-chromium cast irons are also resistant to reducing acids. They are used in saline solutions, organic acids, marine and industrial atmospheres. These materials exhibit excellent resistance to abrasion and with proper alloying additions, they can also resist combinations of abrasion and liquids including some dilute acid solutions.
3. **High-Chromium White Irons** -The high-chromium (> 10 % Cr) white irons have excellent **abrasion resistance** and are used effectively in slurry pumps, coal-grinding mills, shot-blasting equipment, and components for quarrying, hard-rock mining, and milling. In some applications they must also be able to withstand heavy impact loading. These irons always have specified Mo – up

to 3 %, to ensure high hardness. Small amounts of Ni and Cu also can assist in achieving very high hardness and toughness. These alloyed white irons are recognized as providing the best combination of toughness and abrasion resistance attainable among the white cast irons.

#### 4.2.4 Malleable Iron

This type of cast iron was developed much earlier than ductile iron and although a cast iron, offered some ductility and toughness. These desirable properties came from the peculiar structure of free graphite aggregates and a matrix of steel-like ferrite or ferrite and pearlite. Starting from white cast iron, a prolonged heat treatment decomposes carbides to release free carbon as graphite aggregates.

Ferritic and pearlitic malleable irons are both produced by annealing white iron of controlled composition. Malleable irons have largely been replaced by ductile iron in many applications. This is due in part to the necessity of lengthy heat treatments for malleable iron and the difficulty in cooling thick sections rapidly enough to produce white iron. Malleable iron is still often preferred for thin section castings and parts that require maximum machinability and wear resistance. In auto components of limited thickness, malleable iron components are specified as they are more cost effective than ductile iron.

The annealing of malleable iron should be done in a furnace with a controlled atmosphere of dry nitrogen, hydrogen and carbon monoxide.

The annealing treatment involves three important steps:

- i. The first causes nucleation of temper carbon. It is initiated during heating to a high holding temperature, 900 – 970°C. This is First stage graphitization.
- ii. The second step consists of holding at 900 to 970°C. Some carbide still present is decomposed to graphite.
- iii. When the carbides are eliminated, the iron is rapidly cooled to 740°C, at a rate of about 80°C per minute
- iv. The third step in the annealing treatment consists of slow cooling through the temperature range where carbon from the parent phase austenite is converted to graphite. This graphite joins the temper carbon formed earlier. This step is called second-stage graphitization (SSG).

Typical composition:

Name of the alloy	C	Si	Mn	S	P
% of Composition	2.2 – 2.9	1.0-1.9	0.15 – 1.2	0.05 – 0.2	0.01-0.05

**Melting:** Duplexing, that is melting in one furnace - Cupola or electric arc furnace - and holding in another (usually induction furnace- coreless or channel type).

**Types of malleable iron:** Whiteheart (England and Europe) and Blackheart (USA)

The differences of the two types are due to difference in heat treatment atmosphere and the resulting structure and fracture.

**Features of malleable iron:**

- To obtain a ductile malleable iron of limited strength, the annealing cycle should

have very slow cooling from about 740°C. To obtain higher strength faster cooling rate is required. This is done by taking out the castings from the furnace and cooling in air or air blast. This treatment produces combined carbon in the form of pearlite matrix.

- To achieve uniform properties, after pearlite formation, the castings have to be tempered to adjust hardness and ductility. Final hardness of about 240 HB (Brinell) is a typical of strong malleable iron with some ductility.
- It is more difficult to produce castings of malleable iron with large section thickness. This is because (i) producing white cast iron throughout the section will be extremely difficult and (ii) to form temper carbon all through the section also
- Care in controlling the annealing furnace is required. The furnace atmosphere should not contain excess hydrogen, oxygen or carbon di-oxide gas.
- The attractive features of malleable irons in general are good castability, less rigid quality control for scrap, excellent machinability, adequate ductility and ability to be heat treated to produce a variety of combinations of strength and ductility.

#### **Applications of malleable iron:**

Malleable cast iron is used for connecting rods and transmission gears, differential cases and certain gears, power trains, frames, suspensions, and wheels, compressor crankshafts and hubs, flanges, pipe fittings and valve parts for railroad, marine and other heavy-duty applications. Pearlitic grades are highly wear resistant, with hardness ranging from 152 to over 300 BHN. Applications are limited, however, to relatively thin-sectioned castings because of the high shrinkage rate and the need for rapid cooling to produce white iron.

#### **4.2.5 Ductile iron or Spheroidal Graphite (SG) Iron**

Ductile iron derives its name from the fact that, in the as-cast form, it exhibits measurable ductility. By contrast, white iron nor grey irons do not possess ductility. Ductile iron is also known as nodular iron or spheroidal graphite iron.

Ductile iron is defined as a high carbon containing, iron-base alloy in which graphite is present in a spheroidal shape in a background matrix which can be modified as per requirement. Unlike grey iron that contains graphite flakes; the small rounded spheroidal nodules of graphite are present in a matrix similar to steel. Therefore, ductile iron has much higher tensile strength than grey iron, a considerable degree of ductility and hence, reasonable toughness. In addition, because of application of principles of phase change in metallurgy, it has been possible to manipulate the combinations of properties tensile strength, ductility, hardness, toughness, resistance to fracture etc. So, the family of ductile irons is a versatile material system.

#### **Structure and properties of ductile iron**

Because the special properties of ductile iron depend on the shape of graphite, the properties of the family of ductile iron depend chiefly on the structure. Treatment of the melt by Mg-bearing agent is the key to formation of graphite nodules during solidification. Presence of trace amount of residual magnesium ensures that after solidification also the graphite retains that desirable shape. So, the factors that influence the formation of spheroidal graphite are the factors that govern the properties of this iron.

**1. Melting method and process control** - Ductile iron can be produced by treating low sulphur liquid cast iron with an additive usually containing magnesium and then inoculated just before or during casting with a silicon-containing alloy. Carbon contents of unalloyed ductile iron ranges from 3.0 wt.% to 4.0 wt.% and silicon content from 1.6 wt.% to 2.8 wt.%. The sulphur and phosphorus levels of high quality ductile iron, however, must be kept very low at 0.03 wt.% S maximum and 0.1 wt.% P maximum.

So, to attain suitable properties, it is essential to maintain strict quality control on a few points:

- a. **Control of composition:**
  - i) Proper % C, % Si and carbon equivalent ( $CE = C\% + 1/3(\%Si + \%P)$ )
  - ii) Low sulphur, low Mn – these two elements must be controlled.
  - iii ) Absence of harmful elements ('tramp' elements) – like aluminium, lead, titanium etc which hinders graphite nodule.
- b. **Proper Nodularising treatment at correct temperature** – Treatment of the low-sulphur melt with magnesium causes formation of nodular graphite during solidification. Ferro-silicon-magnesium alloy is now commonly used as the nodularising agent, although ductile iron had been developed by using Nickel-magnesium alloys. Ni is not always desired in ductile iron, so Ni-free agents are now popular.
- c. **Controlling the time of treatment** – Delay between i) nodularising treatment and inoculation and ii) inoculation and pouring must be avoided. Otherwise, the effects of nodularising treatment and inoculation will fade.

## 2. Spheroidizing Treatment – details

One of greatest practical difficulties is the add the required amount of magnesium into the melt in such a manner that there is enough time for Mg to react with the melt and start spheroidising it before magnesium boils off. Magnesium boils at 1120°C and when plunged into cast iron at 1400°C, it tends to melt and vaporize instantaneously, escaping with vigorous boiling. The various techniques have been optimised and newer design of ladles have been perfected so that magnesium treatment works consistently, leaving as residue in the metal, a small amount of magnesium.

- a) Tundish Techniques
- b) Sandwich method
- c) Cored Wire Systems

**Amount of Magnesium Required** - In practice it is normal to allow for minimum residual magnesium content of 0.035 to 0.04 wt.%, plus the amount of magnesium required to neutralize the sulfur in the iron. The amount of magnesium alloy required depends on two factors:

- a) The temperature of metal, the higher the temperature, the lower the recovery of magnesium.
- b) Sulphur content of the base iron to be treated; the higher the sulphur content, the greater is the amount of magnesium to be added.

## Features of Ductile iron

The tensile properties of ductile irons are close to, or even sometimes better than plain carbon steel is primarily due to the fact (a) that the graphite is present in a most harmless form and (b) the nature of the matrix and its constituents can be controlled.

Ductile iron offers the design engineers the option of choosing high ductility, more than 10% elongation, or high strength exceeding 825 MPa. Such combinations cannot be achieved by any other cast iron. Ductile iron, when compared to steel and malleable iron castings can be cheaper for many applications, particularly for sections larger than 100 mm.

A major advantage of ductile iron is the ability to produce high strength and toughness, with reasonable ductility. To achieve the full potential of ductile iron, austempering heat treatment is adopted. By adopting austempering heat treatment process instead of conventional hardening and tempering treatment for ductile iron, the chances of cracking and distortion are reduced. Thus, it becomes possible to carry out rough and final machining before heat treatment. It is possible to achieve various combinations of high strength, high hardness, limited ductility or lower strength, lower hardness, high ductility by varying the temperature of austempering.

Ductile iron is finding increasing applications in automobile parts e.g. crankshafts, piston rings and cylinder liners. The use of ductile iron in these applications provides increased strength and permits weight savings. In agricultural and earth-moving application, brackets, sprockets wheels and track components of improved strength are made of ductile iron. General engineering applications include hydraulic cylinders, mandrels, machine frames, switch gears, rolling mill rolls, tunnel segments, bar stock, street furniture and railway rail-clip supports.

Typical Composition of Ductile Iron for Austempered Ductile Ironare

Alloying Element	C	Si	Mn	Cu	Ni	Mo
% of Composition	3.5-3.7	2.5-2.7	0.25-0.31	0.05-0.8	0.01-0.8	If required, 0.25

## Review Questions

1. Name the various types of cast irons and describe their general features
2. Describe the different ways in which carbon is present in different types of cast irons.
3. What is Carbon Equivalent?
4. What practical information is obtained from the value of CE?
5. What are the uses of white cast iron?
6. State the compositions and application of Grey cast iron.
7. Describe briefly the process of producing malleable iron from white cast iron.
8. State the compositions and application of malleable cast iron.
9. Why is ductile iron superior to grey cast iron regarding tensile properties?
10. List the composition and application of ductile iron.
11. Briefly describe the process of producing ductile iron.

## 4.3 Cast Steels Technology

Steel is a versatile material, used widely both in cast form and in wrought form. (Mechanically deformed – as in forging, rolling etc). Unlike cast iron family, which can only be used as castings, steel castings can have properties similar or comparable to rolled or forged steel component with similar composition. Castings as a manufacturing method however possess one great advantage- complex shapes are obtained as a single piece.

Basic classification of steel castings has been mentioned in the previous chapter. Steel castings are classified in two broad categories:

1. Carbon steels and low alloy steels – Low alloy steels
2. High alloy steels for specific applications – a) application at high temperature b) for wear and abrasion resistance and c) for elevated temperature applications.

Discussion on steel castings, their properties and applications etc specially for alloy steels, shall be covered very briefly in this Chapter. This is because to understand how versatile the alloy steels can be, without changing composition but only requires some knowledge of heat treatment, which is far beyond the scope of this syllabus.

### 4.3.1 Classification of steels, particularly used in cast form:

#### A. Plain carbon steels -

- i) Low carbon steels(< 0.20% C)
- ii) Medium carbon (0.20 to 0.50% C)
- iii) High carbon steels (> 0.50% C)

Such steels served useful purpose earlier, but for many versatile applications, these are one replaced by alloy steels, requiring smaller section thickness, hence less weight.

**B. Low alloy steels** - These is a class of steel with alloy content limited to about 5 per cent. Alloying elements are selected for the purpose of improving certain properties, depending on the nature of the alloying elements and their mutual affinity to produce desirable phases.

**C. High alloy steels** - There are a few very useful steels with alloy content being more than 5 wt %. Stainless steels may have a total of 25-30 % of alloy elements. Hadfield high manganese steels are also alloy steels that are used only in cast form

### 4.3.2 Low carbon steels

Low carbon steels are ‘annealed’ after casting. Annealing heat treatment involves heating the castings to a moderate temperature and holding there for sufficient time to make the casting tougher, as ductility is increased and chemical composition becomes more homogeneous.

Strength in carbon steel comes from (i) carbon level – higher carbon, higher strength (ii) Mn and Si in correct proportion – they remain dissolved in iron and provides strength; they also favour the formation of very hard and strong ‘martensite’ phase while cooling the casting from high temperature above 900°C.

