PREFACE

This book is a compilation of different aspects of Metal Casting, covering the latest available information, Industry data and Foundry practices, brought together to serve students of under-graduate and post-graduate courses studying the subject, as well as practising foundry supervisors, engineers and managers. As such, the author does not claim complete originality in the information contained and takes credit only for collecting, selecting and presenting the contributions to the field by many eminent research workers, academicians, practising foundrymen and authors. Detailed acknowledgement is attempted but any omission to mention a work quoted in this book is sincerely regretted as it is only on the grounds of space constraints or ignorance but not by intention.

Under-graduate students may omit certain practical aspects which are intended mainly for foundry personnel.

I thank the publishers M/S New Age International Pvt. Ltd. for their help and guidance in making this book presentable. I am grateful to Shri K.K Sinha, Chairman and Chief Executive of Nuclear Fuel Complex a highly honoured and eminent metallurgist, known to me since long, for encouraging me by giving the Foreword.

Finally, this book is before you only because of the persistent inspiration provided by my wife Chandra and family members, for whom I have no words to thank.

Dr. T.V. Ramana Rao
Author

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Prof. T. V. Ramana Rao
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Contents

1 INTRODUCTION

1.1 Metal casting as a manufacturing process

Metal casting is one of the most ancient techniques used for manufacturing metal parts, Metal casting is the process of forming metallic objects by melting metal, pouring it into the shaped cavity of a mold and allowing it to solidify. The process of casting involves the basic operations of pattern making, sand preparation, molding, melting of metal, pouring in molds, cooling, shake-out, fettling, heat-treatment finishing and inspection. The flow process chart (Fig 1.1) illustrates these stages in sequence.

In comparison to other manufacturing processes like rolling, forging, welding, powder metallurgy, machining, pressing etc., the casting process has the following advantages:

i. Advantages of casting process

a) There is no restriction on the type of metal or alloy for casting operation. In other processes like forging only a few ductile materials can be formed whereas a brittle metal like cast iron cannot be manufactured.
Eg : High alloy steels of high-melting temperature to low-melting aluminium alloys.

b) There is no restriction on the size of the component for casting. Items from a few grams to many tons weight are produced by casting process. There are severe problems in manufacturing larger parts by processes like powder-metallurgy, forging etc.
Eg : Watch cases of few grams to rolling mill-housings, kiln-tyres of 50 tons each

c) The most intricate external and internal shapes can be formed by casting process, by suitable molding and core-making techniques. No such possibility exists in the other forming methods as rolling.
Eg : Automobile cylinder blocks, carburettors, valve bodies

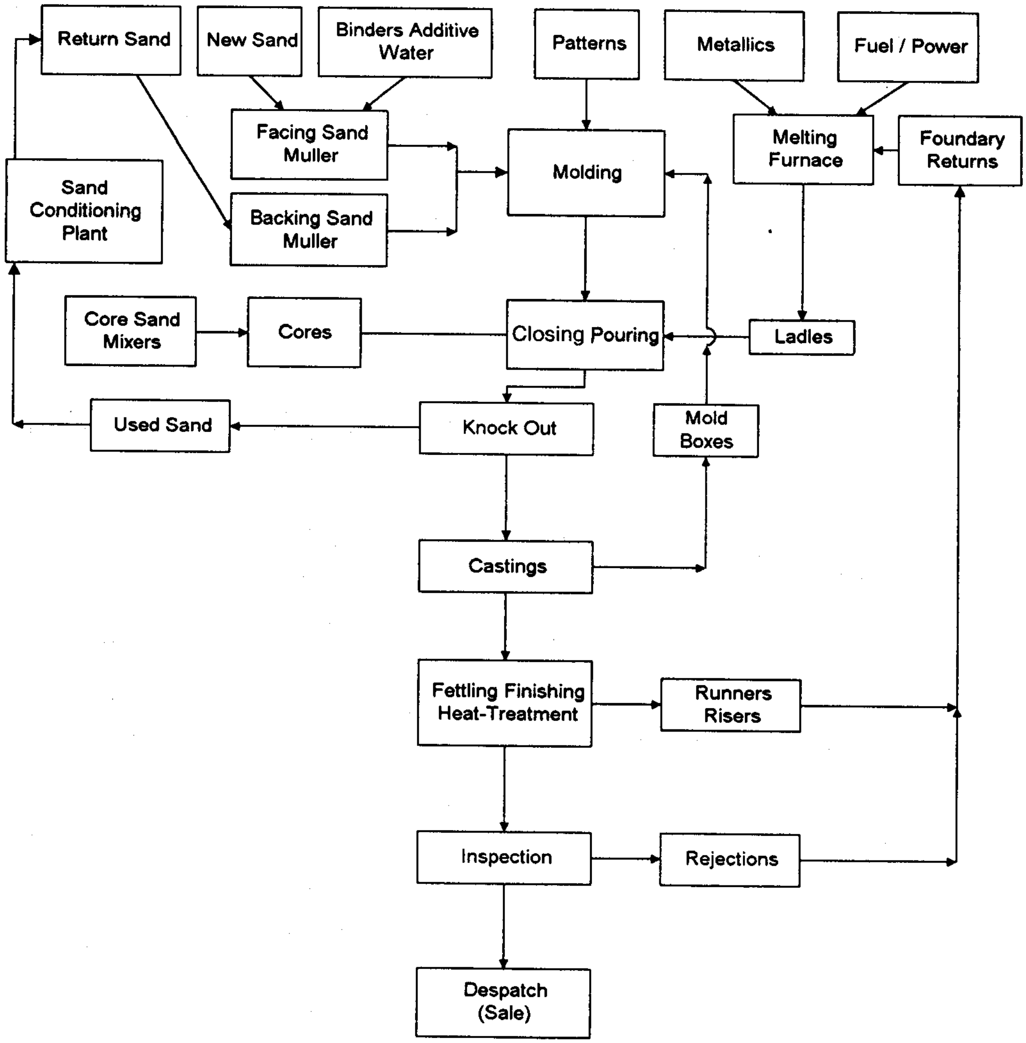

Fig.1.1 Flow Chart for Major Foundary Activities

d) A wide range of properties can be obtained in cast-parts by suitable choice of alloy and heat-treatment. Special properties like corrosion resistance, heat resistance, damping capacity, high strength etc., are possible.

e) The casting process is economically suitable for both small quantity jobbing production as well as mass production by automatic machines. In the other process like rolling or forging, it is difficult to have flexibility in production-run without increasing cost.

f) The casting process is still the cheapest available technique for forming many components from raw materials to the final usable stage. So it remains the fundamental manufacturing process inspite of many developments in other fields.

ii. Disadvantages in casting process

a) Metal casting involves melting of metal which is a high energy consuming process. Due to the growing cost of energy, many restrictions are being imposed on the energy-intensive metal casting units in several countries. For example, about 2000 KWH of power is required to produce a ton of finished steel castings (See Table 1.3)

b) Metal casting is still highly labour-intensive compared to other processes. The productivity is thereby less than in other automatic processes like rolling.

c) The quantum of raw materials required for producing a ton of castings is quite high, needing exhaustive buildings, handling systems, large space and inventory costs. For example, for producing each ton of steel castings about 2.2 tons of metallics, 0.3 ton refractories, 1.2 ton of facing sand, 4 tons of backing sand are needed apart from many other minor materials.

d) The time required for the process of making castings starting from receipt of drawing is quite long compared to other processes like machining. On an average, a medium size ferrous casting takes 2 to 4 months for the first casting. Thus the entire cycle of order execution for castings can take between 3 months to one-and-a-half years depending on size, intricacy, composition, quantity to be cast, etc.

e) The working condition in foundries, due to heat, dust, fumes, heaps of scrap, castings, and, slag etc. at different stages, are quite bad compared to other process industries. The environmental pollution is high in metal casting industries. This is leading to closure of foundries in advanced countries like Germany, Switzerland etc., both by governmental legislation and by unpopularity as a profession.

1.2 Classification of foundries

i) Metal casting units are classified generally according to the type of metal/alloy cast in the unit. Accordingly, we have ferrous foundries casting carbon steels, alloy steels, gray cast iron, S.G. iron, malleable iron etc. The nonferrous foundries include aluminium, copper alloys etc. The melting unit as well as balance equipment in the foundry are installed to suit casting of the particular metal.

ii) Foundries are also known by the nature of their production. Jobbing foundries execute casting orders for even small quantities like one to two pieces per item, specialising in hand molding and heavy items. Mechanised foundries have machines to make large batches of items, specially in sand-mixing, molding etc., where batches form 50 to a few hundreds can be cast per item. Mass production foundries have automation to a high degree with production runs of a few thousand pieces per item. They have automatic molding, pouring and even finishing lines with very little manual handling. This type of foundries produce castings for automobiles, valves etc., needed in very large quantities for each pattern.

Captive foundries are those which cater for the needs of the main industry to which the foundry belongs. For example, all integrated Steel Plants have captive foundries making castings for the maintenance and spares of the particular Steel Plant only. On the other hand jobbing foundries accept making castings form any industry or customer, irrespective of quantity of order.

iii) Foundries are also classified broadly on the basis of the casting process adopted in the unit. Common foundries use sand-casting processes such as green sand, CO_2 - sand, dry-sand etc., to produce medium and large castings in any metal. Foundries using metal molds for making castings with gravity or pressure-injection of metal are known as 'Die casting' units. Special foundries having techniques for high-precision small castings fall under investment or precision casting foundries.

1.3 Foundry Industry in India

Indian Foundry Industry is one of the oldest in the world. The intricate and magnificent idols, sculptures in different metals in historical monuments, temples, churches, other religious places bear testimony to this.

The modern foundry industry is widely spread in India. Casting being the basic operation for any heavy industry, the location of foundries is found around places of developed industrial areas. For example, Calcutta in West Bengal has the highest number of foundries, being nearest to the coal and steel industries in the regions. Similarly, Bombay region has many cast-iron foundries providing components for textile and chemical industries there. Madras and Bangalore regions experienced the growth of foundries later for machine tool and other industries in the region. Due to the government policy of promoting industries in backward areas, now foundries have come up in many regions. The development of foundries is more where electric power is available relatively easily, like recently in Andhra Pradesh. The foundries in Punjab are mainly small and medium scale units, catering to a wide range of customers at highly competitive prices.

The growth of automobile industry in India in the past decade has given tremendous boost to foundries. There is heavy demand for alloy steel castings also from the expanding coal and mineral development sector.

The fast closure of foundry units in advanced countries due to environmental pollution, excess energy needs and general dislike for uncomfortable working conditions has opened new potential for foundry units in India. In addition to the availability of cheap technical collaboration with buy-back clauses from many advanced Western and Japanese foundries, the export potential for quality castings to those countries can be well exploited by modern Indian foundries in the near future.

1.4 Challenges for Indian foundry industry

i. Lack of quality raw material like metallurgical coke, pig-iron, refractories etc. Due to the high ash content of over 25%, cast-iron foundries in India have the perennial problem of non-availability of good metallurgical coke. Poor metal temperature, bridging of cupola, low melting rate etc., are common. Many units had to switch-over to electric induction melting, even though costlier, only due to this. Shortage of proper grade pig-iron is another great problem faced by Indian cast-iron foundries, specially those in Western and Southern India.