**Applications:** These castings of moderate strength and appreciable ductility and toughness are quite economical and used in electrical machinery, as structural components where the expected load is limited – as in transport equipment, textile machinery, etc.

### 4.3.3 Medium carbon steels

Medium carbon steels with carbon level of 0.2 to 0.5 % carbon, are the most popular among plain carbon steels since they provide the widest range of properties. In addition, one advantage is that, a suitable combination of % carbon and % Mn can develop reasonably high strength by a simple treatment of heating to about 950°C in a heat treatment furnace and then, taking the castings out of the furnace and cooling in air. This treatment is ‘normalising’. If more ductility is required at the expense of strength, the castings are to be heated again at moderate temperature (300-500°C). This treatment, called stress relief annealing, should be followed for castings of complex shapes with thin and thick sections. In medium carbon steels, presence of relatively high level of manganese (1-1.5% Mn) increases the range of strength after normalising treatment.

**Application:** In transport sector, in equipment for metal forming and cutting machinery, in earthmoving and agricultural machinery etc. Valve casings, pump covers, impellers, strong pipe manifolds, dies for plastic moulding etc are made from steel castings of medium carbon steel.

### 4.3.4 Low alloy steels

Addition of small percentages of alloying elements, keeping the carbon level low (< 0.4%); significantly improves several properties. Desirable combination of strength and ductility can be obtained, along with the ability to sustain fluctuating load for a long time, durability etc. Such combination of properties cannot be obtained from plain carbon steels. In addition, since carbon level is low, weldability is excellent. Low- alloy steel castings can possess tensile strengths in the range 500- 2000 MPa (70 to 200 ksi). The tensile and yield strengths of low alloy steels, in general, can be 40 to 50% higher than those of plain carbon steels with the same carbon content.

#### Effect of alloying elements:

The following alloying elements are influenced the characteristics of steel casting (Fig 4.8).

**Manganese (Mn)** – improves hardenability, ductility and wear resistance. Mn combines with sulphur to form less harmful MnS, instead of FeS. Used at 12% or more, Mn forms a special steel with unique work-hardenable properties, named Hadfield steel after the name of its inventor.

**Nickel (Ni)** – It is mainly used to improve properties in 1-5% concentration, by a combination of strength and toughness, in conjunction with other strengthening elements like Cr. Mo. It strengthens and toughens. It is extremely useful in increasing impact strength. At high concentrations, nickel imparts resistance against attack by mineral acids.

**Chromium (Cr)** – When used up to 4%, chromium improves hardenability, strength and wear resistance. Strong Chromium carbides form easily but proper heat treatment

is required to gain the benefit of chromium addition, usually along with nickel to improve toughness. Chromium sharply increases corrosion resistance at high concentrations above 12%, to form the basis of stainless steels and heat-resisting steels. Combination of nickel and chromium is the most popular alloy system.

**Molybdenum (Mo)** – increases hardenability and strength particularly at high temperatures and under dynamic conditions. It is very strong carbide former, prevents chromium carbide formation, which is responsible for weld sensitization

**Vanadium (V)** – increases strength, hardness, creep resistance and impact resistance due to formation of hard vanadium carbides, limits grain size.

**Titanium (Ti)and Niobium**– Both of these elements are strong carbide formers and improve strength in very low carbon steels by forming finely dispersed carbides. They are costly alloying elements and are used in small concentrations specially in HSLA (high strength low alloy) steels.

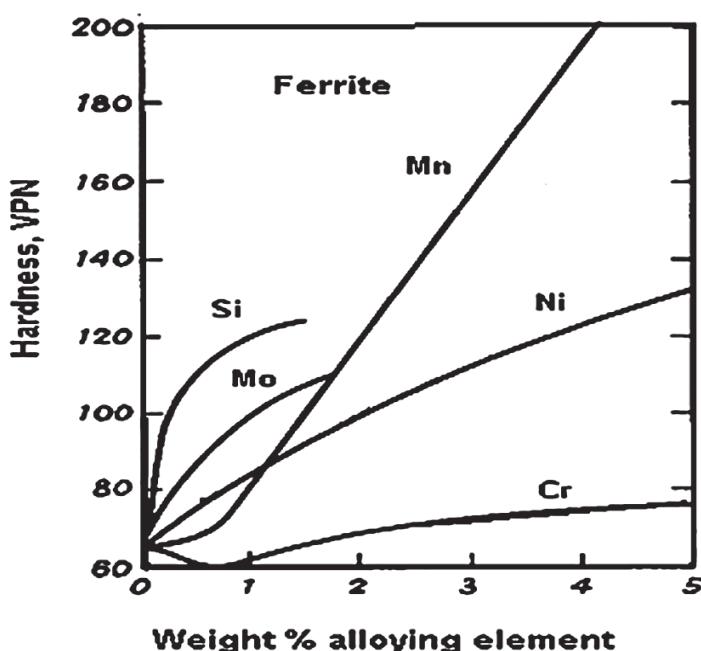


Fig. 4.8 Effect of alloying elements on hardness

### 4.3.5 High-Alloy Steels

The more prominent members of high alloy steels are (1) The family of wear resistant high manganese steels and (2) High Chromium alloys – mainly stainless steels.

#### Austenitic High Manganese Steels (Hadfield steel)

The original austenitic manganese steel, containing about 1.2% C and 12% Mn, was invented by Sir Robert Hadfield in 1882. Hadfield's steel was unique in that it combined high toughness and ductility with high work-hardening capacity.

The special metallurgical feature of this type of steel is its ability to work hardens. Work hardening refers to the fact that the steel becomes harder and harder the more it is impacted or compressed. The "Hadfield" grade has an original hardness of

approximately 220 BHN. With continued impact and /or compression, it will surface harden to over 550 BHN. It should be noted that only the outer skin surface hardens. The material underneath remains highly ductile and tough. As the surface wears during use, it continually renews itself becoming harder and harder. Consequently, it rapidly gained acceptance as a very useful engineering material.

**Applications:** Austenitic high manganese steel is used extensively primarily in the fields of rock crushers, grinding mills, dredge buckets, power shovel buckets and teeth, and pumps for handling gravel and rocks; in the manufacture of cement kiln components etc. Other applications include hammers in hammer mill crushers and grates for automobile recycling and military applications such as tank track pads.

Manganese steel is non-magnetic. This property makes it useful in many applications such as bottom plates for lifting magnets - separator drum shells for magnetic materials - wear shoes on electric brakes etc. Hadfield steel has wide use as railway points etc in quenched condition, since it can withstand long periods of abrasion and compressive load with vibration. The mechanical properties of manganese steel vary with both carbon and manganese content. As carbon is increased beyond 1.2 %, tensile strength and ductility are reduced.

### Corrosion – Resistant steels; Stainless steels

The families of stainless steels have several members, classified usually according to their crystal structure or phase – Austenitic, Ferritic, Duplex and Martensitic (Table 4.1). These steels are used as rolled sheets, plates, tubes and as castings. Only austenitic grades can be rolled into thin sheets, for use in food processing, in medical appliances, body of equipment etc; as well as castings. Stainless steels are designed to make them resistant to corrosion in general – except corrosion by chlorides. This corrosion resistant property, or ‘stainlessness’ property is due to the presence of chromium; usually 18% Cr in most of the alloys. Higher % Cr is specified when greater resistance to corrosion is required. High Chromium grades of stainless steel show excellent resistance to oxidation as well.

The common grades of cast stainless steels are presented in the table below (NB: This table is not for memorizing, or nor should be used for setting questions in examinations but only for illustrating the combinations of alloying elements in standard grades)

Table 4.1 Grade and Compositions of common cast stainless steels

Alloy grade	Composition, wt %				
	C	Cr	Ni	Mo	Remarks
CF 3	0.03	17-21	9-13	-	(Austenitic)
CF 8	0.08	18-21	8- 11	-	(Austenitic)
CF 8M	0.08	18-21	9-12	2.0-3.0	(Austenitic)
CA 15	0.15	11.5 - 14	1.0	0.15- 1.5	(Martensite)
CA 40	0.2-0.4	11.5 - 14	1.0	0.5	(Martensitic)
CC 50	0.5	26- 30	4.0		(Ferritic)
CD 4MCu (Duplex)	0.05	25	5	2	Cu= 3 %,
Ferralium 255 (Duplex)		25	6	3 -4	Cu= 2 %, N= 0.16 %

[Note: For austenitic and martensitic grades, Mn: 1.5 %, Si = 1.5 – 2.0 %]

A few special features of corrosion resistant high alloy steels, including stainless steels are mentioned below:

- Unlike 'wrought' stainless steels which are produced as bar, rod or plate by rolling, forging etc, cast stainless steels typically have low carbon content. Carbon is less than 0.1 % if corrosion resistance is of primary concern. Some grades with high Cr, > 20 %, can have 0.2 % C or more.
- In popular terms, stainless steel means 'austenitic' Chromium-nickel steels; with at least 18 % Cr and 8 % Ni with low carbon. These are non-magnetic if Cr is on the lower lever and Ni, is 12-13 %.
- If the components are to be welded, then % Cr should be on the higher range (20% or more), as in CF 8. These are more resistant to surface pitting in contaminated water. In addition, this alloy has the important property of withstanding load under corrosive medium.
- Use of molybdenum improves all the desirable properties. In other words, the resistance to stress corrosion cracking (SCC) is higher. Mo also has marked beneficial effect in resistance to localised corrosion such as surface pitting. Mo-containing grades have 'M' is their designated grades.
- A new addition in the family of stainless steels is the Duplex stainless steels. After prolonged research, new alloy combinations have been optimized to develop a new group of stainless steels having much greater corrosion resistance in contaminated or acidified water, as is usually present in underground mines. Presence of high levels of Cr and balancing nickel produces a structure suitable for corrosion resistant applications in cast or wrought form.

The modern Duplex stainless steel contains a special and uncommon alloying element – Nitrogen. Traditionally, nitrogen is considered harmful for structural steels that should have high strength coupled with toughness, since dissolved nitrogen tends to make the steel brittle. However, in the latest grades of stainless steels, nitrogen dissolved in steel has beneficial effects. Nitrogen can partly replace nickel as alloy in presence of Cr and it is possible during melting stainless steel to introduce nitrogen-bearing additives. The most important effect of nitrogen, above about 0.15 %, is the significant improvement in resistance to 'pitting' corrosion. Local corrosion causes loss of metal by dissolving in contaminated or acidified water, reducing the thickness. For components that bear load, loss in thickness by pitting can be dangerous, since the component can break suddenly due to overload. New duplex grades can be welded easily.

Ferritic stainless steel castings have high levels of Cr but low levels of nickel. They have better corrosion resistance than common austenitic stainless steels (CF3, 8) due to higher chromium level. These alloys have very good resistance to scale formation at high temperature.

Martensitic stainless steels are harder and stronger than most other grades and thus are chosen where liquid or slurry is to be pumped and transported. They are also slightly cheaper because they contain low levels of costly nickel. This is one grade of stainless steel whose required martensite structure is obtained only after heat treatment. Castings can be heat treated to be uniformly strong across the section. They have excellent resistance to atmospheric corrosion, have good erosion resistance and can handle many organic fluids.

**Heat Treatment:** Eventhough the carbon content is low in stainless steels, there is a tendency to form carbides across grain boundaries in castings in as-cast condition. This factor sharply reduces corrosion resistance as well as ductility. So, a heat treatment process is adopted to dissolve the carbides in the castings by holding at high temperature, then cooling rapidly by 'quenching' in water. This treatment keeps the carbon dissolved and harmless.

### 4.3.6 Applications:

**Austenitic grades:** Valves, pump components, components in chemical and petrochemical Industry; components; mineral dressing and handling, food processing industry, paper industry components, etc.

**Ferritic grades:** Equipment if paper mill, pump and impellers working for a long time in mild alkaline water or pulp; components to be used at service temperature up to 500 0C. This grade has excellent resistance to SCC and though less ductile than austenitic grades, are used where the component is subjected to tensile load

**Martensitic grades:** For pumps, impellers, valves and turbines for water and other liquids. Due to high hardness, they can also handle slurry and find use in hydraulic machinery, heavy duty compressors etc.

**Duplex grades:** Pump, valves, housings for pumping acidified water; for components under load in contact withmildly corrosive liquids. Among all types of stainless steels, duplex stainless steels have the best resistance against corrosion in chloride media and thus find use in service conditions of mild saline water.