Similarly, steel foundries suffer due to poor quality refractories for arc-furnaces causing frequent lining repairs, damages to sides and roof and consequent production losses.

Being a developing nation, even availability of steel scrap, essential for electric furnace melting in steel foundries, is in short supply.

The recent policy of the government in allowing import of coking coal, pig-iron and steel scrap, available at very competitive prices in other countries like Australia, and use of sponge iron will help in improving the productivity.

ii. The shortage of electric power in many regions in India, specially during summer season, causes power-cuts in foundries which are the main high-tension power consumers. Recently, states like West Bengal, Tamil Nadu and Karnataka suffered badly. The improving supply of power from the new power projects of National Thermal Power Corporation of India holds good promise.

iii. Due to shortage of capital/finance, most of the Indian foundries use obsolete equipment causing low productivity. Good handling systems, speed mullers etc., are rarely found in Indian foundries. Poor output and frequent break down are common.

iv. Lack of trained manpower, specially in melting, molding and technology at various levels from skilled artisans to engineers is another cause for low productivity. Indian foundries employ 3 to 4 times more workers and supervisors per ton of castings produced compared to the developed countries, only due to this. Specialised trade training after matriculation level for artisans is essential to solve this problem. Even though many Universities offer courses in undergraduate level in a few subjects of foundry, it is not adequate for actual working in the industry.

v. Metal casting in India is generally a low profit-making, low productive industry with larger risks from capital, employees, power and materials. The process cycle from the acceptance of order with drawings and specification to completion of order involves many stages, sometimes lasting upto one-and-a-half years in case of steel castings. This involves large working capital requirements for patterns, process stock and finished stock pending final formalities of inspection or machining. Due to inadequate availability of public finance, foundries have an eternal problem of cash-shortage.

vi. Now even in India, environmental pollution control measures being gradually introduced by the Government cause extra expenditure for the already low profit-making foundries. So metal casting units should gear up for these inevitable changes. On an average at least 5% of the cost of the total unit is required for pollution control equipment alone, in foundries.

vii. All the above problems are responsible for the meager allocation of Research and Development expenditure in metal casting industries. Indian foundries are unable to get the benefits of latest advancements in technology like new materials, processes, machines. computers etc., and continue to slog with low productive equipment, poor working conditions and low profits. Thus it is a spiral of problems each contributing to the other.

viii. The general condition of low productivity and low profits have created a situation of low quality level in most of the Indian foundries. Standardisation, adherence to national and international quality standards, systems of internal quality assurance are sadly lacking in majority of foundries. Even the public sector, which is the largest buyer of castings, does not differentiate low quality and high quality casting manufactures, buying only on the "lowest quotation" basis giving no incentive to develop higher quality standards. This has reflected in losing export market as well as importing sophisticated castings like automobile cylinder block etc.

The challenges in quality level now being insisted upon by automobile manufacturers is illustrated in Table 1.1 which serves as a warning for metal casting units in India.

It can be concluded from the above that the Indian metal casting industry has to face the challenges and gear up itself suitably if it were to survive and prosper in future.

1.5 Important Industrial Sectors using castings/examples

i Mining and Mineral Processing

Very large and growing requirement of alloy and steel castings is in mining and processing minerals like coal, iron ore, zinc, copper, limestone, alumina, uranium etc. Typical castings used are for excavators, earth moving machinery, conveyors, crushers, grinders etc., like track pads, shovel teeth, bowl and mantel liners, hammers, jaw plates.

ii Core-Sector

Manufacture of core-sector items like steel, cement, thermal, hydro and nuclear power need many castings of iron, steel and alloy steels. Typical components are ingot molds, rolls, furnace-parts, turbine parts, kiln-tyres, drive-unit gears, crushing and grinding equipment parts etc.

iii Chemicals, machine tools, transport, textiles etc.

Industries like fertilizers plants, petrol refineries, sugar and chemicals need many corrosion resistant alloy castings, valves, pump-parts, heat-resistant castings etc. Different types of cast irons are used extensively in manufacture of machine-tools, railway rolling stock, textile machinery and automobiles. These days, die-cast non-ferrous alloy components are replacing ferrous metals in automobiles and in air-craft/space applications.

A few important Cast-metals, their properties and applications are given in Table 1.2

Table 1.1: Acceptance standards of automotive grey iron castings

Sl. No.	Details	Demands: Past	Demands: Present	Foundry requirements to meet the demands
1.	As cast will thickness variation - mm	± 2.0	- 0.5 + 1.5	Latest core & molding technology. Better quality melting raw materials & inoculating machines to get chill-free castings.
2.	Machining allowance - mm	5 ± 1.0	3 ± 1.0	Accurate pattern equipment, rigid molds and cores, strict process control.
3.	Weight tolerance %	± 5	± 2	Rigid molds & uniformly compacted
4.	Core shift tolerance	± 2	± 0.5 - 1.0	Accurate core transfer jigs & handling facilities
5.	Core joint	Not specific	Perfect flatness	Strict core assembly control
6.	Core joint mismatch - mm	± 2.5	± 1	Strict core assembly control
7.	Cylinder head port dimensions	Not specific	Port shift ± 0.8 mm in XYZ direction, smooth surface & port profile	Accurate pattern equipment and core process to get close dimensional clearance cores with consistency and core assembly perfect.
8.	Cylinder head inner surface	Not specific	Free from metal projection, veining and sand fusion	High refractory core sand, core washes, chemically bonded cores.
9.	General dimensional tolerance	Flexible	Consistent & close dimensional tolerance	Accurate pattern equipments, rigid molds, chemically bonded cores, latest inspection equipments, better handling facilities to reduce human error etc.
10.	Surface finish	Net specific	Specific finish	Better process and better fettling facilities and quality raw-materials for cores and molds, strict process selection.
11.	Machine shop scrap %	5 - 10	5 max.	On-line quality /inspection equipments (X-ray fluoroscopy, ultrasonic, emission spectrometry, computerised thermal analysis equipment, etc.)

Sl. No.	Details	Demands		Foundry requirements to meet the demands
		Past	Present	
12.	Service reliability	Obligatory	Mandatory	Total quality demanded
13.	Design flexibility of suit foundry methods	Flexible	Very rigid	Latest foundry processes
14.	Metallurgical Properties:			
	a) Test certificate	No test certificate	For every melt casting with test certificate	Extra quality assurance facility
	b) Machinablity	Not specific	Specific demand, & close hardness range	Strict process control
	c) Homogenous properties	Not specific	Increasing demand	Copper, Molybdenum, Tin alloying
	d) Microstructure (Blocks & Heads)	85-90% Pearlite	98-100% Pearlite	Quality raw-materials, inoculant, chemically bonded cores, quality core washes required, strict metallurgical control.
	e) Elevated temperature properties	Not specific	Increasing demand	Alloying
	f) Salvaging	Need based	Very rigid quality demanded	Better process control
15.	Casting development time (Blocks & Heads)	12-18 months	5-7 months	CAD/CAM, CNC machines in pattern shop & extra foundry capacity to prove the casting quicker
16.	Foundry process selection (mold/core)	Not specific	Specific demand	Chemically bonded cores, high density molds

Table 1.2: Common Cast metals/alloys

Sl. No.	Cast metal	Melting furnace (Temp.)	Composition %	Properties (Average)	Applications	Limitations
1.	Grey Cast Iron	Cupola (1200 °C)	2.8 - 3.4 Carbon 0.8 max. Mn, Si 0.08 max. P, S	UTS: 150 -300 Elong: 1 max. BHN: 130-280 Impact: negligible Th. Cond: 45-53 Good castability, machinablity, high damping capacity, good bearing-properties, good corrosion-resistance and good compressive strength	Cheapest of ferrous alloys. Man-hole covers, lathe-beds, machine foundations, columns, valves, sanitary fittings, textile machine frames, grills, ornamental castings, water pipes, piston rings, cylinder blocks, brake drum	Brittle, poor toughness/ poor ductility, low tensile strength, poor weldability
2.	White Cast Iron	Hot blast-Cupola, Induction furnace (mains frequencies) (1250 °C)	2-5-2.8 C 0.8 max. Mn 0.5 max. Si 0.06 max. S, P	Very hard - BHN above 400 Very brittle, Elong - Nil, good abrasion-resistance, unmachinable	Grinding balls, grinding mill-liners	Tool hard/ brittle
3.	Malleable Cast Iron	By heat-treatment of White C.I.	2-5-2.8 C 0.8 max. Mn 0.5 max. Si 0.06 max. S, P	UTS: 270-500 Elong: 5-12 BHN: 120-240 Impact: 2-10 Sp.gr: 7.8	Pipe fittings, valves, levers, differential- housings, couplings, wheel hubs, pedals	Only of small castings. Limited upto 50 mm thick section only (malleablelisation difficult for heavier sections)

Note: UTS: Ultimate tensile strength - N/mm^2 or MPa
BHN: Hardness Brinnel
Impact: Impact Strength - Joules (Izod)
Elong: Percentage elongation %
Th. Cond: Thermal Conductivity W/m°C
Sp. gr: Specific gravity Mg/m^3

Sl. No.	Cast metal	Melting furnace (Temp.)	Composition %	Properties (Average)	Applications	Limitations
4.	Spheroidal Graphite, Ductile/ Nodular Cast Iron	Induction furnace (mains frequency) (1200 °C)	3.2 - 3.8 C 0.5 max. Mn, Si 0.05 max. S, P	UTS: 400 - 700 Elong: 5 - 15 BHN: 120 - 300 Impact: 5 - 15 Castable, machineable, good damping capacity, corrosion resistance and heat-treatable	Critical machine parts like crank shafts, gears, valves, pump castings, paper mill rollers, substitute for plain carbon steels for lower strength applications.	Low weldability
5.	Cast Steels:					
	i) Carbon Steels	Electric arc/ electric induction (High frequency) (1500 °C)	0.3-0.50 C 0.80 Mn, Si 0.05 max. S, P	UTS: 500 - 750 Elong: 15 - 30 BHN: 180 - 250 Impact: 40 - 90 Good weldability, heat-treatable	Gears, shafts, pressure-parts, vessels, valves, casings, housings, die-blocks	Corrosion resistance, high melting cost
	ii) Low Alloy Steels	Electric arc (1600 °C)	Upto 0.3 C 0.50 - 1.0 Ni 0.50 - 1.0 Cr 0.20 Mo 0.04 max S, P	UTS: 700 - 1200 Elong: 10 - 15 BHN: 180 - 250 Impact: 28 - 50 Th. cond: 35 - 50 Sp. gr: 7.8 Good weldability, heat-treatable, high creep and fatigue resistance	Creep/ fatigue resistance parts like turbine housing, heavy machines, heavy duty gears, turbines	Close composition control required, high melting cost

Note: UTS: Ultimate tensile strength - N/mm^2 or MPa
BHN: Hardness Brinnel
Impact: Impact Strength - Joules (Izod)
Elong: Percentage elongation %
Th. Cond: Thermal Conductivity W/m°C
Sp. gr: Specific gravity Mg/m^3