### Heat resistant steels

Engineering components that are used in service conditions at elevated temperature should have:

- Adequate resistance to oxidation and scaling in air or in furnace gas/ exhaust gas
- Ability to retain adequate strength even at elevated temperature without softening
- Ability to withstand load during service enough even when the service temperature is periodically going up and down ('thermal cycling').

Cast components of heat resistant steel grades can operate up to 1200 0C. These grades are basically

- iron-chromium – nickel alloys – such as high chromium ferritic stainless steels where temperature remains more or less constant
- Iron- nickel- chromium alloys, with 18-37 % Ni, 18-22 % Cr, balance iron. Nickel provides the ability to resist thermal cycling. Higher the temperature or more drastic is the temperature gradient, more nickel is required.

### Review Questions:

1. Explain various types of steel castings with applications.
2. Write shore notes on plain carbon steels
3. Difference between low carbon steels and medium carbon steels.

4. What are the effects of alloying elements in the low alloy steel castings?
5. What are the compositions and application of high alloy steels?

## 4.4 Non-Ferrous Cast Alloys

The application of castings of non-ferrous alloys has direct link with the range of properties available from suitable alloying. As in the previous chapter, the typical properties and applications of only Copper-base, Aluminium-base and Magnesium base alloys shall be discussed.

### 4.4.1 CAST COPPER ALLOYS:

Cast copper alloys possess many desirable features:

- Flexibility of casting methods
- Corrosion resistance
- Low Frictional Properties and Good Resistance to Wear.
- Non-Sparking Characteristics
- High Electrical and Thermal Conductivity
- Good Mechanical Properties at room temperature and at sub-zero temperature

The most widely used copper-base alloys belong either to the family of brass (Cu-Zn alloy) or bronze (Cu-Sn alloys).

As mentioned in the previous chapter, there are a few alloys the names of which are misleading – such as Aluminium bronze. This is a copper-aluminium alloy, containing 8-11 % Al; without tin.

Another example of a misnomer is the name “Manganese bronze”; which is actually ‘High-tensile brass’: containing Mn and Al ; 4 %; small amount of nickel and iron, 55 % Cu and balance Zinc. This combination of alloys in high tensile brass result in very high tensile strength of 60 – 70 kg/ mm<sup>2</sup>, compared to 20-30 kg/ mm<sup>2</sup> for common tin bronze but at the expense of ductility (% elongation).

**Applications of Al-bronze:** Aluminium bronzes are most commonly used in applications where their resistance to corrosion makes them preferable to other engineering materials. These applications include bushings and landing gear components on aircraft, engine components (especially for seagoing ships), underwater fastenings in naval architecture, and ship propellers. The attractive gold-toned coloration of aluminium bronzes has also led to their use in jewellery.

Aluminium bronzes are in the highest demand from the following industries and areas:

Most aluminum bronzes contain from 0.75 to 4% Fe to refine grain structure and increase strength. Alloys containing from 8 to 9.5% Al have higher tensile strength and greater ductility and toughness than any of the ordinary tin bronzes. Applications include valve nuts, cam bearings, impellers, hangers in pickling baths, agitators, crane gears and connecting rods. Aluminum bronzes resist corrosion in many substances, including pickling solutions. Castings required for high strength and resistance to cyclic load (fatigue).

Apart from strength, selection of proper alloy should also consider other properties that may be required in service; such as corrosion resistance or wear resistance.

- **The aluminum bronzes and copper-manganese-aluminum alloys** are superior to high tensile brasses regarding corrosion resistance.
- For use in saline water, as for components under marine conditions the high tensile brasses are suitable. Generally, the high tensile brasses should not be used in applications involving rubbing
- **Manganese Bronze or High Tensile brass** are copper alloys, containing 25-38% of zinc as the major alloying element and 0.8-4.3% of manganese, 1-3% of iron and up to 6.8% of aluminum as additional alloying elements. Manganese, iron and aluminum are added to the Manganese Bronzes for increasing their hardness and strength.

Manganese Bronzes are used for manufacturing large valve stems, flanges, gears, shafts, cams, heavy load bearings, bushings, screw down nuts, gun mounts, hydraulic cylinder parts, pump components, impellers, frames, high strength machine parts.

### **Castings required for resistance to corrosion**

Copper and copper base alloys are noteworthy for their resistance to corrosion and this is often the main reason for their use. Copper alloys are prone to rapid attack in atmosphere containing ammonia or in solutions containing ammonia salts.

**Atmospheric Corrosion-** All cast copper alloys have good resistance to atmospheric corrosion, although most undergo superficial tarnishing, with a greenish layer. Corrosion rates of copper base alloys are higher in sulphur bearing atmospheres, near power plants or in industrial area.

**Seawater-** The phosphor bronzes and gun metals have notably good resistance to corrosion by seawater and are used for such purposes as pipe fittings, cocks and pump bodies. The high zinc brasses tend to undergo slow de-zincification, but this is very much reduced by the addition of tin. High tensile brasses of suitable composition are widely used for marine propellers.

### **COPPER-TIN ALLOYS**

**90:10 Copper-Tin Alloy:** This is typical **gun-metal**, most varieties of which, however, contain a deoxidizer, frequently zinc (e.g. Admiralty gun-metal, copper 88%, tin 10%, zinc 2%). This alloy has much superior corrosion resistance in sea water than brasses. For application as marine fittings due to good resistance to salt water corrosion, these alloys contain small amount of lead to improve machinability and about 1 % Ni, to improve ductility, mechanical properties and corrosion resistance and used as bearing material.

**80 -20 Copper-Tin Alloy (Bell metal) -** This chemical composition is typical for a number of bronzes used as bearing metals, most of which, however, contain a little zinc as a deoxidizer. It is also the approximate composition of Bell metal. Smaller bells, made by casting, for household or temples had typical composition of 78 % Cu and 22 % Sn with a small amount of zinc and iron for strength, giving sonorous sound upon ringing. Tin is responsible for the generating the typical vibrations for a bell.

**Copper-Nickel alloys** constitute a special group of nickel bearing alloys with % Ni

being about 10 % in copper-nickel-zinc alloys or ‘German silver’ and about 30 % or above in **Cupronickels**. Presence of nickel makes the alloy white or silvery in colour, in contrast with reddish colour of copper-case conventional alloys. Copper-nickel alloys are used as kitchen alliances, ornamental fittings, decorative hardware, equipment in dairy, food processing and beverage equipment. They have good pressure tightness and corrosion resistance. Cupronickels are costlier alloys that are used where higher corrosion resistance and durability is desired.

#### 4.4.2 Cast Aluminium Alloys:

Aluminium alloys and magnesium alloys are two common light metal alloys that can develop relatively high strength. Research and development of Aluminium alloys in particular have received tremendous attention in recent decades because designers for aerospace components were interested to exploit the low density and high strength of this family of alloys. In addition, since fuel costs are rising rapidly, if the weight of any transport system - motor car, motor cycle or aircraft – can be reduced by selecting suitable strong but light weight material, fuel consumption can be reduced.

Both wrought (mechanically worked- rolling, forging, extrusion etc) and cast alloys have been developed to meet these requirements.

Cast aluminium alloys can be classified according to their processing route:

##### 1. Cast Non-Heat Treatable Alloys

**Al-Si alloys;** The maximum amount of silicon in cast alloys is of the order of 22-24% Si. Alloys with lower range of silicon are cast by plaster or investment casting or sand casting. Al-Si-Cu alloys are popular die casting alloys.

The mechanical properties of the family of Al-Si alloys depend on the alloy composition and the final as-cast grain structure. By a treatment of the melt, called ‘Modification’ by alkali metals or strontium, refined grain structure is obtained in castings of Al- 11 % Si alloys. Al-Si alloys with lower silicon, say Al-8% Si, do not require this treatment. These alloys have excellent casting properties and good corrosion resistance with moderate strength. The presence of silicon gives two benefits- high fluidity and low shrinkage, which result in good castability and weldability.

- The low thermal expansion coefficient of the alloy is exploited for pistons,
- The high hardness of the silicon particles in this alloy makes Al-Si alloys suitable for applications where wear resistance is required.

Copper, chromium, nickel are sometimes added to improve strength at high temperature, without loss of castability, but at the expense of corrosion resistance.

**Applications:** Piston for small vehicles, Pump casings, thin wall castings. For high silicon alloys, wear resistance is excellent.

##### 2. Heat treatable cast aluminium alloys

These alloys form a growing family of high strength aluminium alloys, where the strength can be adjusted by controlling heat treatment. The two important members in this group are (a) Al- Cu alloys (b) and the following benefits are obtained by proper heat treatment of this group;

- Ability to attain the desired set of mechanical properties

- To remove internal stress in complex-shaped castings and to obtain dimensional stability
- To stabilize tensile properties- so that the alloy component do not have gradual increase in hardness during service with loss of toughness and ductility (which can occur in certain alloys).

## **Designation of alloys**

Following are thermal treatment designations (tempers) and what they specify:

**F** - As-cast.

**O** - Stress relieve or anneal.

For aluminum castings, “T” designates thermal treatment and is always followed by one or more digits that indicate specific sequences of basic treatments. A second digit indicates a modification of the heat treatment to obtain specific properties.

**T4** - Solution heat treat and quench. This is an unstable treatment. While it improves mechanical properties (such properties increase through aging at room temperature over a period of weeks), it is a usual practice to artificially age to attain maximum mechanical values.

### **i) Aluminium-Copper alloys:**

Copper has been the most common alloying element almost since the beginning of the aluminum industry, and a variety of alloys in which copper is the major addition were developed. Cast alloys with 5% Cu, often with small amounts of silicon and magnesium to improve fluidity, are applied for fly wheels, component for transport vehicles carrying load. Many of the cast alloys and of the aluminum-copper-nickel alloys are used for high-temperature applications.

### **ii) Aluminum-magnesium alloys:**

possessing a high, stable combination of strength, shock resistance and ductility. It is suited for parts in instruments and computing devices where dimensional stability is of major importance.

In addition to the high ductility and tensile strength, this makes it suitable for shock-resistant applications. In addition, this alloy doesn't require heat treatment. Brackets, C-clamps and machined parts that need strength as well as impellers, optical equipment and similar applications requiring a high polish or anodized finish are typical uses. In many cases, this alloy has replaced grey iron and malleable iron because its use reduces weight without sacrificing strength.

### **iii) Aluminium- Silicon -Magnesium alloys:**

These alloys are noted for their excellent corrosion resistance in marine conditions. With addition of silicon, casting and mechanical properties improve significantly. Cast components of this class of Al-Si-Mg alloys are used widely in food processing equipments, water treatment equipment, components requiring corrosion resistance in aviation; in motor boats, as components in outboard motors, and ship. Addition of titanium and zirconium further improves oxidation resistance, refines grains and increases toughness.

A special feature of this class of alloy is that due to the presence of low-density magnesium (specific gravity 1.74), these alloys possess very high strength / density ratio, called specific strength. This property is desirable for components to be used for aircraft – wheels, instrument panels and certain other load bearing items. Of course, special casting methods have been developed to avoid the risk of common casting defects of gas defects and entrapped dross.

#### 4.4.3 Cast Magnesium Alloys

Interest on development of magnesium alloys have recently increased because of the special and somewhat peculiar properties displayed by magnesium:

- ❖ Magnesium is very light metal , but can be alloyed to give excellent combination of strength and rigidity are major advantage, such as for chain saw bodies, computer components, camera bodies, and certain portable tools and equipment.
- ❖ Magnesium alloy sand castings are used extensively in aerospace components because of weight advantage.
- ❖ Magnesium is known to be a very reactive element, but it can be handled without difficulty in a foundry, with certain precautions.
- ❖ At present, a modern foundry can produce magnesium casting by using a number of moulding processes - nearly all of the conventional casting methods, namely, sand mould, permanent, and semi-permanent mould and shell, investment moulding and die casting
- ❖ Magnesium die cast alloys are used widely. The most popular die cast alloys were based on **magnesium- 6-10 % aluminium** alloys, with some zinc. However, magnesium can form alloys with uncommon elements – zirconium (Zr) and Rare earths (RE). These are used in investment casting, permanent mould casting and in pressure die casting.
- ❖ The **magnesium-zinc- rare earth** alloys are specially selected for rigidity, strength and low specific gravity at elevated service temperature of about 150°C.
- ❖ Magnesium alloys have excellent machinability.

At present, magnesium alloy castings are being used in components of landing gear of small and large aircraft, rudder, cockpit instrument panel, helicopter gear housing, radiator support and other components. In automobiles also, application of magnesium alloys are increasing and heat treatment of various alloys widen the areas of application of these alloys.

Mention can be made in brief of a new alloying element for aluminium and magnesium–lithium. Lithium is unique in two ways. First, with density less than that of water (sp. gr. 0.534), it is the lightest alloying element used to improve the ratio of strength and specific gravity and secondly, its presence in correct proportion can increase the Young's modulus (stress/strain in Hooke's law) significantly in aluminium alloys. However, at present research and development of lithium-containing alloys are largely applied to aerospace sector, mostly under government agencies. Magnesium- lithium castings are used in several modern aerospace systems, including missiles, instrument boxes, etc.

## Review Questions

1. Describe the general features of copper-zinc base engineering alloys.
2. Name any two useful Copper-zinc alloys and indicate their applications
3. What is Aluminum Bronze? What are its special features?
4. Name any two types of bronze and state their applications.
5. What are the differences between brass and bronze?
6. Name an aluminum alloy of highest strength? Describe its alloying elements and state the applications.

## 4.5 Summary

The unit starts with explanation of the various cooling curves for pure metal and alloys. Exploring the various classifications of cast iron and their properties. Understanding about the various properties enhanced by individual alloying element in the steel castings. And also studies the various fields of applications of cast copper alloys, cast aluminum alloys and cast magnesium alloys.

## Exercise Questions-

1. Outline the various characteristics of metals.
2. Why alloys are used to manufacture components for industrial applications?
3. Discuss the Directional solidification process in the metals
4. Describe the nucleation and mechanism of growth.
5. Name the various types of cast irons and their characteristics
6. What are the compositions and uses of white cast iron?
7. State the compositions and application of grey cast iron.
8. Describe the process of producing malleable iron from white cast iron.
9. State the compositions and application of malleable cast iron.
10. Why is ductile iron superior to grey cast iron regarding tensile properties?
11. Describe the production process of ductile iron.
12. Write short notes on medium carbon steels
13. Differentiate between low carbon steels and high carbon steels.
14. What are the effects of alloying elements in the low alloy steel castings?
15. What are the compositions and application of high alloy steels?
16. Describe the compositions and application of copper-zinc base alloys.
17. What is Aluminum Bronze? What are its special features?
18. Name any two types of bronze and state their applications.
19. Describe the various aluminum alloys with their engineering applications.

# CHAPTER 5: TESTING AND QUALITY ASSURANCE IN FOUNDRY

## 5.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource Material
- Duration
- Learning outcomes
- Assessment Plan

### 5.1 Introduction

### 5.2 Cleaning of Castings

### 5.3 Testing of Castings

### 5.4 Casting Defects: Causes and Remedial Measures

## 5.0 Unit Overview & Description:

### Overview

This unit will provide the students, knowledge about the various testing methods such as tensile testing, hardness testing, impact testing, ultrasonic testing, radiographics testing and eddy current testing in the foundry industry. This chapter gives the various methods for cleaning of the cast components. It's provides the knowledge about the various casting defects and their causes and remedies.

### Knowledge and skill outcomes

After completing this chapter the learners would be able to:

- i) Knowledge about the various methods of cleaning of castings
- ii) Understand various principles involved in destructive and non-destructive tests
- iii) Understand the various principles involved in measuring hardness, tensile strength.
- iv) Get a clear idea on stress strain curves of ductile and brittle materials.
- v) Know the various tests involved in measuring toughness.
- vi) Select a suitable NDT for internal and external defects occurring in casting.
- vii) Know the various casting defects and their remedies.

### Resource Materials:

1. Jain R K, "Engineering Metrology", Khanna Publishers, 2008.
2. Mahajan M, "Statistical Quality Control", Dhanpatrai & Sons, 2009
3. Jain P L, "Principles of Foundry Technology", Tata McGraw Hill Publishing Company Ltd., 2010.

<b>Duration:</b>	Total Hours 20
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## Learning Outcomes:

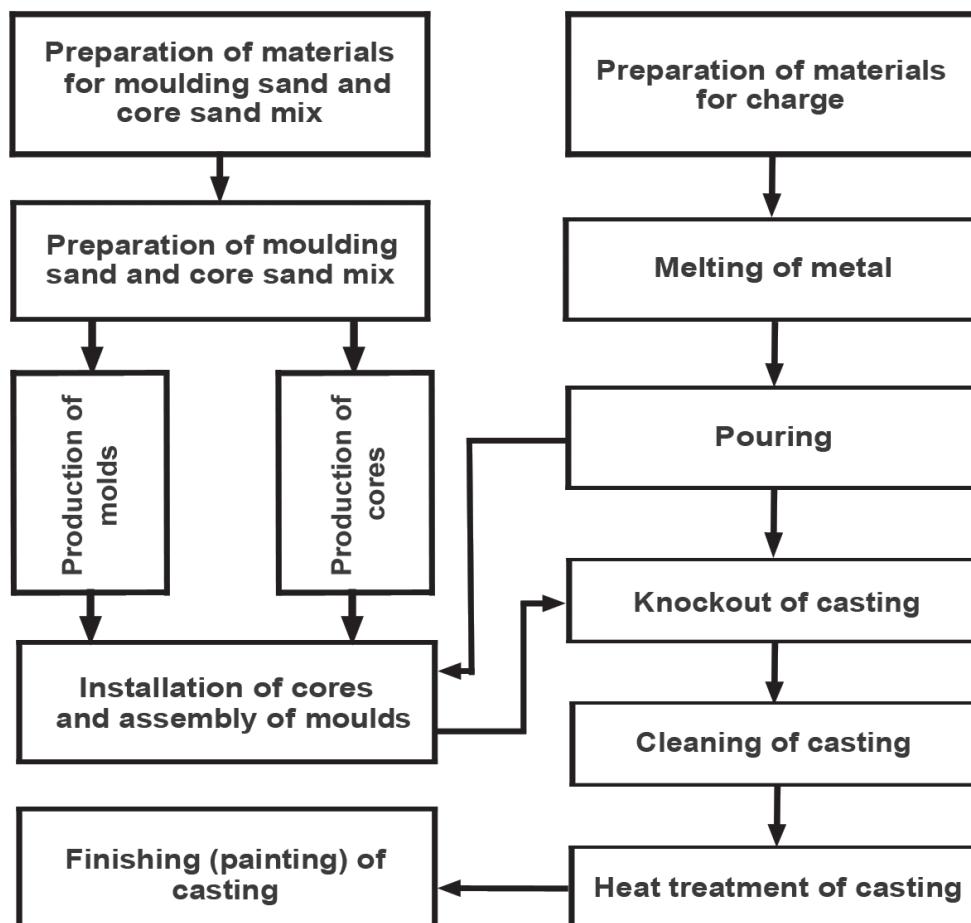
Unit-5	Testing And Quality Assurance In Foundry	Outcomes
5.1	Introduction	<ul style="list-style-type: none"> <li>Demonstrate process flow in the foundry industry</li> </ul>
5.2	Cleaning of castings	<ul style="list-style-type: none"> <li>List importance of the cleaning of castings</li> <li>Identify methods of cleaning of castings</li> <li>Demonstrate purpose of the surface finish</li> </ul>
5.3	Testing of Castings	<ul style="list-style-type: none"> <li>List techniques of the testing of castings.</li> <li>Understand principle of tensile testing</li> <li>Demonstrate procedure for the measuring hardness</li> <li>Identify testing procedure for impact testing</li> <li>List methods of flaw detection</li> <li>Demonstrate use of radiographic testing for casting inspection</li> <li>List principle of ultrasonic testing</li> <li>Identify eddy current method of inspection</li> </ul>
5.4	Casting Defects: Causes and Remedial Measures	<ul style="list-style-type: none"> <li>Classify casting defects</li> <li>List various causes of the casting defects</li> <li>Identify possible remedies for the defects</li> </ul>

## Assessment Plan: (For the Teacher)

Unit-1	Topic	Assessment Method	Time Plan	Remarks
5.1	Introduction	Exercise: Question & Answer		
5.2	Cleaning of Castings	Exercise: Question & Answer		
5.3	Testing of Casting	Exercise: Question & Answer		
5.4	Casting Defects: Causes and Remedial Measures	Exercise: Question & Answer		

## 5.1 Introduction

Before going to the details in this chapter let us examine what is the importance of cleaning operations in a foundry by simply viewing the following block diagram is shown in Fig 5.1.



*Fig 5.1 Foundry Process block diagram*

## 5.2 Cleaning of Casting

After the solidification of metal and cooling of sand mould, the casting is knocked out by breaking the mould either manually on the pouring floor itself or mechanically. In the latter case, the mould is rapidly jarred by mechanical vibrations so that the sand becomes loose and falls through a grater screen into a pit or on a belt conveyer arranged below the floor. The casting and moulding boxes are then removed from the grate. The casting removed from the mould as such is not fit for use since it contains unwanted parts such as sprue, risers, gates, etc, and sand particles. Therefore, the cleaning of castings may be considered as the group of operations involved in the removal of adhering sand and core residues, separation of feeder heads and runners and elimination of flash, fins, wires, chaplets and other metal not a part of casting.

The cleaning operations are carried out in the shop known as fettling shop and thus operations are also referred as fettling operations. The various cleaning operations include the following.

- Removal of dry sand cores
- Removal of feed heads and runners
- Removal of unwanted projections such as fins, wires, flash, etc.
- Final cleaning and smoothening of casting surfaces.

### 5.2.1 Removal of Dry Sand Cores

The main mass of the moulding material is usually removed at the knock out station, but heaviest castings and castings with confined internal cavities contain residual sand and dry sand cores. This residual sand and cores are loosened with crow bars and pneumatic or hydraulic iron pricks. These devices knock out the cores and also help in cleaning and smoothening of the casting.

### 5.2.2 Removal of Feed Heads and Gates

Numerous alternative methods are available for the removal of feeding and gating systems and the choice depends upon the size and shape of the casting and type of the metal. The options extend from simple knocking off through the standard methods of machine cutting by saw, abrasive wheel or parting tool to a highly versatile range of flame cutting processes. All these methods are useful in carrying out the useful functions in the foundry depending upon the type of alloy and dimensions of the casting.

### 5.2.3 Knocking Off or Breaking With Hammer

This method can be applied to the castings having low ductility, particularly where the area of junction with the casting is small. This method is particularly suitable for grey cast iron casings and other brittle metals. The fracture may be facilitated by the use of various types of necks and knock off cores, both to reduce the metal section and to provide a notch effect. However, one of the slitting processes may also be used to produce initial notch.

### 5.2.4 Sawing

Although, sawing can be adopted for most types of cast metals, it is most commonly employed for the softer non-ferrous alloys. The various types of saw used include bandsaws, hacksaws and circular saw, but the band saw is the most versatile as it can be used over a wide range of speeds (25m/s-0.25 m/s). At still higher speeds (75 m/s) the principle of friction cutting comes into effect in which sufficient heat is generated to bring the temperature at the root of the cut into the plastic range causing the high rate of stock removal. Friction cutting finds its use in ferrous alloy castings including work hardening components not amenable to sawing upto about 25 mm in section thickness.

### 5.2.5 Abrasive Wheel Cutting

Abrasive cut off machines can be used for all metals but these are specially designed for hard metals which are difficult to saw or shear. On a full sized machine the wheel can be mounted in fixed position and the casting is pushed against it, or the casting may be clamped to the table and the mounted wheel is swung into the contact position. In general, much use is made of portable machines on which abrasive disc are mounted on a right angled shaft. The wheel thickness may vary from about 3 mm to about 500 mm. For each type of wheel there is an optimum peripheral speed (48 – 81 m/s) and thus the machine should have the provision for an increase in rotational speed to compensate wear of wheel.

### 5.2.6 Machining

In some cases heads can be easily removed by machine parting. The method is mainly suitable for large heads and those where a continuous cut can be achieved, e.g. in case of axially positioned and annular heads. In this method, a narrow parting tool is employed and further finishing becomes unnecessary.

### 5.2.7 Removal of Unwanted Projections and Fins

Either after, before or during the surface cleaning, the castings are subjected to dressing for the removal of excess metal which include flash, fins, pads and the stumps of feeder heads and gates, chaplets, wires, etc. which are not a part of the casting's final dimensions. The principal techniques employed in dressing of castings include chipping and grinding but hot fettling techniques with specially designed torches are also used.