Sl. No.	Cast metal	Melting furnace (Temp.)	Composition %	Properties (Average)	Applications	Limitations
	iii) High Alloy Steel	Electric Induction (High frequency) Electric arc	a) 1.0 - 1.4 C, 12-14 Mn (1250 °C)	Abrasion-resistance work-hardening (water quench heat treatment)	Jaws, crusher parts, track shoes, liners of ball mills, excavator parts, cheap	Machining very difficult, poor weldability
			b) 0.2 C, 10-12 Cr	Corrosion-resistance	Valves, turbine parts, pump impellers, casings	Costly
			c) 0.1 C, 8 Ni, 18 Cr	Stainless steel, Th. cond: 16	Acid/Chemical resisting vessels, pumps, impellers, stirrers	Costly
			d) 0.3 C, 20-60 Ni, 8-15 Cr	Heat-resistance steels (300 - 1000 °C)	Furnace parts, burner parts, heat-treatment oven grills, hearth/ grate parts, cooler plates, gas turbine components, radiant tubes	Very costly
6.	Non-Ferrous Copper Alloys:					
	i) Yellow brass	Oil-fired crucible induction (950-1100 °C)	70 Cu, 30 Zn, 0.5 Pb	UTS: 100 - 700, Elong: 15-30, BHN: 120-200, Th. cond: 116, High ductility, malleability, corrosion-resistance (to sea water), bearing properties, electrical conductivity, machinability	Corrosion-resistant valves, hydraulic pump parts, switch gear component, electric/ thermal conductor, boiler/ heat exchange tubes, hardware (domestic)	High cost and melting losses, low availability in India

Note: UTS: Ultimate tensile strength - N/mm^2 or MPa
BHN: Hardness Brinnel
Elong: Percentage elongation %
Th. Cond: Thermal Conductivity W/m^oC
Sp. gr: Specific gravity Mg/m^3

Sl. No.	Cast metal	Melting furnace (Temp.)	Composition %	Properties (Average)	Applications	Limitations
	ii) Gun Metal	Oil-fired crucible Induction (950 -1100 °C)	85 Cu 5 Sn 7 Zn 3 Pb	UTS/BHN - higher than brass Sp. gr: 8.5	Medium/Heavy bearings, artistic castings, bushes, ship/ naval parts, valves, propellers, rudders, gears	High cost and melting losses, low availability in India
	iii) Bronze	Oil-fired crucible induction (950-1100 °C)	75-85 Cu 10 Sn 2-5 Pb 0.5 P 5 Al (Upto 20% Ni)	High UTS/BHN Heat-treatable, high wear-resistance, high corrosion resistance (sea water)	Spring parts, instrument parts, marine propeller, shafts, valves, sanitary fittings	High cost, melting losses, low availability in India
7.	Aluminium Alloys	Oil-fired crucible induction (650-700 °C)	Al, Mg, Zn, Cu Si	UTS: 140 -310, Elong: 3 - 10 BHN: 40 - 120, Sp. gr: 2.7 Th. cond: 150-200 Corrosion- resistance, castability, fluidity, high thermal conductivity, electrical conductivity. Die-casting possible. Low energy requirements	High strength: weight ratio- for automobile, scooter, motor cycle parts like engine cylinder, pistons, carburetor, aircraft and space parts, crank case, pumps valves, electrical machinery parts	Costly Low melting point
8.	Fibre reinforced plastic	Below 200°C or not needed (Low energy needs)	Varies	UTS: 50-150, Th.cond: 0.2 Sp.gr: 1.8	Replacement for cast-metals in low strength applications, automobiles, consumer durables	High cost

Note: UTS: Ultimate tensile strength - N/mm^2 or MPa
BHN: Hardness Brinnel
Elong: Percentage elongation %
Th. Cond: Thermal Conductivity W/m°C
Sp. gr: Specific gravity Mg/m^3

Table 1.3: Energy requirements for producing steel castings

Sl. No.	Description	Energy requirements in KWH/Ton Castings
1.	Melting	1400
2.	Molding, Finishing	130
3.	Heat Treatment	350
4.	Auxiliaries/Services (Compressed air etc.)	120
	Total	2000

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QUESTIONS

1. Compare the advantages and disadvantages, through a table, of
   a. metal casting Vs. metal forming (forging, rolling)
   b. metal casting Vs. welding (fabrication)
2. Describe the major activities in metal casting through a flow-chart.
3. How are metal casting units (foundries) classified ?
4. Name the important industries using castings, giving typical uses.
5. Compare the casting and mechanical properties of the following:
   a. cast iron Vs. cast steel
   b. aluminum Vs. copper alloys
6. Identify important problems/challenges in the Indian metal casting Industry.
7. Name the major Research & Development thrust areas of metal casting in India.
8. Giving reasons, identify which of the following components are made by casting process: (Industry-wise)

   Mineral processing: jaw-crusher plates, crusher housings, shaft-bearings, cone-crusher cones, hammer-mill hammers, holding bolts, excavator buckets, ball-mill liner plates, drive-axle spindle.

   Steel Plants: blast furnace bell, hopper, tuyres, wind-box and piping, rolling mill rolls, roll-housing, ingot molds, ladles, crane-hooks, drive shafts, lancing pipes, furnace shell.

   Cement plants, oil refineries: cement kiln, kiln support rollers, kiln drive gears (girth-gear), burner nozzles, cooler plates, clinker drive-sprockets, elevator buckets, excavator dipper teeth, track pads of shovel, heat-exchanger pipes, control valves, reactor vessels.

   Machine tools: lathe bed, milling machine column, drilling machine base, driving shaft, lead screw, arbour, check jaws, cutters, shaper body, planer work table, drive gears, tail stock, coolant pipes, drill bit, motor housing, pulleys for belt.

Automobiles: car body, scooter body, car chassis, engine cylinder, radiator, gear box housing, gear, piston, piston rings, carburetor, axle, crank shaft, connecting rod, engine valves, wheels, cylinder head, brake drum, brake housing, differential gears.

General: bridges, railway track (rails), wagon wheels, track points, couplings, bolsters, cross head, fan blades, pressure cooker, steel furniture, cabinets (almirah), turbine housing, shaft, turbine blades, impellers. electric heater elements, water tap, main water pipes, man-hole covers, floor-plates in factory, gas cylinders, gas regulator body

9. Go round the Work-shops, Laboratories in your college and examine each equipment carefully. Identify the components and parts that are made by casting process. Find the reason why other parts cannot be cast from material, manufacturing and economic points of view.

10. Collect the latest Statistics regarding the production of casting, specification-wise, sector-wise and export-wise.

11. Suggest steps to be taken to improve the performance of metal casting industry (Foundry) in India.

12. Find out the professional associations connected with metal casting activity, the journals published and seminars conducted at both national and inter-national level. Try to become a student or full-fledged member to participate and gain up-to-date professional knowledge.

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2 SAND MOLDING PROCESSES

The casting processes involving the use of sand as molding medium can be classified as sand molding processes. These are used for over seventy percent of castings produced.

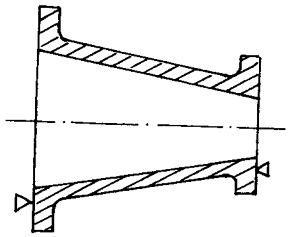
The stages involved in the sand molding process are: sand preparation, pattern making, core making (if required), molding and closing.

The normal procedure of molding is described below, illustrated in Figs 2.1 (a, b, c) and 2.2 (d, e, f)

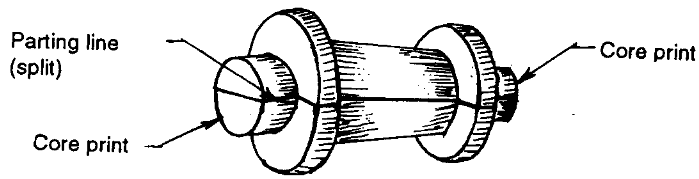
In hand molding the bottom/drag part of the pattern is placed on a bottom plate and a drag molding box is located around it. Consideration should be given to the positioning of runner, ingates and sprue-base as well as the minimum sand thickness to be kept around casting while locating the mold box. Facing sand to a thickness of 30 to 100mm is packed uniformly over the pattern and parting face, by hand. It is then rammed properly to cover all the grooves and projections of the pattern. Backing sand is then rammed in layers till the top of the box. The top surface is finished with a straight-edge.

The drag is then inverted and the cope part of the pattern is placed on the bottom using dowel pins. Cope mold box is located on the drag box with closing pins, and parting powder is sprinkled on the surface for easy stripping. Gating, sprue and risers/flow-offs are placed around the pattern while packing facing sand around them. Finishing of the mold is carried out by ramming backing sand till the top and strikling the top surface with straight-edge. Vent holes are given to proper depth at suitable distances using vent wire.

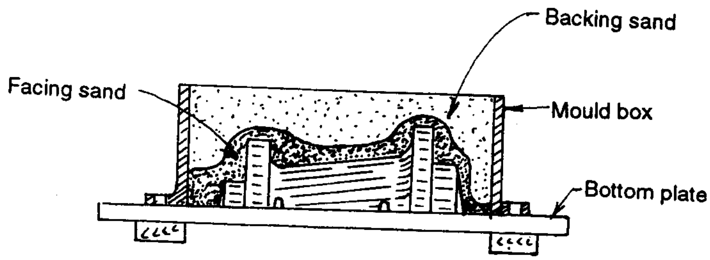
The cope is separated and kept inverted on a level place. The pattern halves are carefully removed from the mold, without breakage of the mold cavity or pattern. The mold-halves are neatly smoothened and finished, taking special care for the joints at gating, sprue etc. Cores, where necessary are carefully set (in drag) with the location provided by the core-prints, and connected to mold vents. The loose sand particles are



(a) Casting drawing



(b) Pattern



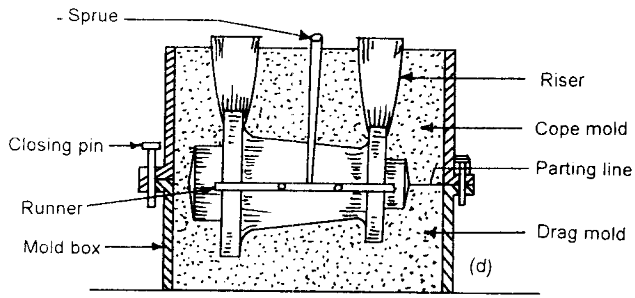
(C) Drag mould

Fig.2.1 Stages in molding process

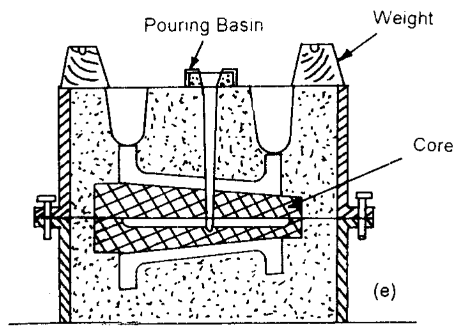
(Contd.)

cleaned out using lifter or suction pipe. Suitable sealing by a thick clay rope is done all around the edge of the mold to prevent leakage. The cope mold is closed carefully using closing-pins. Pouring basin is located on the top of sprue. Suitable clamping with clamps or by placing weights is done to prevent the lifting of cope due to metal pressure during pouring of liquid metal / casting.