### 5.2.8 Chipping

Though chipping of fins, riser pads, wires, etc. can be carried out by hand hammers and chisels, the principal tool is the pneumatic chipping hammers or chisels operating at the pressure of 500-700 KN/m<sup>2</sup>. A variety of hammer and chisel sizes are used for different casting alloys. Light grey and white iron castings can be chipped conveniently by hand tools, whereas heavier castings and casting more difficult to trim, are chipped conveniently with pneumatic tools.

### 5.2.9 Grinding

The grinding operations remove excess metal and is carried out by three principal types of grinders, i.e. swing frame, pedestal or bench stand and portable grinders. In addition, specialized machines such as disk grinders, belts and cut offs are also used. The swing frame grinder is suitable for the removal of stumps of feeder heads and often heavy duty grinding on large castings. In this case, the grinder is mounted on a swing frame, the casting is positioned under the grinder and then grinding is carried out. Pedestal or bench grinders using wheels upto about 750 mm diameter are suitable for small castings which can be handled individually. In pedestal grinders mechanized feeding and positioning fixtures may be employed to speed up grinding, when large numbers of same type castings are involved.

Portable grinder is the most universal tool for general dressing. This uses a wide variety of abrasive wheels (made of either aluminium oxide or silicon carbide) for manual operations on castings of all sizes. These grinders are electrically powered. The commonest design of portable grinder uses an axially mounted wheel but angled shafts with flexible drives. Though many shapes of wheel are available, plain wheels are most common, e.g 150x25x16 mm size. Delicate shaping and polishing are accomplished by small high speed pneumatic or electric machines with mounted points and tungsten carbide burrs.

Abrasive belt machines are the further development in grinding of castings. A very high rate of metal removal can be achieved with these machines. Other methods of surface abrasion include filing and wire brushing which are usually employed for the softer non-ferrous metals in which fettling problems are less severe.

### **5.2.10 Hot Fettling Processes**

These methods have the particular advantage of avoiding dust generation and are adopted for ferrous alloys. Hot fettling processes include powder washing process, air-carbon arc process and plasma torches. In the first method, iron powder is dispersed through a specially designed torch into an oxyacetylene flame, which is played across the surface of the casting to remove excess metal. In the air-carbon arc process, an arc is applied to obtain local melting of excess metal which is blown away by a stream of compressed air as in the cutting process. Plasma torches can be used for cutting as well as removal of metal.

### **5.2.11 Cleaning and Smoothening of Casting**

In general, surface cleaning operations are carried out after the removal of gates, fins, projections etc. However, surface cleaning may also facilitate gate removal, e.g, elimination of sand favours sawing and torch cutting particularly in case of nonferrous alloys and in these instances, surface cleaning may be carried out before the removal of feeder heads and gates. Sometimes surface cleaning operation may be repeated after heat treatment to remove adhering scale on the castings. The various methods available for surface cleaning are sand blasting, shot blasting, tumbling, hydraulic cleaning and chemical cleaning.

### **5.2.12 Blast Cleaning**

Blast cleaning is accomplished by streams of dry abrasive particles to impinge on the castings. The abrasive particles are energized either by compressed air or high speed centrifugal impeller. Depending upon the system of particles and energizer used, the blast cleaning may be either sand blasting or shot blasting.

In sand blasting, a high velocity stream of compressed air along with nonmetallic abrasive particles such as sand, alumina, slag, silicon carbide, etc., is directed with the help of a blast gun against the casting surface. The blasting operation is usually carried out in special chambers. The discharged sand drops through a perforated floor from where it is conveyed to the moulding section for reuse. Suitable mechanical means are provided to handle the castings. The sand blasting method can be used for both fragile and large sized castings. This method also imparts good finish to the castings.

In case of shot blasting, instead of compressed air, centrifugal force is extended by means of high speed centrifugal impeller to impinge abrasive shots on the castings. The abrasives used in this case may be steel shots or chilled iron grits. The latter is cheaper but it is subject to loss by fragmentation.

A number of designs of shot blast equipment are employed. Heavy castings are usually treated in a fixed chamber and the nozzle is manipulated either by operator or remotely controlled from outside. Very small castings are blast cleaned in the glove box cabinet units. Castings of a wide range of intermediate sizes are processed automatically in two ways, i.e.

- i. Castings are supported on a turn-able table or suspended from a pendulum conveyor with in a fixed chamber and the shot stream is traversed to obtain complete coverage of the exposed surfaces.
- ii. The castings can be tumbled in the shot stream through continuous rotation of chamber itself about the horizontal axis. Automatic blast plants give high production rates but involve high operative costs due to high abrasive wear of plants. Provision is made for dust extraction and for cleaning and recirculation of the abrasive.

Similar to the blast cleaning operation is shot peening in which angular grits are avoided in favour of round shots or prerounded cut wires which ensure smooth indentations rather than pitting of the surface. Shot peening is employed to improve fatigue resistance by cold working the surface layers of castings.

### Review Questions

1. What is the purpose of the cleaning of castings?
2. List the various methods for cleaning of castings.
3. How the sand core removes from the castings?
4. How the gates and fins are removed for the castings?
5. Discuss the Chipping and machining process
6. Describe the grinding and wheel cutting method of cleaning.
7. What is hot fettling process?
8. Write short notes on Blast cleaning.
9. Write sawing process.

## 5.3 Testing of Castings

Cast products are tested for mechanical properties like hardness, impact strength, tensile strength etc. They are also tested for finding any flaws like crack, blow hole, porosity etc. these tests are done in two ways:

### i) Destructive Tests

In this type of test, the specimen is destroyed in the process of testing, that means the test specimen cannot be used any further. The result of the test becomes important information for the engineers. Hardness test, impact test, tensile test are few examples of such type of test.

## ii) Non Destructive Tests

In this type of test, the work piece becomes the test specimen, as a result, it is not destroyed in the process of testing, that means the test specimen can be used in practical field for which it has been made. Testing for crack, blow hole, porosity etc. are few examples of such type of test.

### 5.3.1 Principle of Hardness Testing

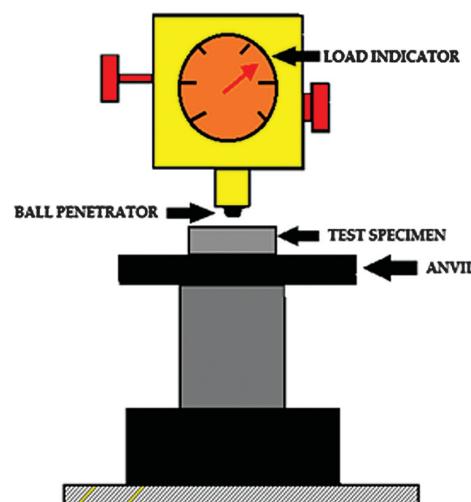
Hardness is the resistance of a material to localized permanent deformation. The deformation may be due to indentation, scratching, cutting or bending. In metals, ceramics and most polymers, the deformation is considered to be a plastic deformation of the surface.

If we want to create scratch mark on a piece of glass by a knife, we will fail. Because glass is a hard material and due to its hardness it will resist indentation. Diamond is harder than glass, so we can make indentation by a diamond on the surface of glass. Examples of hard material used in engineering practices are cast iron, concrete etc.

The Brinell Hardness Test is the most widely used and oldest method of hardness testing commonly used today. This test was invented in Sweden by Dr. Johan August Brinell in 1900. This test is very often used to determine the hardness of castings and forgings. Almost all metals may be tested with the Brinell test by simply varying the ball size and test load. As long as the ball size to test load ratio remains constant, the results are considered accurate.

The test procedure is as under:

- i. The test specimen is kept at the Brinnell Hardness Tester as shown in Fig 5.2.
- ii. A pre-determined test load (generally 3000 kgf) is set on the machine.
- iii. An indenter (generally 10 mm diameter) is chosen and affixed in the machine as shown in Fig 5.3.
- iv. The test load is applied on the specimen and kept indented for a pre-determined time period and then removed.

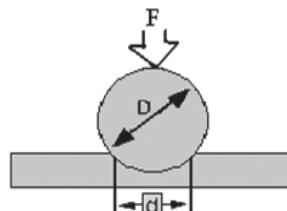


**Fig 5.2 The Brinell Hardness Testing Machine**

- v. The diameter of the indentation is measured in at least twice, one measurement in any direction and the other at right angle to the former. The mean of the two measurements is calculated. The Brinell hardness value is computed by using the following formula:

$$HB = \frac{2F}{\pi D (D - \sqrt{D^2 - d^2})}$$

D = ball diameter  
d = impression diameter  
F = test load  
HB = brinell hardness no.

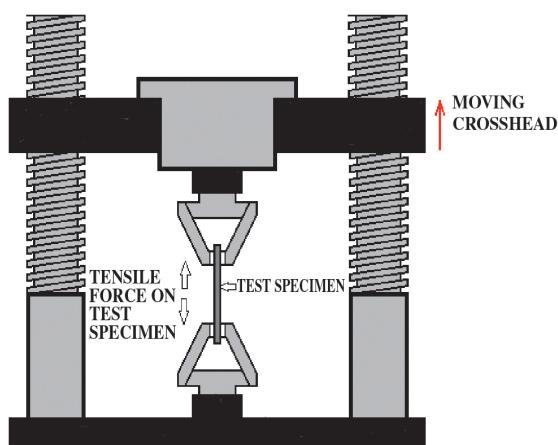
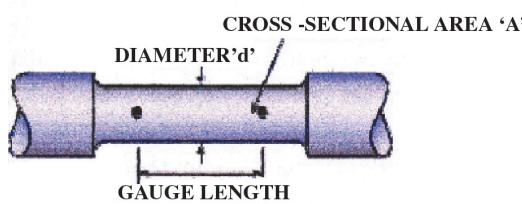


**Fig 5.3 Indentation and Brinell Hardness Number**

In Brinell hardness test, the test load may range from 1 kgf to 3000 kgf and diameter of the indenter from 1 mm to 10 mm. A time of 10 to 15 seconds is generally specified as test standard.

### 5.3.2 Tensile Tests

Tensile testing is conducted in universal testing machine. In this test, a specimen is subjected to gradual increase in load from zero till it breaks into two pieces and corresponding data on load applied and elongation suffered are noted. From the data obtained, material properties like modulus of elasticity, yield strength, ductility, ultimate tensile strength, breaking stress etc. are calculated. For convenience, let us consider the test specimen (Fig 5.4) to be a mild steel piece having following dimensions:



**Fig 5.4 (a) The tensile test specimen**

**Fig 5.4(b) Tensile testing machine**

Initial gauge length = L = 50 mm

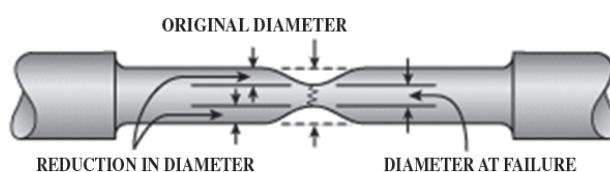
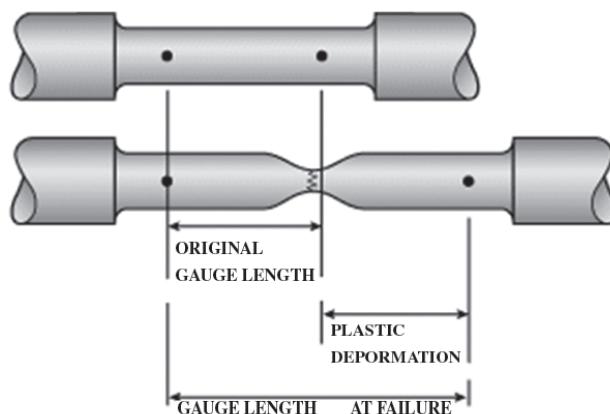
Average initial diameter = d = 14 mm

Original area of cross-section =

$$A = \pi r^2 = \pi \times 7^2 = 154 \text{ mm}^2 \text{ (approx)}$$

To understand the test procedure, let us consider the following method and load values:

- The test specimen is held vertically and firmly in the jaws of Universal testing machine and the machine is adjusted to read zero.
- An extensometer is attached firmly to the specimen and adjusted it to read zero.
- The load is gradually increased to 6300 N (say) and the extensometer reading at each increment of loading are recorded.
- The extensometer shows a high value of extension at a point when the load is increased by, say 2300 N (this may not be a 6300 N increment), this point being the yield point.
- The extensometer is removed at this point and loading continued, the extension at different values of load is recorded by a vernier until fracture occurs.
- Maximum load attained by the specimen is recorded as 69000 N (say) and its breaking load is recorded as 61600 N (say).