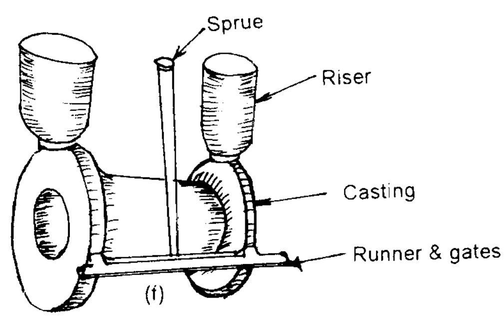
In machine-molding, packing/ramming sand, lifting pattern and mold-half are done by mechanical devices, normally pneumatic-operated.



Ramming cope



Closed mold read for pouring



(f) Casting with runners risers

Fig.2.2 Stages in molding process

2.1 Functions of molding sand

The basic tool for casting liquid metal to attain the required shape is 'mold'. In sand molding processes, mold is prepared using molding sand as medium, ramming it around a pattern, which is a model of the final casting and withdrawing pattern to leave a cavity. Once a mold of suitable quality is made and poured with liquid metal, it cannot be re-used.

2.1.1. Requirements of a good molding sand

a. Refractoriness

As the mold should withstand the liquid metal temperature while it is poured, the molding sand should have sufficient refractoriness. For example, sand used for steel castings should withstand high pouring temperatures of above 1500°C of liquid steel, whereas the molding sands for cast iron are subjected to temperatures of about 1200°C. Non ferrous alloys of copper (950°C) and aluminium alloys (650°C) need lower refractoriness. Without sufficient refractoriness, the sand partially melts and fuses with the liquid metal giving rise to very rough sand-fused casting surface, causing rejection.

b. Chemical resistivity

The sand used for molding should be inert and not react chemically with the metal/alloy being poured into it. Special care has to be taken while casting more reactive metals like magnesium and titanium alloys while preparing molding sand.

c. Strength with proper binder

The molding sand, when combined with suitable binder, should develop adequate cohesion among its grains to be able to form and stay as a mold. It should also adhere to the mold-box or other container when rammed, and withstand movement and handling of molds before pouring.

Molding sand should also develop adequate strength with binder to withstand the compressive and erosive force exercised by liquid metal while filling in the mold cavity. As the alloys poured have generally high specific gravity (Eg. Ferrous metals 7.8) they tend to erode, enlarge and break the mold. Low strength molding sands cause casting defects such as bulge, swell, burst and leaked castings.

d. Permeability

Liquid metals poured into mold cause evolution of gases as hydrogen, nitrogen, carbondioxide as well as steam due to their reaction with molding ingredients such as binders, additives and water. Each cc of water added in molding sand can evolve 16000 cc of steam in the few seconds while liquid metal is filling the mold. So, unless the mold has sufficient porosity to allow these gases and vapours to escape, they tend to get entrapped in the casting during solidification. This results in defects like blow holes, gas-holes etc., in castings. Permeability of molding sand is very important for high pouring temperature metals like steels and to a limited extent for alloy cast iron and copper alloys.

e. Surface finish

The surface smoothness of a casting is necessary for appearance as well as avoiding costly finishing operations. The casting surface smoothness depends on the condition of mold which is contributed by the size, shape and distribution of the molding sand grains. Finer grains give smoother mold surface. However this criterion has to be compromised with that of permeability which is its opposite, depending upon the size and material of cast-metal.

f. Flowability

The capacity of molding sand to flow to different corners and intricate details in mold without much special effort to ram is a useful requirement of molding sand, specially in machine-molding.

g. Collapsibility

Once the casting solidifies in the mold after pouring, the mold-material should peel off and disintegrate easily so that the cooled casting can be taken out and finished. If the sand is not collapsible, it will strongly adhere to the casting, becoming very hard to separate involving in high cost of fettling and finishing. In some alloys with long freezing solidification and high volumetric contraction like steels, gun-metals etc., the hard non-collapsible sand causes defects like cracks and hot-tears in the castings. Collapsibility can be improved by using special additives which cause break down of molding sand at elevated temperature.

h. Availability & Economy

The quantity of molding sand required to manufacture each ton of finished castings can vary from 3 to 6 tons depending on the size and metal poured. In normal sand molding, once a mold is poured, it cannot be re-poured and is normally shaken-out form the mold box. Due to the burning off of adjacent layers of sand by liquid metal, much of the used sand needs replacement. Due to the need of such large quantities of molding sand in foundry, it's easy and cheap availability becomes almost a basic requirement.

2.2 Classification of Foundry Sands

Foundry Sands can be classified by different methods depending on their application and the nature of molding process.

i. Base Sand - Ready (mixed) Sand

The base sand for molding/core application is the basic, thermally refractive, chemically inert medium with proper grain size, grain shape and distribution. By itself, the base sand does not develop bond or cohesion to form and retain the shape of mold when rammed. The base sand has to be blended with a suitable bonding system like clay-water, resin-oxidation or sodium silicate - carbondioxide to develop strength.

a. Silica Sand

The most common base sand universally used is quartz or silica (SiO_2) obtained from either crushing of sand stone rocks or from sand dunes or river beds. The fusion point of pure quartz is 1760°C, but it is drastically lowered by the presence of impurities like alumina, iron oxide, felspar, mica etc. So, for high-temperature applications of casting steels, a minimum of 98% pure SiO_2 is recommended. For cast-irons and non-ferrous castings, depending on the pouring temperatures, higher level of impurities and consequently lower levels of silica (94 - 98%) can be tolerated. Good deposits of high silica sands (98% SiO_2) are available in India in the regions of Allahabad, Rajmahal (UP), Durgapur (WB), Jabalpur (MP), Hyderabad (AP), Madras (TN) and from quartz mines in different states. The almost universal application of silica as base sand is due to its abundant availability and low cost. Silica sand grains are hard and abrasion-resistant while ramming in the mold. The disadvantages of silica compared to other base sands are the high coefficient of thermal expansion (1.6% at 900°C) for high temperature applications causing casting defects like scabs due to the allotropic modifications, lowering of fusion point drastically by impurities causing bond fusion at casting surface and relatively lower thermal conductivity affecting soundness of casting to certain extent. The fine dust of silica can cause diseases like "Silicosis" by prolonged inhalation in the foundry, which is also an environmental pollution problem. Silica being acidic in nature, has tendency to react with certain basic metals/alloys while pouring, causing poor casting surface.

b. *Olivine Sands*

Olivine is a complex mix of ortho silicates of iron and magnesium from the mineral 'dunite', which has limited availability in India. Being free from silica, it is suitable for basic-nature metals like manganese steels. It has lower thermal expansion and higher thermal conductivity and higher fusion point (1800°C) all helping to improve casting quality. It is safer to use in foundries, being less hazardous than silica and is popular in Europe.

c. *Chromite Sands*

Chromite is a solid solution of many complex metallic oxides (spinels). It contains low percentage of silica and has a very high fusion point at 1850°C. Its thermal conductivity is much higher, improving casting quality. Thus for alloy-steel moldings and core-making to reduce sand-fusion, metal-penetration and better chilling, chromite sand is used. In India, due to limited availability chromite sand is ten times more costlier than silica.

d. *Zircon Sands*

Zircon contains the oxides zircon (Zr_2O) 67% and silica (SiO_2) 33% approximately as a compound. It has the highest refractoriness among the different base sands (2600°C). It also has very low thermal expansion (0.25% at 900°C) and high thermal conductivity or chilling power, all helping to achieve good surface finish and casting soundness. It is very dense with a specific gravity of 4.5, almost double of silica. It is used for high quality castings in alloy steels and precision casting of costly alloys. It is extensively used for coatings or washes for molding and cores to improve surface finish. It is available in India in the beaches of Kerala. Due to its strategic applications in atomic minerals, its supply is controlled by defence (BARC) and so is limited in availability. The cost is approximately six times that of silica sand.

e. *Chamotte Sand*

Chamotte is obtained by calcining fire-clay (Al_2O_3-SiO_2)at above 1100°C. It has a high fusion point (1750°C) and low thermal expansion (0.5% at 900°C). As it is cheaper compared to chromite, olivine or zircon, it is used for heavy steel castings in preference to silica sand. Its use is limited to dry-sand molding, where molds, after making are dried to about 300°C before pouring. The molds need extensive application of coatings to improve surface finish as the grain-size of chamotte sands is very coarse. Chamotte is approximately twice as costly as silica sand.

As the properties of base-sand determine to a large extent the properties of final molding or core-sand mixture, the base-sand should be selected with care. Once selected, no changes are made in a foundry in the base-sand specification, the only changes are being made are in the composition of binders and additives for different application.

After the selection of a suitable base-sand, an appropriate binder-system has to be adopted to give adequate bond and suitable additives for any special properties required for molding and core-making. Such mixed sands with base sand and different ingredients, ready for molding/core-making are termed as ready/prepared sands.

ii. Natural sand Vs. Synthetic sand

a. Natural sand

Silica sand occurs in some regions in a naturally mixed condition along with clay and other minerals. These naturally occurring sands, mainly from river beds and some quarries have properties adequate for being used directly as molding and core sands. Such natural sands need only minor grading or sieving to remove large grains and organic matter and addition of water for bonding. For example, natural sands occurring at Londha in Maharashtra contain about 80% SiO_2, 3% Al_2O_3, 6% Fe_2O_3 and about 20% American Foundrymen Society clay. Similarly, Haridwar (UP) sand contains about 90% SiO_2, 4% Al_2O_3 and upto 5% AFS clay. Such sands are used for molding directly after sieving. The advantages of natural sand are mainly economy (very cheap), are adequate for light ferrous castings, dry-sand molding and for normal quality non-ferrous castings. Natural sands occur in finely mixed condition and therefore do not need costly sand mixing equipment and process. They have better capacity to tolerate variations of moisture (water) in mixing and use than synthetic sands. Difficulty over control of properties, low refractoriness and permeability are problems for their use in high quality, intricate and expensive casting production.

b. Synthetic sand

Synthetic sands are prepared by blending binder-free base-sand with suitable binder system like clay-water, resin-oxidizer, sodium silicate - CO_2 and also with special additives. Any base sand with suitable refractoriness, grain size and distribution can be selected depending upon the pouring temperature and quality requirements of casting metals. Additives help to get special properties like surface-finish, lower finishing cost and higher quality. For example, highly refractory base sand like zircon is used with resin binders for alloy steel castings, high silica sand with bentonite and coal dust for alloy special cast irons and many special additives like tellurium are used for magnesium castings. For such specific needs, natural molding sands are not adequate. Synthetic sands are much costlier compared to natural sands. They need special prepartion with costly mixing equipment and procedure to develop required properties. The moisture range has to be closely controlled when used with clay-bond.

iii. Facing sand, backing sand & system sand

In the molding of medium and large size castings, synthetic sand with special properties is used only around the pattern, for about 30 to 100 mm thickness. The balance mold is filled with cheaper sand of low bond-strength. This is mainly for economy as the new sand, binder system and special additives on preparation to synthetic sand are quite costly. (See Fig: 2.1 (c))

The liquid metal poured into the mold cavity comes into direct contact only with this specially made sand of about 20% mold volume and is called 'facing sand', helping to achieve the required casting quality. 'Backing sand', which is almost 80% of volume of the mold, is of ordinary quality or even once used (return) sand, mixed with a small quality of binder and water without any special additives. This saves the cost of molding sand considerably, at the same time satisfying the quality requirements. This method is most common for large size molds in both machine molding as well as hand molding.