**Fig 5.5: Test specimen after breaking**

The broken pieces are taken away from the machine and type of fracture is noted. By fitting the broken pieces together, final length (gauge length at failure) of the specimen is recorded (Fig 5.5). Final diameter at the neck (diameter at failure) is also recorded.

Stress, strain, yield point, ultimate stress, nominal rupture stress etc. are calculated as per following formulae:

$$\text{Stress} = \frac{\text{Load}}{\text{Area of cross - section of the test specimen}}$$

$$\text{Strain} = \frac{\text{Elastometer reading} (= \text{elongation})}{\text{Original length}}$$

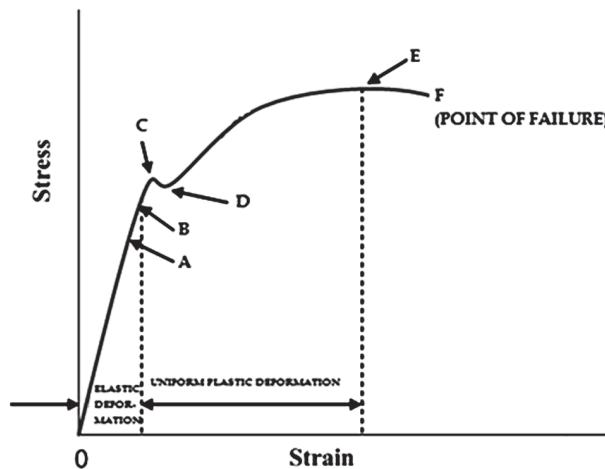
$$\text{Yield strength} = \frac{\text{Load at yield point}}{\text{Area of cross - section of the test specimen}}$$

$$\text{Ultimate tensile strength} = \frac{\text{Maximum load}}{\text{Area of cross - section of the test specimen}}$$

$$\text{Modulus of elasticity} = \frac{\text{Difference in stress between two widely spaced loads below yield point}}{\text{Corresponding change in strain}}$$

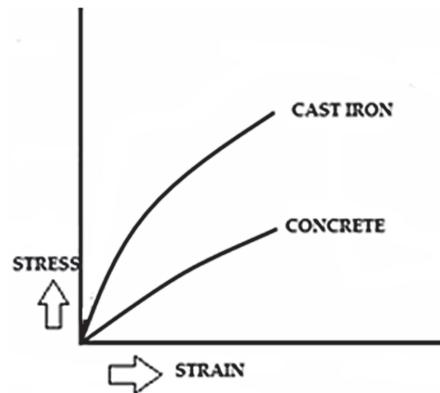
### 5.3.3 The Stress–Strain Diagram of Ductile Material

Stress-strain diagram of ductile material helps to understand some of the material properties in a greater detail. This diagram is derived from the data obtained in the tension test of a ductile material. The ductile material (test specimen) is subjected to gradual increase in load from zero to a value till the specimen breaks into pieces. Different values of loads and corresponding elongations are noted and from these data recorded, different values of strains and corresponding stresses are calculated. The data so obtained are plotted in a two-axes system keeping strain in the horizontal axis and stress in the vertical axis. The graph looks like that shown in Figure 5.6, which is a representative stress strain diagram of mild steel, a ductile material.



*Fig 5.6 Stress-strain diagram of mild steel*

### 5.3.4 The Stress-Strain Diagram for Brittle Material



*Fig 5.7 Stress-strain diagram of brittle material*

Brittle materials such as cast iron etc do not yield. That means they fail on yielding. If the tensile load on brittle material is gradually increased, it will reach proportional limit as well as elastic limit. But as soon as it crosses elastic limit, it ruptures. This is shown in Fig 5.7. OA is the proportional limit as shown in the figure indicating that Hooke's Law is obeyed from O to A. The slope of straight line OA indicates elasticity of the material. B is the elastic limit. When deforming force is withdrawn till point B, the material will retrace the path B-A-O and regain its original configuration. If deforming force is further increased beyond point B, the brittle material breaks into pieces instantaneously. This is shown by the point F. Tensile strength is the most important mechanical property for inspecting grey iron and ductile iron castings. Tension test specimen is also called as tensile bar, or tensile test bar.

### **Significance and Use**

Tension tests provide information on the strength and ductility of materials under uniaxial tensile stresses. This information may be useful in comparisons of materials, alloy development, quality control, and design under certain circumstances.

Testing the tensile strength of a casting ensures that it is capable to withstand more strain than it will ever see in its working environment. Included in testing tensile strength are testing for yield strength, ultimate strength, and breaking strength. Yield strength determines the point up to which the casting can be strained and still return to its normal shape. Ultimate strength is the maximum stress the casting can develop before reaching the breaking strength or rupture point.

### **5.3.5 Impact Tests**

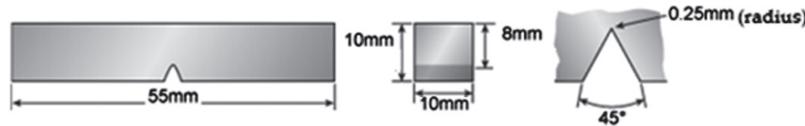
Impact test is only one method by which material property known as 'toughness' is measured. Toughness is the measure of the amount of energy absorbed by a material per unit volume before fracture and fail. More the energy absorbed per unit volume of the material more is its toughness.

The area under the stress/strain curve up to the UTS gives the measure of toughness of the material. However, in the context of an impact test we are looking at notch toughness, a measure of the metal's resistance to brittle or fast fracture in the presence of a flaw or notch and fast loading conditions.

There are two types of impact test, Charpy Test and Izod Test. Both the tests involve striking a standard test specimen with a controlled weight pendulum travelling at a definite speed. The amount of energy absorbed by the test specimen before fracturing is measured and this gives an indication of the notch toughness of the test material.

From these tests we can interpret whether a material is 'brittle' or 'ductile'. A brittle material will absorb small amount of energy when impact tested, ductile materials, being tougher, will absorb a large amount of energy before fracturing.

The Charpy specimen may be used (Fig 5.8) with one of three different types of notch, a 'keyhole', a 'U' and a 'V'. The keyhole and U-notch are used for the testing of brittle materials such as cast iron. The V-notch specimen is the specimen of choice for weld testing and is the one discussed here. The standard specimen for Charpy test is generally 55mm long, 10mm square and has a 2mm deep notch with a tip radius of 0.25mm machined on one face.

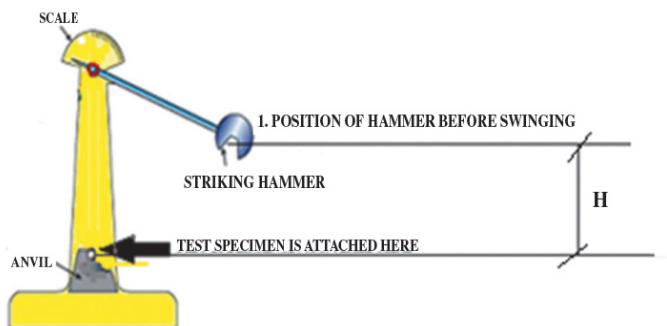


*Fig 5.8 The Charpy test specimen*

### 5.3.6 The Charpy Impact Test Procedure:

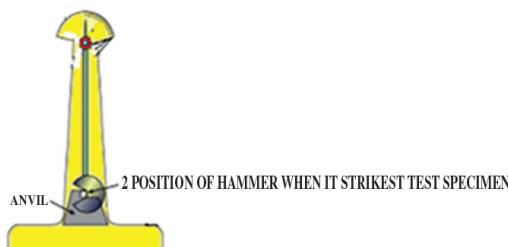
- i. The standard specimen is supported at its two ends on an anvil.
- ii. The pendulum type hammer is set at a suitable position as shown in the Fig 5.9 at a vertical height 'H'. Let the potential energy of the hammer at this position be  $E_1$ .
- iii. The hammer is released and it strikes the test specimen (Fig 5.10). The specimen breaks into two pieces. The energy for fracture of the specimen being supplied by the striking hammer itself. Let the energy for fracture of the test specimen be ' $E'$ .
- iv. The hammer moves through a height 'h' on the other side of the testing machine after breaking the test piece. This is the final position of the hammer and let energy possessed by the hammer at this position be ' $E_2$ '.
- v. The energy required to break the test specimen is found by taking the difference between the energy possessed by the hammer in its initial and final positions (Fig 5.11).

That is, energy required to fracture the test specimen,  $E = E_1 - E_2$ .



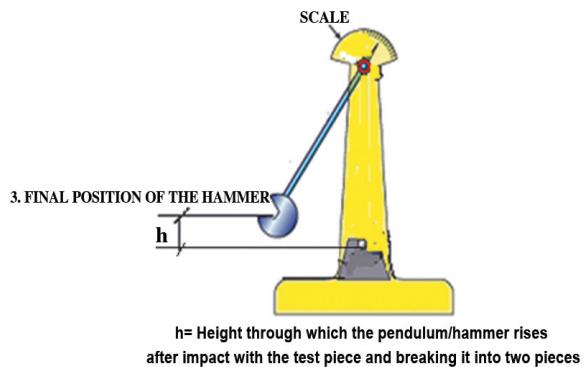
$H$  = Height through which the hammer is set before striking the test piece.  
The gives the measure of initial potential energy of the striking hammer.

*Fig 5.9 Initial position of the striking hammer in a Charpy test*



The hammer strikes the test piece and breaks it into two pieces. A part of the energy of the hammer is used in breaking the test piece.

*Fig 5.10 The hammer strikes the test specimen*

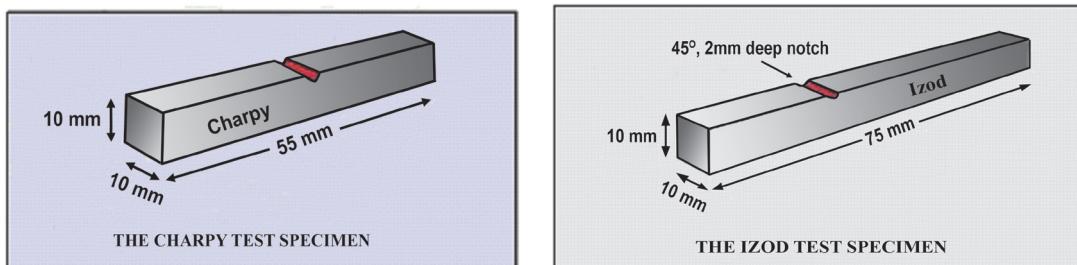


**Fig 5.11**The final position of the hammer after it has fractured the test specimen

### 5.3.7 The Izod Impact Test Procedure

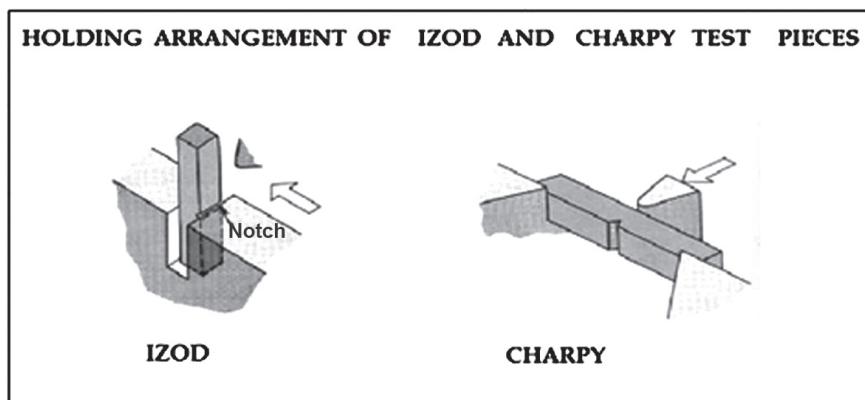
The same test procedure is followed for an Izod impact test as that of Charpy impact test as shown in Fig 5.12. The test specimen is held on the anvil of the testing machine and hammer /pendulum is allowed to strike the test specimen such that it breaks into two pieces. The difference between the energy possessed by the hammer at its initial and final position gives the measure of energy required to fracture the test specimen. But the two tests differ in the following ways:

- (i) The dimension of the test specimen is different and the same are shown below:



**Fig 5.12(a): Dimension of test specimen used in Charpy andf Izod tests**

- (iii) The holding arrangement of test pieces are different as shown in the figure:

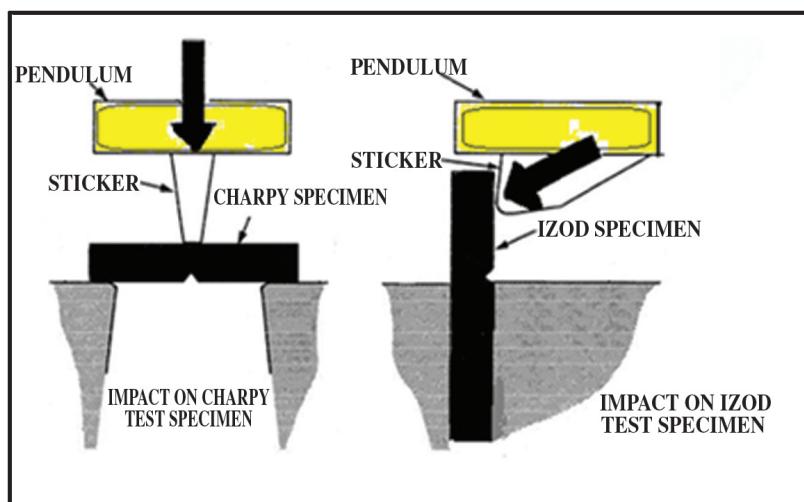


**Fig 5.12(b): Holding arrangement of test specimen in Charpy and Izod tests**

In Izod Test, the test specimen is held in such a way that its one end remains fixed while the other end is free. This type of holding can be compared to a cantilever beam.

In Charpy Test, the test specimen is rigidly fixed at its both ends. This type of holding is comparable to a beam with two ends fixed.

- (iv) The location of impact loads applied are different. In the Izod test, impact is against the end of the exposed cantilever; in the Charpy test, the impact is struck directly behind the test notch such that the specimen undergoes three point bending.



*Fig 5.12(c): Application of impact loads on test specimen in Charpy and Izod tests*

### 5.3.8 Non-Destructive Tests

Nondestructive testing, popularly referred to as NDT is the test methods to examine an object, material or system without destroying the object or impairing its future usefulness. Non-destructive testing is often required to verify the quality of a product or a system.

NDT is useful in finding defects of the following types:

- i. **Inherent defects:** Defects those are introduced in the product at the very beginning of the production process.
- ii. **Processing defects:** Defects those are introduced in the product or part thereof, as the process goes on.
- iii. **Service defects:** Defects those are introduced during the operating cycle of the product.

Commonly used techniques for Non Destructive Testing are

- i. Visual Testing (or Visual Inspection)
- ii. Pressure and Leak Testing
- iii. Dye Penetrant Testing
- iv. Magnetic Particle Testing

- v. Eddy Current Method
- vi. Radiographic Testing
- vii. Ultrasonic Testing

### 5.3.9 Visual Testing (or Visual Inspection)

Visual testing or inspection is probably the most widely used NDT technique. Even though a material is to be undergone other non-destructive testing method, it should be given a good visual examination. Adequate illumination is absolutely necessary for visual examination.

### 5.3.10 Pressure and Leak Testing

In this method, defects are revealed by flow of liquid or gas into or through the defects. Generally hollow test objects are tested by this method. The hollow test object is filled with gas at a pressure greater than the pressure of surrounding air. Under this condition, the test object is immersed in water. Bubbles are formed at the leaky portion of the object.

### 5.3.11 Dye Penetrant Testing

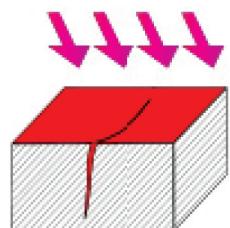
This technique is applied to locate discontinuities on material surfaces or internal flaws which extend to the surface of the test object. This method is applicable to both magnetic and non-magnetic materials. Penetrants may be of two kinds: dye penetrant and fluorescent penetrant. In case of dye penetrant, the dye is dissolved in a liquid penetrant. In fluorescent, fluorescent material is dissolved in the penetrant. The liquid substance, in which dye or fluorescent materials are dissolved, is called developer.

The basic steps in this method are described in Fig 5.13:

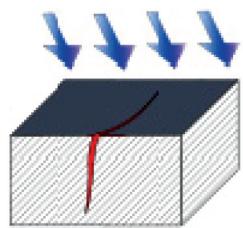
- i. Clean the surface of the material
- ii. Apply the penetrant throughout the surface; the liquid is pulled into the surface-breaking defects by capillary action.
- iii. Remove excess penetrant
- iv. Apply developer to pull the trapped penetrant back to the surface
- v. Allow sufficient time, developer along with penetrant spreads out and form an indication of the location of the defect
- vi. The indication is much easier to see than actual defect. Inspect and interpret the observation.



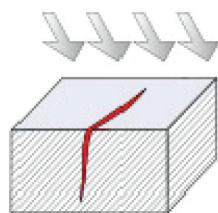
1. A crack appears on the surface of a work piece, but the location of the crack is not so much visible



2. Penetrant is applied on the surface of the work piece



3. Excess penetrant is removed from the surface

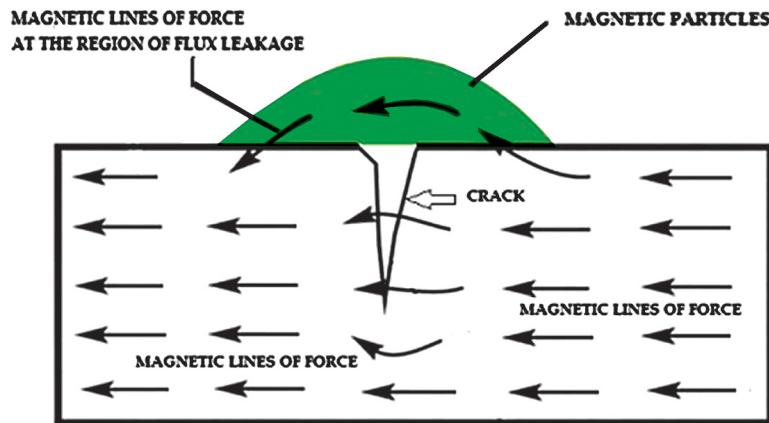


4. Developer is applied, crack becomes visible.

*Fig 5.13 Different stages of dye penetrant testing*

### 5.3.12 Magnetic Particle Testing

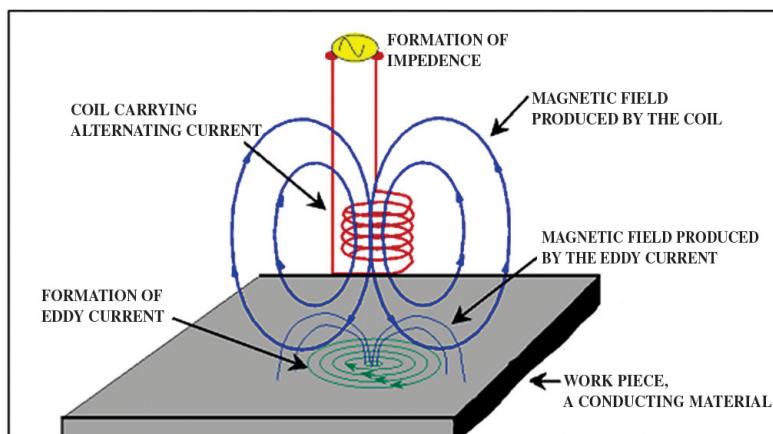
This method is applicable to magnetic materials only. Inhomogeneities in the work piece such as blow holes, cracks, and inclusions can be well detected by this method as shown in Fig 5.14. If the work piece is put under the influence of magnetic field, the path of the magnetic flux is distorted. This happens because the inhomogeneities exhibit different properties than the surrounding material. To make the inhomogeneities visible, some particles or powder of magnetic material (for example, iron fillings) is spread over the surface of the test object. Defects such as cracks or voids present in the work piece cannot support as much flux as its surrounding homogeneous part can. As a result, it forces some of the flux outside the work piece. This phenomenon is known as flux leakage. The magnetic powder is attracted and held by the magnetic flux created at the defective portion. This forms a visible location of the defect and its extent.



*Fig 5.14 Magnetic Particle Testing*

### 5.3.13 Eddy Current Method

This technique is applied to electrically conducting materials for finding defects like cracks, voids, and inclusions near the surface of the material (Fig 5.15). When a coil carrying alternating current is brought near a metal object, eddy currents are induced in the metal. The magnitude of eddy current is affected by the presence of discontinuities or inhomogeneities in the metal object. The eddy currents induced in the metal object set up a magnetic field which opposes the original magnetic field. This condition favours the formation of impedance (and is termed apparent impedance). The path of the eddy current is affected due to the presence of a defect. This causes a change in impedance. This change in impedance can be measured and gives an indication of presence of a defect.

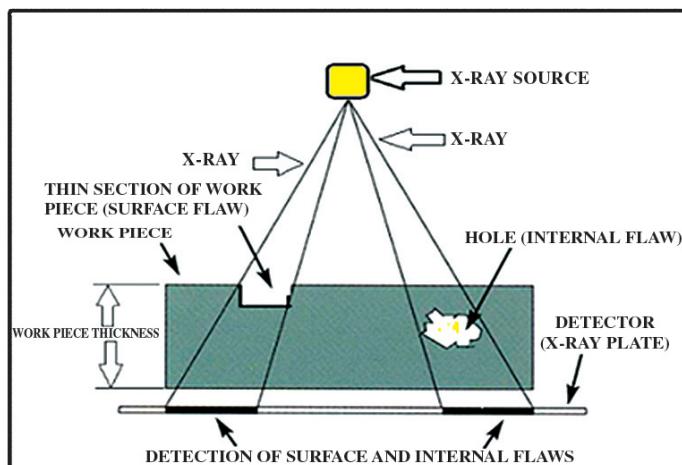


*Fig 5.15 Eddy Current Testing*

### 5.3.14 Radiographic Testing

The NDT procedures stated so far are helpful to detect surface flaws. But blow holes, cracks etc. may remain inside the work piece. Such type of flaws is very dangerous and fracture of the work piece may occur without any indication. In order to detect such internal defects, radiographic testing is used (Fig 5.16).

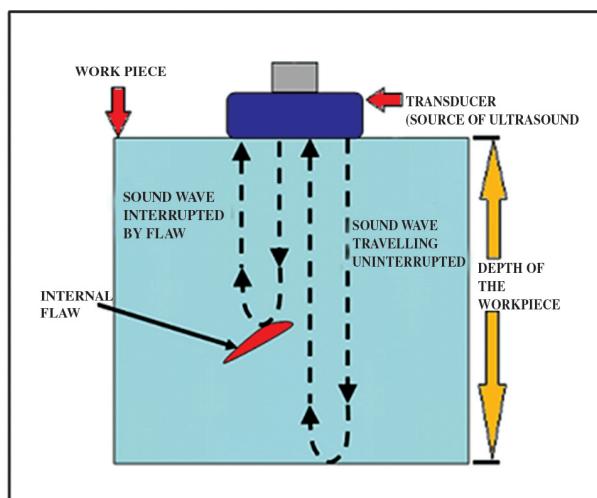
The work piece is placed between the radiation source and detector. Amount of radiation depends upon the thickness and density if the work piece. The density and thickness of in the blow hole or cracked area is different from those of surrounding area of the work piece. As a result, amount of radiation needed for these areas are different from the other area. This variation in radiation produces an image of the blow hole or crack on the detector. This helps in finding the actual location of the blow hole or crack.



**Fig 5.16 Radiographic Testing**

### 5.3.15 Ultrasonic Testing

Ultrasonic testing (Fig 5.17) is generally employed to detect internal flaws. High frequency sound wave is created by a device called 'transducer'. Transducer is fitted at one end of the work piece and high frequency sound is released. The sound wave travels through the thickness of the work piece and returns back. This returned sound wave is either received by the same transducer or a second one. If there is any flaw inside the work piece, the sound wave returns from there. The amount of energy transmitted or received, and the time span between release of sound energy and receipt of the same, is analysed to determine the location of the flaw.



**Fig 5.17 Ultrasonic Testing**

## Review Questions

1. What are the methods of testing of castings?
2. What is the principle of Hardness Testing?
3. How you can measure the brines Hardness for the given component?
4. Describe the testing procedure for the charpy impact testing?
5. Describe the tensile testing for the given component.
6. State the test procedure for Brinell hardness testing.
7. Draw the stress-strain diagram for a ductile material showing salient points on it.
8. Draw the stress-strain diagram for a brittle material showing salient points on it.
9. What are the basic differences between Charpy and Izod impact tests?
10. Name the various Non Destructive methods of Testing.
11. Explain the methods of flaw detection by NDT.
12. Describe the use of radiographic testing for casting inspection
13. What is the basic principle of ultrasonic testing?
14. Discuss the eddy current method of inspection.