However, for mass production of small machine-molded casting using mechanized production lines and sand-supply, it is not convenient to use two types of sand for each mold-half. For such application, a synthetic sand mix of suitable proportion is used for the entire mold and is called 'system sand'.

iv. Classification of foundry sands based on molding process

Molding sands are also classified as per the molding process for which they are used. 'Green sand' is the molding sand mix used for molds poured as they are fresh, without drying. This is the most common method used for ferrous and non-ferrous castings due to its simplicity, economy and high productivity. In 'dry sand' system, the molds after being made are dried thoroughly in ovens or by flame before pouring the liquid metal. This process is used for heavy and complicated castings. Details of other sand systems such as 'loam-sand', 'resin-air set sand', 'shell molding sand' etc. are given under the section "molding processes", later in this chapter.

2.3 Ingredients of molding sands

i. Base Sand

As discussed, the molding sand mix is made up of the base refractory aggregate like silica, zircon etc., suitably crushed and graded, to which a proper binder system is blended. Obviously, unless the base sand has adequate refractoriness, chemical resistivity, suitable grain shape, size and distribution, the final molding sand mix cannot change these basic features, the difference being the bonding strength and marginal special properties through additives.

ii. Binders

Binders are the materials added to base sand to give bond, cohesion and strength to the mixed sand on ramming so as to take the shape in mold and retain it under the pressure, temperature and erosion of liquid metal when poured.

a. Clay-Water System

This is the most common binder system used. clay is a weathered product of silicious rocks, containing hydrosilicates of alumina (Al_2O_3) as flake-shaped particles of about 0.2 mm diameter in softened condition. When combined with water, they produce a plastic or semi-plastic mass. The commonly used clays in foundry are bentonite and kaolinite. Bentonite is the most commonly used clay for molding sand and belongs to 'mont-morillonite' class. Western bentonite is a superior clay of this class, having high softening point of about 1250°C, highly gel-forming It has high base-exchange capacity, with sodium (Na) as the adsorbed ion and so called as "sodium bentonite". It produces higher green strength to molding for the given additives. Southern bentonite or "calcium bentonite" has calcium (Ca) as the adsorbed ion, has lower softening point (980°C), low swelling index and gives less strength to molding sand compared to sodium bentonite.

b. Bonding Action of Clay

Various theories explain the bonding actions of clay around base sand grains. Clay becomes plastic and develops bond only in the presence of liquids having (OH) negative and (CH) positive ions such as water, acetic acid etc. As water is added, the flaky particles of clay get separated by films of water which are assumed to be highly viscous. With less addition of water, the clay is very stiff and the water films are such that all the molecules are arranged layers with water in viscous state. As moisture content is increased, the water films become thicker and the layers midway between the flakes become gradually easier to move and the clay becomes more plastic. At a certain water content. the randomly oriented water particles produce clay with maximum stickiness or bond. When sand and clay with water are mixed together, each sand grain gets coated evenly with clay after minimum mulling. Upto certain addition of water, the clay flakes receive water-films creating an amorphous gel firmly holding the sand grains, creating the bond or adhesion and help to develop the strength for the molding sand when rammed in the mold box. Any further addition of water will not strengthen the micro-coating but will create loosening of the bond, thereby weakening it. Thus, it is essential to control the water addition to clay-bonded sands to close limits. Obviously the optimum water addition increases with the increase of clay. (See Fig 2.7)

Excess moisture not only reduces the bond strength but creates the problem to lower permeability and high generation of steam when liquid metal is poured causing blow holes in casting.

In India good quality bentonite clay is obtained from Rajasthan, Bihar and Kutch which belong to the more superior sodium-based (western) class having approximately SiO_2-50%, Al_2O_3-20%, Fe_2O_3-8%, fusion point 1180° C, PCE 8 to 9 and high swelling index (6). Kashmir bentonites are calcium-based type. Kaolinite (fire clay) type clay are obtained from weathered feldspar or other alumina minerals and contain higher proportion of Al_2O_2 - upto 40%. It is the main constitutent of china clay and fire clay used for making ceramics and refractory bricks. It has higher fusion temperature of upto 1700°C compared to bentonite, has coarse particle sizes, has low swelling capacity when mixed with water. These clays cannot develop adequate bond in green condition and so are not used as binders in green sand system. Due to their higher refractoriness these are used as binders in dry sand molding of steel castings, specially with chamotte as base-sand. Good quality kaolinite clay is available in Bihar, Bengal and Kerala in India.

c. Sodium Silicate as Binder

Sodium Silicate (Na_2SiO_3) or $(Na_2O)_n$ $(Sio2)_m$ used as a major raw material in washing soap manufacture is obtained by high temperature (1650°C) fusion of pure silica (SiO_2) with washing soda (Na_2CO_3). It is a thick, viscous fluid which generates a strong bond when mixed with silica sand and made to react with CO_2 gas.

$$Na_2O.2\,(SiO_2) + CO_2 \rightleftharpoons Na_2\,CO_3 + 2SiO_2 + \text{Heat}$$

The SiO_2 liberated is amorphous and forms a gel causing increase in viscosity giving bonding strength to the sand grains. This process is used both for molding and core-making, the advantage being a very fast cold chemical hardening with no requirement of baking as well as obtaining very high strength values. In fact, the excessive strength of bonding is the main draw back of this process causing problems in fettling and cleaning as well as hot tears in castings.

d. Oils as Binders

Various types of vegetable oils such as linseed oil as well as marine oils can also produce bonding of sand. These develop bond and strength by curing involving oxidation and polymerisation. The linolenic acid in these oils acts as the main hardening constituent, the polymers becoming solid and hard by heating to 120 - 200° C. During baking, hot-softening and gas-evolution occur and at a higher temperature the bond becomes brittle thereby weakening the mix. So much care should be exercised about the rate and temperature of baking for oil sands. Recently, due to the high cost of oils as well as baking cost and time, oil sand systems are being discontinued.

e. Resin Binders

Resins are high melting point gums obtained by chemical alterations of vegetable gum or made synthetically from furans and phenolics. Urea formaldehyde (UF) resin modified with furfuryl alcohol produces, good bonding strength of sand grains when mixed and heated. Similarly, phenol formal-dehyde (PF) resins have higher heat resistance after mixing and baking and are less costly than UF resins. The advantage of resin as binder is that large variation in final properties can be obtained by suitable mixing of resin, catalyst and oxidizing agent and strength can be obtained even without baking (cold-set resins), overcoming the restrictions imposed by oil-sand systems. Due to the high quality level, collapsibility, lower gas evolution, ease of finishing and smoother surface finish resin-bonded sand systems have become highly popular for non-baking molds and cores.

iii. Additives

Additives are materials added to molding and core sands to give special properties other than normal bonding, such as:

a. Surface finish
b. Dry strength/ (increase) at skin or mold surface
c. Refractoriness for mold or core
d. Cushioning materials which burn off and allow expansion of sand grains preventing expansion-oriented defects such as scabbing or improve collapsibility

a. Surface finish improvement

Reducing agents like coal powder, pitch, sea-coal, creosote or fuel oil are added upto 5% to prevent wetting of the sand grains by liquid metal. They improve surface finish, decrease metal-penetration, minimise surface defects such as "burn-on" on castings. In cast-iron foundries, sea-coal or coal dust is added between 3 to 5% for this purpose. Reducing agents are not added for steel sands due to the fear of carbon pick up by liquid metal. The reason for improved surface finish by coal dust or other carbonaceous additives is explained by formation of a protective gaseous envelope at mold surface preventing the fusion of sand with hot liquid metal during pouring. Excess coal dust addition reduces permeability of sand-mix and also need higher binder moisture content to give the sand strength at optimum level.

b. Dry strength and higher strength at the skin or mold surface

Cereal binders like dextrin, starch as well as sulphite lye and molasses when mixed with molding or core sands (upto 2%) increase dry strength and provide a hard impervious skin at mold/core surface to give smoother casting surface. In addition these organic compounds burn off finally at the high pouring temperatures of liquid metal causing better collapsibility and easier finishing of castings. cereal binders are costly.

c. Refractoriness

Higher refractoriness is given by the addition of iron oxide powder (Fe_2O_3) upto 2% to molding and core sands. It prevents hot cracking of molds and cores by improving hot strength and reduces metal penetration. Silica flour (99% SiO_2) or zircon flour improve refractoriness of mold/core sand mix through their high sintering point to prevent metal penetration or sand-fusion, especially in ferrous castings. Care should be taken however as these materials in very fine form (100 to 200 mesh) reduce permeability drastically.

d. Cushioning materials

In high temperature casting metals as some cast-iron and steels, the sand-grains of tightly rammed molds expand and cause defects like scabbing. Sometimes the higher strength developed from various binders and additives may cause hot-tears, hot cracks as well as generally poor collapsibility of sand after the casting is cooled, which increases the cost and time of finishing exorbitantly. To prevent this cushioning, agents which are organic fibrous materials like wood-flour, saw-dust, powdered husks, peat, straw are added to molding and core sands upto 3%. These materials burn-off while pouring and create voids to allow expansion of sand-grains, preventing scabbing. They also help in better collapsibility of molding sand around casting and reduce finishing cost.

iv. Parting compounds

While preparing the mold, molding sand is rammed against the pattern. After the mold is made, it is necessary to remove the pattern to form the mold cavity into which liquid metal will be poured for final casting. For smooth and easy release of the pattern from rammed mold, parting materials are used in molding. These are very fine powders with 100 to 200 mesh (75-150 microns) particle size, sometimes in liquid form. The powders of soap stone (talc) and graphite have natural flakes and give smooth and easy parting. Dry silica powder is also used as it is cheaper to prevent sticking of mold material to the pattern. Mineral oil or water-based silicon solution are used as parting agents, mainly for metal patterns and large wooden patterns, especially in processes when the pattern is heated to high temperature.

2.4 Core sands

'Core' is a shape made in core sand placed in a mold to produce an accurate hollow shape or cavity in a casting. When liquid metal is poured into the mold, it occupies all the empty spaces restricted on outside by mold and internally by core, finally forming the casting.

i. Functions of a core

a. To provide an accurate internal shape of the casting

b. To help in simplifying molding for difficult outer shapes of castings

c. To provide gating system through cores

d. To prepare important/critical areas of casting accurately as it is easier than by molding

e. To avoid top-box by using a 'cover core' and simplify molding or for all core-assembly in large castings to avoid use of large molding boxes. (Fig 2.4)

ii. Requirement of core sand

Being entrapped all round by liquid metal, the requirements of core sand are more critical than molding sand:

a. Core sand should have good refractoriness so that it does not fuse when surrounded by liquid metal

b. Should give good surface finish as it is very difficult and costly in many complicated castings to machine or finish inner shapes later. The core sand should be of proper fineness accordingly.

c. It should evolve less gases and be permeable as otherwise the casting will have defects like blow holes and gas porosity

d. It should be collapsible for easy cleaning of internal shape, which is often much more difficult than outer shape of casting (made by mold)

e. It should retain its dimensional accuracy and shape during pouring and casting solidification, possessing proper hot and dry strength.

Normally, cores being less in volume and more critical than molds, costlier and better sand mixtures are used for core sand compared to molding sands. The properties tested for core sands are fineness of base sand, green and baked strength, permeability, scratch-hardness and collapsibility.

iii. Commonly used core sand mixtures

a. Clay-bonded sands

For cheap and simple castings, internal shapes can be formed by using normal green sands with bentonite (4-5%) dextrine (1-2%) and water (3-4%).