## 5.4 Casting Defects And Remedies

### 5.4.1 Introduction

The manufacturing process of casting involves a number of operations, each having a number of operational variables. Many of the variables are considered to have only a minor impact on the outcome such as either physical quality or metallurgical structure or properties. Therefore, all the variables are not attempted to be controlled or documented in a foundry. Such variables, which have a profound effect on the properties, are documented, studied and altered.

When there are a number of variable elements in a process, they can singularly or in combination lead to a condition which might not be ideal. Under such circumstances, one ends up manufacturing castings which do not meet the quality standards, resulting in rejection. The rejected material can only be remelted and the value addition in the form of various processes - melting, moulding, fettling, heat treatment results in irrecoverable losses.

In casting process, rejection at any stage would affect the energy consumption, since metal casting process is energy intensive. Moreover, melting is the first step in the processing of metal and it consumes more than 2/3rd of total energy consumed. Therefore, even if the casting is rejected just after the first step i.e., melting, considerable damage to the gross energy consumption per ton of saleable castings would have been already done. This necessitates strict control of quality of every input used, so that the final outcome is predictable.

Despite care, there are always chances of rejection. As long as this is detected at early stages of manufacturing, loss is limited. Sometimes the defect is detected at

the customers end. In such cases, the damage caused by single defective casting is significant. The defective castings that increase beyond acceptable level may get rejected. Such an eventuality will have a profound effect on yield, profitability, productivity and result in poor customer relations since such returns can cause unavoidable delays in the production activity of the customer.

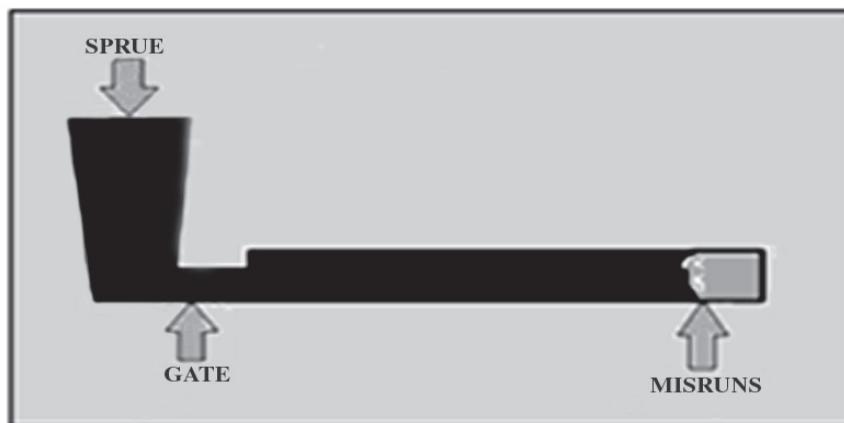
### 5.4.2 Classification of Defects

Some of the common defects are described below:

- i) Misrun
- ii) Cold shuts
- iii) Shrinkage
- iv) Porosity
- v) Blow holes
- vi) Mismatch
- vii) Cracks
- viii) Rough surfaces
- ix) Hot tear
- x) Scabs
- xi) Distortion
- xii) Slag

### 5.4.3 Causes and Remedies of casting Defects

Defect	Misruns
Appearance	Cavity due to incomplete filling, mainly found in thin section of casting
Causes	Low pouring temperature, low fluidity, inadequate venting, faulty pouring practice
Remedies	Provide hotter metal at cupola spout, reduce heat losses in ladles by using flux coverings



*Fig 5.18 Misrun in casting*

Defect	Cold shuts
Appearance	White dividing zone where streams of melt fails to merge in molten condition
Causes	Low pouring temperature, lack of fluidity of alloy, too much gas forming material in the facing sand
Remedies	Modify system of moulding, ensure correct pouring temperature for the alloy

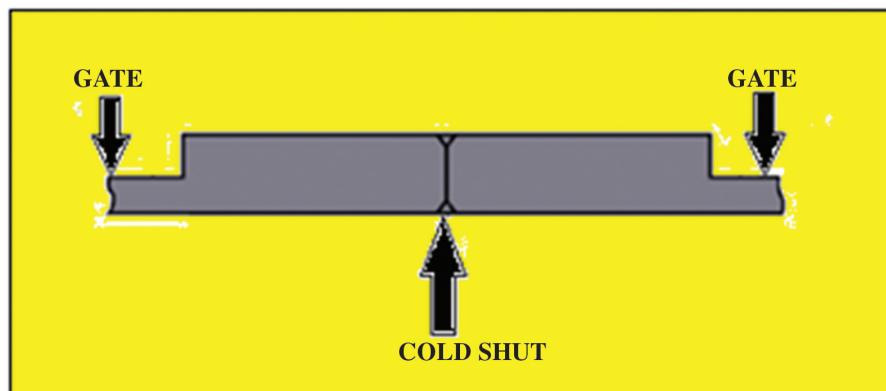


Fig 5.19 Cold shut in casting

Defect	Shrinkage
Appearance	Rough cavities at heavy sections, or at joints at which there is change of sections
Causes	Incorrect gating and feeding
Remedies	Use separate risers to feed heavy sections



Fig 5.20 Different shrinkages in casting

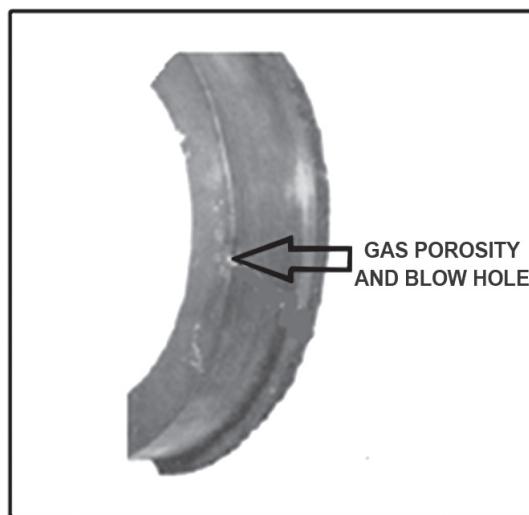
Defect	Porosity
Appearance	Cavities appear in machined surfaces
Causes	Wrong composition of metal, improper running and feeding, use of impermeable mould
Remedies	Reduce sulphur and phosphorus content of the charge, improve venting of mould

**POROSITIES APPEAR  
IN MACHINED SURFACE**



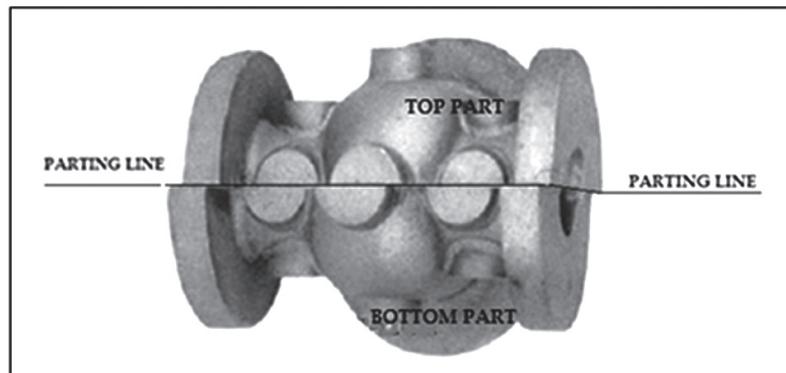
*Fig. 5.21 Porosity in casting*

Defect	Blow holes
Appearance	Outer surfaces of the thicker sections of the cast shows rough shaped holes
Causes	High moisture content and low permeability of the mould sand, insufficient venting
Remedies	Improve permeability using venting wire, reduce moisture content, avoid excess ramming



*Fig 5.22 Blow hole in casting*

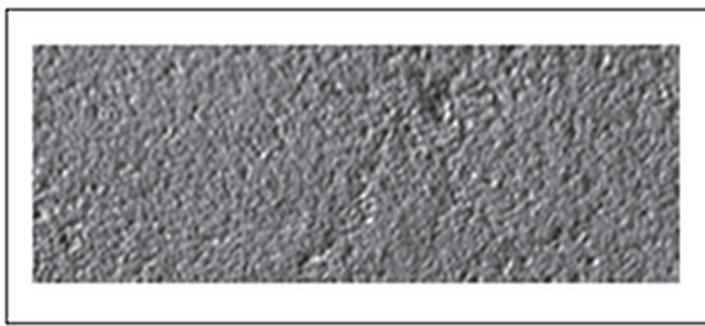
Defect	Mismatch
Appearance	Two or more sections of the cast product fail alignment
Causes	Improper positioning of cope and drag patterns
Remedies	Take more care in placing cope on the drag, use appropriate pattern dowel pins, tight fit the box pins

*Fig 5.23 Mismatch in casting*

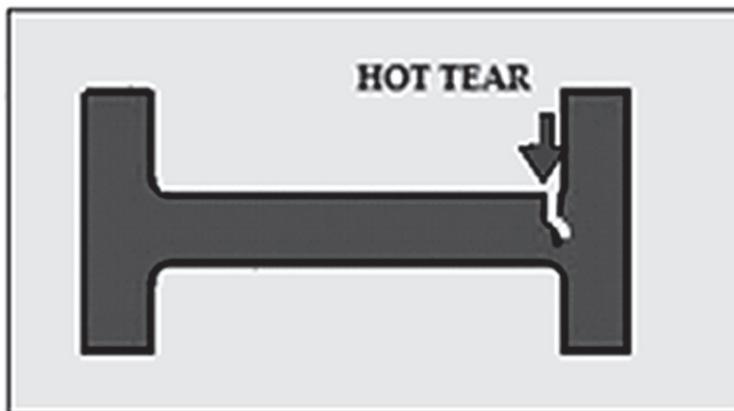
<b>Defect</b>	<b>Cracks</b>
Appearance	Hairline cracks on casting are found
Causes	High dry strength of the sand, too hard cores
Remedies	Reduce oil content, ram evenly

*Fig 5.24 Cracks in casting*

<b>Defect</b>	<b>Rough surfaces</b>
Appearance	Rough casting surfaces
Causes	Due to reasons like too open moulding sand, low coal dust content, uneven ramming the metal penetrate onto the mould surfaces
Remedies	Ram sand more evenly, add coal dust, use finer sand

*Fig 5.25 Rough surfaces in casting*

Defect	Hot tear
Appearance	Ragged irregular internal and external cracks appear immediately after the metal have solidified
Causes	Poor design of casting which have abrupt change in section at different parts
Remedies	Place proper gates and risers, ensure correct pouring temperature



*Fig 5.26 Hot tear in casting*

### Review Questions

1. List the various types of casting defects.
2. For the following casting defects, state the possible causes of occurrence of such defects, the appearance of the finished product and remedial actions to be taken for combating such defects:i) misrun, ii) cold shut, iii) shrinkage, iv) blow holes, v) cracks, vi) mismatch, vii) rough surfaces, viii) hot tear.

## 5.5 Summary

The unit starts with explanation of the various methods of cleaning of the casting and importance of the surface finish of the cast components. Discussion about the various destructive testing methods and non destructive testing methods for the finished cast components. Exploring the various classification in the casting defects and the possible causes of occurrence and their remedial methods.

## Exercise Questions

1. What are the purposes of the cleaning of castings?
2. What are the general steps in cleaning of castings?
3. List the various methods for cleaning of castings.
4. How the sand core, gates and fins are removed from the steel castings?
5. Discuss the chipping and machining process
6. Describe the blast cleaning and wheel cutting method of cleaning.
7. Explain grinding operation using swing grinders.
8. What are the steps involved in cleaning of small ferrous castings?
9. What is the casting inspection?
10. List the methods of testing of castings?
11. How you can measure the Brinell Hardness for the given component?
12. Describe the testing procedure for the Charpy impact testing?
13. State the test procedure for Brinell hardness testing.
14. Draw the stress-strain diagram for a ductile material and brittle materials. Explain it.
15. Define NDT. Name the various NDT methods.
16. Explain the methods of flaw detection by NDT.
17. Describe the use of radiographic testing for casting inspection
18. Explain the basic principle of ultrasonic testing?
19. Discuss the Eddy current method of inspection.
20. Give the advantages, limitations and applications of various NDT techniques.
21. List the various types of casting defects.
22. State and explain any seven major casting defects, their causes and remedies.