For heavier castings the cores can be made using fire clay (4%) in addition and drying the cores in ovens (upto 150°C) to dry away free moisture. The dry sand cores are strong and have less gases compared to green sand.

b. Oil sands

Various vegetable oils like linseed oil (upto 15%) can be used to bind silica sand grains without using clay or water. These do not possess much green strength but develop very good strength after baking at 225-250°C. The surface finish and collapsibility are its additional advantages over clay-bonded sands. Due to the excessive cost of oils and requirement of fuel-fired ovens and pollution, oil-sands are being replaced by other systems now.

c. Resin sands

Many organic and inorganic resins (Urea Formaldehyde, Phenol Formaldehyde) can give very good bonds either in green condition through additional activators and chemicals or by baking to about 220°C. Resin sands give adequate green strength for dimensional stability in green condition, give high surface finish and excellent collapsibility. Air-set systems are very popular. Hot-box or Shell-molding system sands give highly accurate dimensions as the 'curing' takes place within core-boxes, before removing from core-boxes.

d. CO_2- sodium silicate sands

Silica sands with 3 - 4% sodium silicate can be rammed into core-boxes and then gassed with cheap CO_2 gas to prepare very hard and cheap cores fast. The problem of collapsibility and surface finish can be reduced by suitable additives and core-paints (washes). These cores are used for very large cores as they do not need drying or curing.

iv. Additives in core-sands

a. For improving refractoriness-zircon flour, pitch

b. For improving hot-strength-iron oxide (Fe_2O_3)

c. For surface finish-paints or washes with zircon flour & silica flour, graphite bonded with resin and carrier like petrol or water

d. For collapsibility-organic additives like sawdust, cereals.

2.5 Testing of molding sands and its control

i Testing of base / raw sand

The properties of base sand will ultimately decide the properties of molding or core sand mix containing additions. The common tests conducted on base sand are:

a. Chemical analysis

b. Refractoriness

c. Grain fineness, size, distribution and shape

d. Clay content

e. Thermal expansion

Chemical analysis is done to establish the level of impurities other than the main ingredient. For example, even 2% impurities like iron oxides reduce the refractoriness of pure silica by over 200°C making it unusable for steel foundry. Refractoriness is tested by subjecting the sand sample to a high temperatures to find the fusion/softening/sintering point. It is also expressed as Pyrometric cone Equivalent (PCE). Grain fineness, size and distribution are tested by Sieve Analysis using standard sieves with mesh-opening sizes. Sand sample of known weight (100 gm) is placed on the top most sieve with largest mesh-opening and the set of sieves containing finer sizes are mechanically vibrated for about 5 minutes. The weight of sand retained in each sieve is measured. From the multiplier provided for each size of sieve grain fineness number, which is the weighted average particle size of the sand tested, is calculated as given in the following example: Table 2.1

Table 2.1

Sieve Designation		**Multiplier**	**% Retained**	**Product**
AFS	**IS (microns)**	**M**	**R**	**M x R**
30	600	20	-	-
40	425	30	1.2	36.0
50	300	40	14.8	592.0
70	212	50	36.2	1810.0
100	150	70	28.8	2016.0
140	106	100	14.2	1420.0
200	75	145	2.5	362.5
270	53	200	1.8	360.0
PAN	0	300	0.5	150.0
Total			100.0	6,746.5

AFS Fineness Number = Total Product / Total % retained

= 6746.5 / 100

= 67.465, say 67

Distribution

To achieve dense packing of sand grains, it is necessary to have a mixture of larger and smaller grains so that the voids are less compared to only uniform grains. Generally in a sand the majority of the grains which are distributed over 3 or 4 successive sieves are considered suitable, (in the example, sieves 50, 70, 100, and 140 AFS). The percentage distribution should have only one peak value (70 in the example) which is nearest to the overall fineness.

Grain shape

Incoming raw sand grains have different shapes, as seen under magnifying glass. Round grains have better life and reusabilty when mulled and rammed compared to compound grains. Angular grains pack densely.

Clay content

Unwashed silica sand from mines or river beds contains some amount of natural clay, flake-shaped particles of clay minerals. Before accepting base sand for use, the amount of clay present should be tested so that the quantum of additives can be decided. The AFS clay content test is to find the amount of clay in a sample of 50 gm sand, by repeated stirring and washing with water and dilute caustic soda. The difference in initial and final dry weight is multiplied by 2 to give the AFS clay content.

Thermal expansion

Thermal expansion of base sand grains is critical as it causes scabbing and other defects in high melting alloys. It is mainly due to the phase changes of the material at high temperature. Pure silica (SiO_2) has more expansion compared to magnesite of zircon as base sand. So, for critical castings of high melting alloys (over 1750°C), silica sand is not preferred.

ii. Testing of molding and core sand mixtures

After preparing the sand mixture with suitable binders and additives, it is necessary to test it for suitability as for the function.

Some the common tests performed are:

a. Green Compressive Strength (G.C.S)
b. Permeability
c. Moisture content
d. Dry compressive strength
e. Shear strength - green/dry
f. Shatter index
g. Flowability
h. Clay content
i. Liquid limit
j. Mold and core hardness

Out of the above, tests (a). (b) and (c), are called routine tests as they are regularly done for every batch of sand mixed.

Test-procedure

As the tests given above are not absolute but applicable only for a sand-specimen prepared under a standard method to give comparative values only, sand-rammer and tube (container) are the starting point for sand testing.

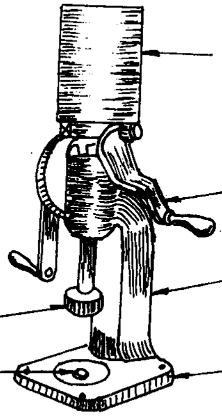


Fig. 2.3a Rammer for standard sand specimen

The standard rammer consists of a strong supporting frame to hold, lift and a drop a standard hammer of weight and size over a controlled height, sliding into a tube containing sand mixture. The cylindrical tube with inner dia. 50mm is filled with molding sand to be tested and placed at a location on the rammer-base under the hammer (Fig.2.3a) The hammer is lifted by a lever-handle and dropped from a standard height, compressing the loose sand in the container-tube. The operation is repeated thrice, (total 3 rams) after which the height of sand compressed in the specimen tube is read in the scale provided at the top end of the hammer. The reading should be 50 ± 1.0 mm. If it is above or below the value, the specimen has to be rejected and a new one made, after suitable adjustment in the amount of sand placed in the specimen-tube. If accepted, the standard sand specimen is stripped from the tube using a stripping stand, for conducting the tests.

a. Green compressive strength

The prepared standard sand specimen having 50mm dia. and 50mm length, is subjected to gradual compressive load from each of the round faces. As the load is applied between the end holders gradually without jerks, the specimen fails at a stage when the compressive force exerted is more than it can withstand. The value can be directly read on the scale provided on the tester.

Sand strength testing equipment, called Universal testing machine, can be used to test green and dry compression strength. Loading systems may be vertical spring loaded or horizantal hydraulic force. (Fig.2.4)

As already mentioned, this being a non-absolute test, unlike tensile testing of steel, the procedure for standard specimen is vital and at least 3 readings, out of which two should be nearly equal, are necessary to conclude the test result.

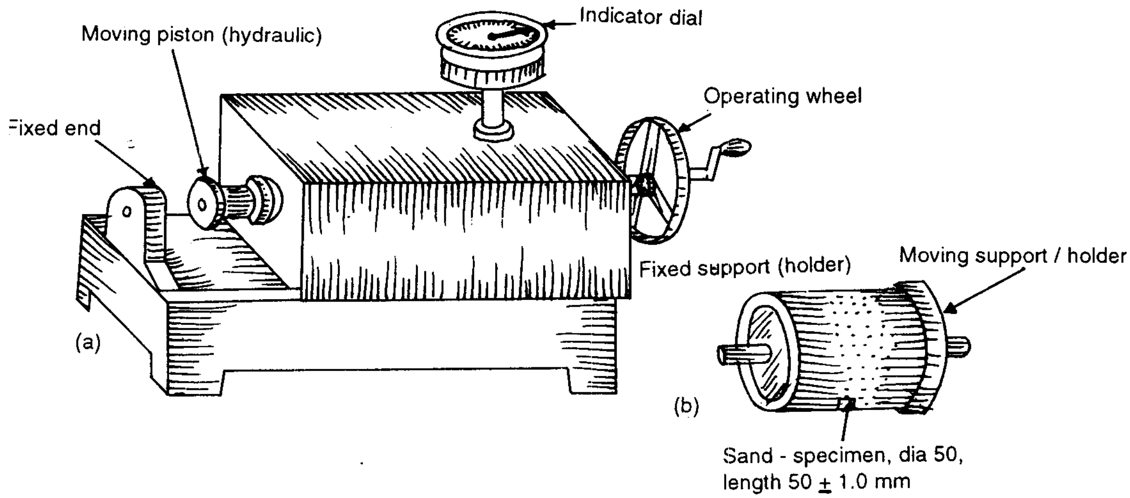


Fig. 2.4 Universal sand strength tester

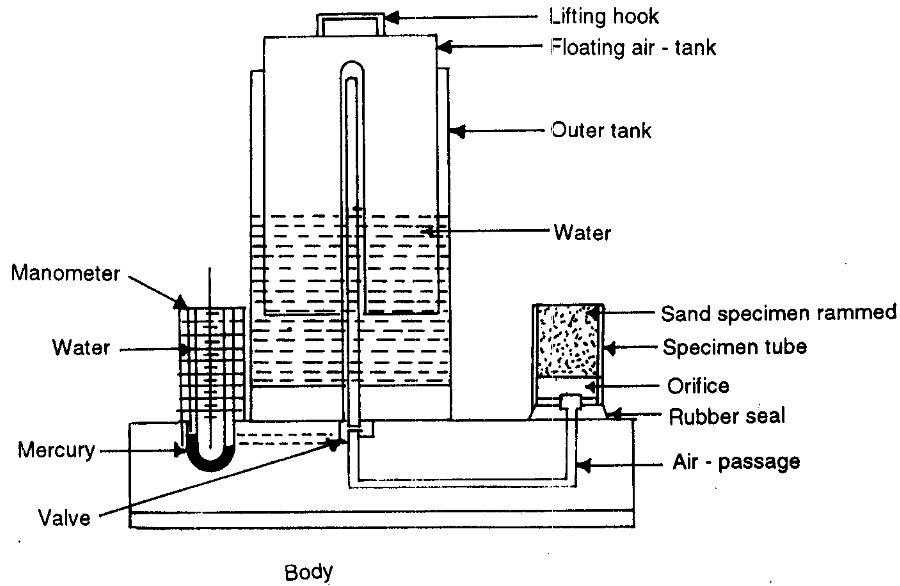


Fig. 2.3b Permrability meter

b. Permeability

Permeability meter is the instrument used for testing the permeability of sand specimen. The principle is that when a fixed volume of air, trapped in a chamber at a fixed height is made to pass through the sand specimen from a standard orifice, back-pressure is developed in the tube. This back-pressure is inversely proportional to the permeability of the sand-mixture in the specimen. If air can easily pass through the specimen due to more voids, less back-pressure is created showing higher permeability reading. The reverse applies to low permeable sand, more densely packed, causing higher back-pressure. The permeability number value can be directly read on the scale in the instrument or can be calculated from the pressure reading of the manometer provided. (Fig.2.3 b)

c. Moisture content

The moisture content of mixed sand can be found by either standard gravemetric methods or recording the weights before and after a sand sample is dried, or by chemical methods by measuring reaction products on the water contained. Many direct reading instruments are now available for fast accurate measurement.

d. Dry compressive strength

Dry compressive strength is tested in the same way as green, using a dried sand specimen.

e. Green and dry shear strength

Green and dry shear strengths are tested using suitable holders on universal sand tester.

The following tests are conducted on sand mixtures, not regularly but a few times:

f. Shatter Index

This property indicates the ability of rammed sand to resist impact. The test-equipment consists of a specimen holder at a height of 2 metres attached to a vertical pipe, at the base of which is kept a sieve with opening size 12mm. When the specimen is dropped from the height, it falls on the sieve and disintegrates. The percentage of sand lumps retained above the sieve out of the total weight of the specimen indicates the resistance to shatter of the sand-mix.

g. Flowability

This property, which indicates the capabilty of the sand mix to flow and occupy intricate voids in machine molding, is measured by a special attachment on the standard sand rammer. A dial indicator is pre-loaded to 100 and positioned on the top of the rammer piston after 3 strokes are given. When the fourth stroke is given, the specimen gets further compressed. This change in the height is measured by the dial guage, which is directly calibrated to give "flowability index".

h. Clay-content test

This is a repetition of AFS clay content test normally done for base sands. The purpose is to find the amount of "dead" or non-binding clay in the sand mixture existing due to repeated mixing of used or return sand. High percentage of burnt clay causes severe problems in sand.

i. Liquid-limit test

This test conducted on binder clay, normally bentonite, gives the amount of tempering water needed to develop proper bond for a particular clay. This is also a comparative test, where, the time taken to fill a groove in clay mixed with certain quantity of water is taken as its capacity to absorb water.

j. Mold and core hardness test

Tests based on dial guage principle are used for testing mold or core surface hardness after they are rammed, before closing. The bottom ball or knife edge, under a spring load, presses into the mold or core and the depth penetrated is calibrate to a scale of 100 points on the dial. A higher reading indicates lower penetration and hence higher rammed hardness on the surface. This can be tested on the sand specimen or directly on mold or core.

Other special tests:

Compactability, observation of sand behaviour during sample pouring using special equipment etc..

iii. Control of molding and core sands

The purpose of testing sand mixtures is to decide their suitability for a particular application. Often in the production floor, due to change in the source of ingredients, mistakes and human error, the final properties may not be as required, which affects the casting quality. The green compressive strength of (GCS) of sand indicates the capacity of the mold to resist breakage/damage while handling and closing the mold, its capability to withstand the abrasive action of liquid metal during pouring and the dynamic and static pressure exerted by it. If it is inadequate, by suitable addition of binder and additives, it can be enhanced. However, the GCS increases gradually with increase of binders only to a certain value, beyond which it reduces. So, the range of optimum binder (with water) should be decided in advance by systematic experiments for specific application, using known ingredients.

The variation in GCS with varying bentonite and water are shown in (Fig.2.5)

Permeability for critical applications is another important property to be checked and controlled. The basic permeability level is decided by the base sand fineness, shape and distribution, partially indicated by the Fineness Number. Normally, for proper packing density a 3-sieve distribution with round grains is recommended. Permeability is directly affected by grain-fineness, as finer/smaller grains reduce the gaps in between, causing low permeability. Similarly, higher green strength contributed by higher binder and additives content causes lower permeability. Low permeability results in blow holes in higher melting alloys like steels, CI and copper, as gases/steam generated cannot escape easily. However, with larger grains and higher permeability, a different problem arises - poor surface finish, even after proper ramming. This causes difficulties in finishing and rejection if in cores.

So, the main purpose of molding/core sand control is to establish an optimum combination of properties among strength-permeability-fineness to achieve high casting quality, with minimum defects.

Table 2.2 gives suggested sand mixtures with ingredients, properties for specific applications. Each foundry, from experience, establishes its own sand-mixes depending on the available raw ingredients, range of castings and other critical factors.

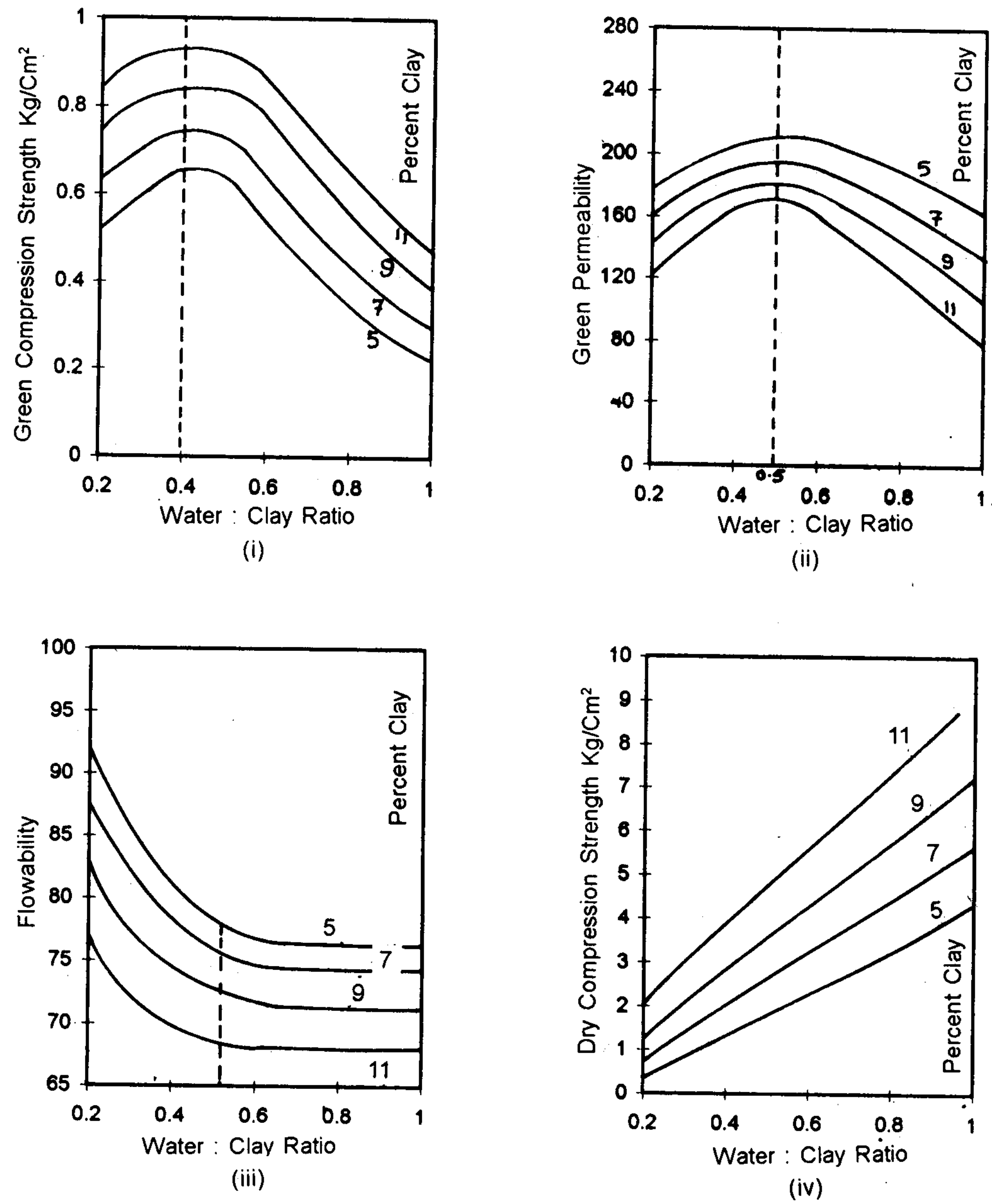


Fig. 2.5 Variation in sand properties (with clay percent and water: clay ratio)

Experiments conducted to study the effect of variations in water and clay (bentonite) on the properties of sand mixture are described below:

The effect of changing water to clay ratio on important properties of sand-mix is illustrated in Fig. 2.5 using silica sand with a fineness of 50-60, clay contents 5,7,9,11 percent and water: clay ratios 0.2, 0.4, 0.6, 0.8 and 1.0 for each clay percentage.

Table 2.2 Typical Molding Sand Mixtures & Properties

Cast Metal	Type of sand / Application	Base IS:1987 Grade Min. SiO_2%	Sand AFS Fineness microns No.	Ingredients %		Properties	
1. Steel (Temp. 1500°C)	Green sand (Light castings / Machine Molding)	A 99%	40-60	Bentonite Dextrin Water	4-5 1 3-4	GCS Perm. MH	0.6-0.8 120-200 85-95
	Dry sand (Heavy castings)	A 99%	40-50	Bentonite Fire clay Water	4-5 5 5-6	GCS Perm. MH	0.6.-0.8 150-300 Above 90
2. Grey cast Iron, Malleable S.G. Iron (Temp. 1200°C)	(a) Green sand Small castings / Machine Molding	C 94%	65-85	Bentonite Coal dust Water	3-4 1-2 3-4	GCS Perm. MH	0.5-0.7 70-80 75-85
	(b) Hand molding (Medium)	B 96%	60-80	Bentonite Coal dust Dextrin Water	3-4 1-2 0.5-1 4-5	GCS Perm. MH	0.6-0.8 80-100 80-90
	Dry sand (Heavy castings)	A 98%	50-60	Bentonite Fire clay Coal dust Dextrin Water	3-4 4-5 1-2 0.5-1 5-7	GCS DCS Perm. MH	0.8-1.0 3.5-6.0 100-150 80-90
3. Non-Ferrous Copper Alloys (Temp. 950°C)	Green Sand	C 94%	80-120	Bentonite Dextrin Others Water	5-6 1 2 5-7	GCS Perm. MH	0.5-0.8 50-80 70-80
4. Aluminium	Green sand	C 92%	100-140	Bentonite Dextrin Others Water	5-6 1 2 5-7	GCS Perm. MH	0.5-0.7 40-70 70

Note:
DCS --- Dry Compressive Strength - Kg/Cm^2
GCS --- Green Compressive Strength - Kg/Cm^2
MH --- Mold Hardness (Max. 100)
Perm. --- Permeability number

a. Green compression strength increases with increase in water/clay ratio, reaches a maximum around 0.4 and subsequently decreases with further increase in water/clay ratio. Similar trend is noticed for green mold-hardness.

b. Green permeability increases with increase in water/clay ratio upto a maximum around 0.5 and subsequently decreases.

c. Flowability decreases with increase in water/clay ratio upto 0.5 and remains almost constant with further increase in the ratio.

d. Dry compression strength increases almost in a linear manner with increase in water/clay ratio.

Conclusions

The above experiments show that there is an optimum value of water/clay ratio to achieve the highest green compression strength along with green permeability for each percent of clay (bentonite) added. Flowability, which is important for machine molding is achieved at lower water addition. Dry compression strength, applicable for heavy castings in dry sand molds, increases with increased clay content and water/clay ratio.

Considering these trends in properties, each foundry has to establish optimum clay content and water/clay ratio for their specific sand-mix ingredients like sand, clay and required properties.

2.6 Pattern equipment

A pattern is a model used to make a dimensionally accurate mold cavity in which liquid metal is later poured, to make a casting.

i. Differences between pattern and casting

Even though the pattern used closely resembles the final casting formed, the following are the differences between the pattern and the casting:

a. Material used for pattern is normally wood, whereas the final casting may be in any metal or alloy.

b. The dimensions of the pattern are normally larger than the final casting, as allowances for contraction, draft, machining etc., are added in the pattern.

c. Pattern may have additional projections called 'core-prints' used to locate and support 'cores' that form the internal shape of the casting.

ii. Requirements of good pattern equipment

Pattern equipment consists of sets of patterns, supporting plates, core-boxes, sweeps, templates guages etc., used in molding to produce proper mold cavity including assembly of cores.

Good pattern equipments require

a. Dimensional accuracy to get high quality casting.

b. Strength to withstand ramming and abrasion of molding sand.

c. Rigidity to prevent distortion and warpage through seasonal changes over a long period of use.

d. Good surface for easy removal from mold.

e. Proper color-code to indicate to the molder, information regarding final casting and precaution during molding.

f. Should help to increase molding productivity through suitable design and construction and achieve over all economy in molding.

Good pattern equipment is recognised as the starting point in getting a high quality casting without sacrificing molding-productivity and economy.

iii Types of patterns

a. Single piece, loose or Solid pattern

For simple castings needing small quantities of molds to be made (upto 20), patterns are made as a single piece Fig.. 2.6. These are very cheap to make but require more skill and additional molding labour compared to other types.

b. Split pattern

In the process of molding, two separate mold-halves are to be made, separated at the parting line (plane). For faster molding, the pattern is made in two pieces, split at the parting plane. This requires less molding skill, especially when irregular partings are to be made, compared to solid pattern and in ideal for larger quantities of molds (above 20 to 50 molds)Fig. 2.7.

c. Plated pattern, cope & drag pattern, Mounted/Match-Plate pattern

When large quantity of molds (above 100) are to be made from one pattern, to improve plate or board of suitable size for the mold-box, separately for cope and drag. To avoid delays in making gating system later, the pattern is connected with wooden/metal gating system, also fixed on the same plate. Such plated patterns may be used even for hand-molding to achieve significant improvement in productivity and quality of molding. For machine molding, plated-patterns are essential. The plate has guide pins and bushes for fixing on molding machine and for locating the mold-box. (Fig. 2.8). Sometimes, patterns with gating system are fixed on either side of a single 'match plate' for simultaneous production of cope and drag molds (Fig. 2.9)

d. Sweep pattern

For circular, symmetrical-shaped castings like rings, wheels etc., of very large sizes but needed in small quantity (1 to 2 pcs) sweep patterns give easy, fast and economic solution in molding. The sweep pattern equipment (See Fig. 2.10) consists of a thick wooden board forming the casting section made by rotation or sweeping, fixed to a metallic arm with rings. A solid steel round shaft, mounted on a suitable base, supports the sweep-arm and sweep-board, allowing it to rotate. The mold is made in a pit, using loam sand, which is a thick slurry that can be cut to shape by the rotation of the sweep-board. The internal contour may be made by another sweep-board or by assembly of cores. For cope, a normal mold-box rammed with molding sand, containing

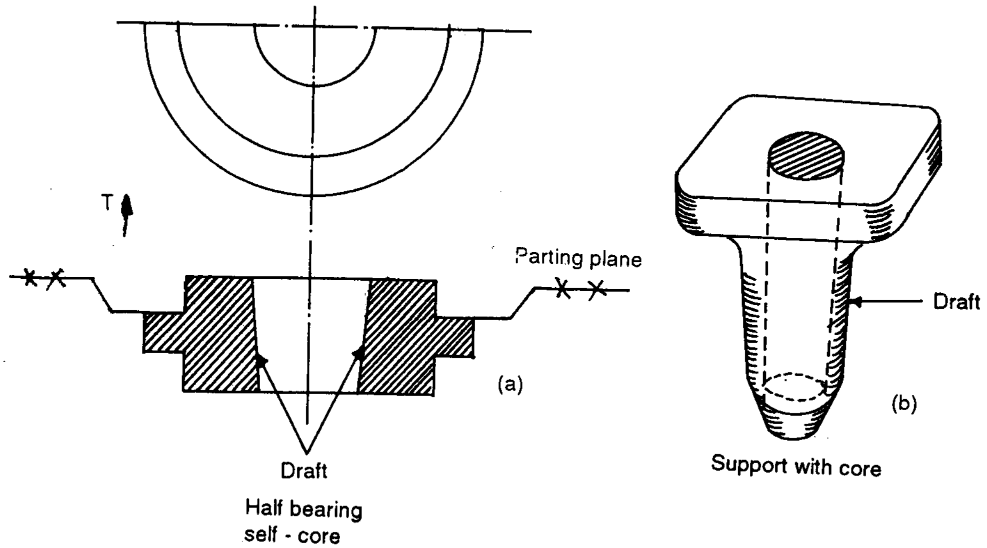


Fig.2.6 Solid/single piece patterns

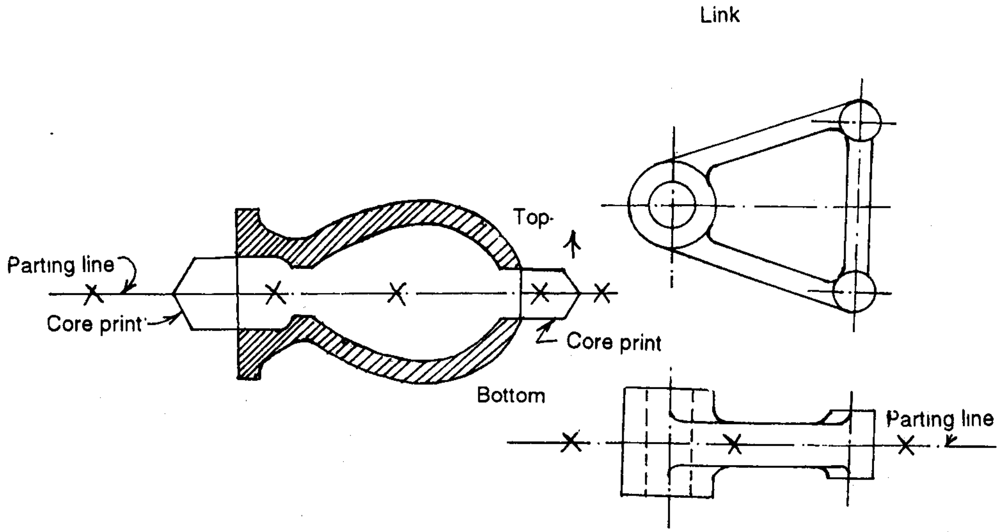


Fig.2.7 Split patterns

risers and gating with sprue may be used. Sweep molding is a very slow process, needing a highly skilled molder to achieve casting quality. But under specific conditions of simple geometry, large sizes and few castings, it is most economic molding method, due to the large saving in pattern-cost.

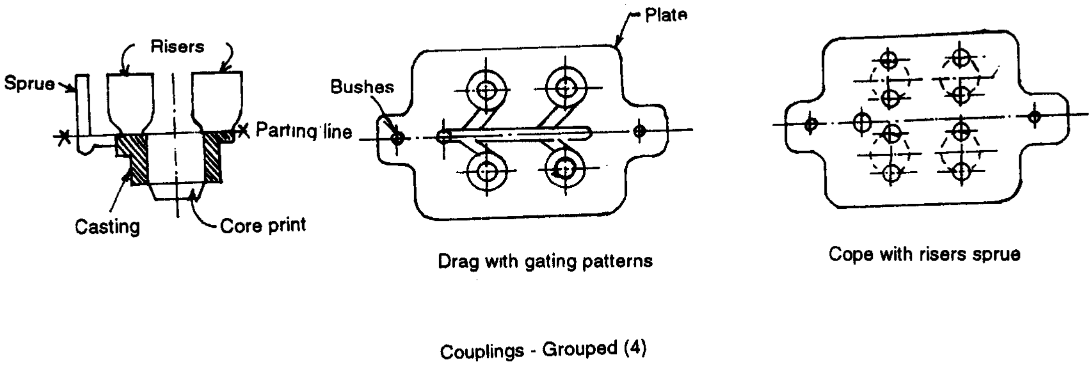


Fig.2.8 Plated/mounted patterns

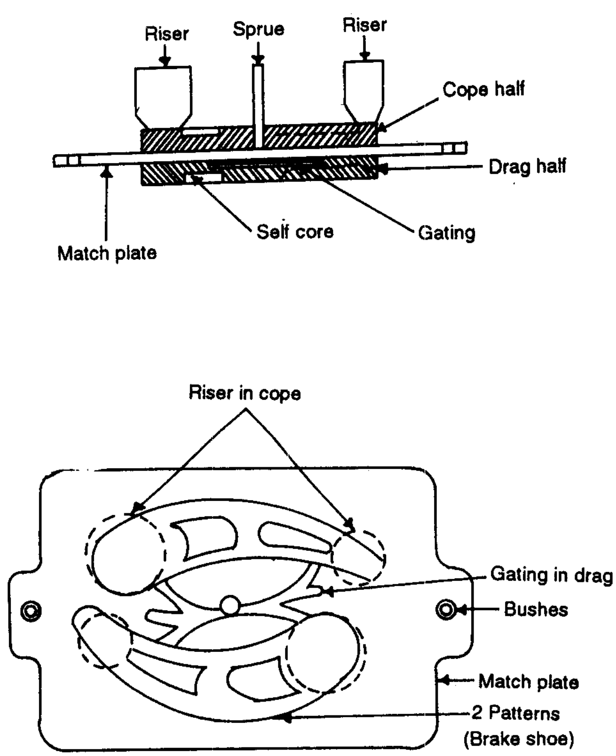


Fig.2.9 Match plate pattern (Drag parts fixed on same pattern-plate)

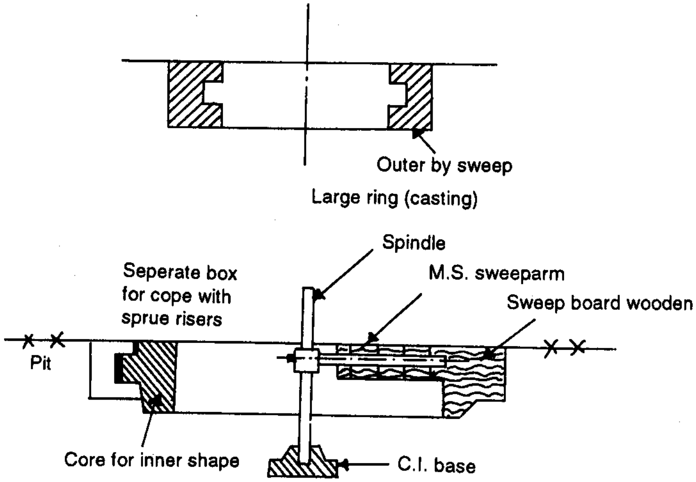


Fig. 2.10 Sweep/pattern molding system

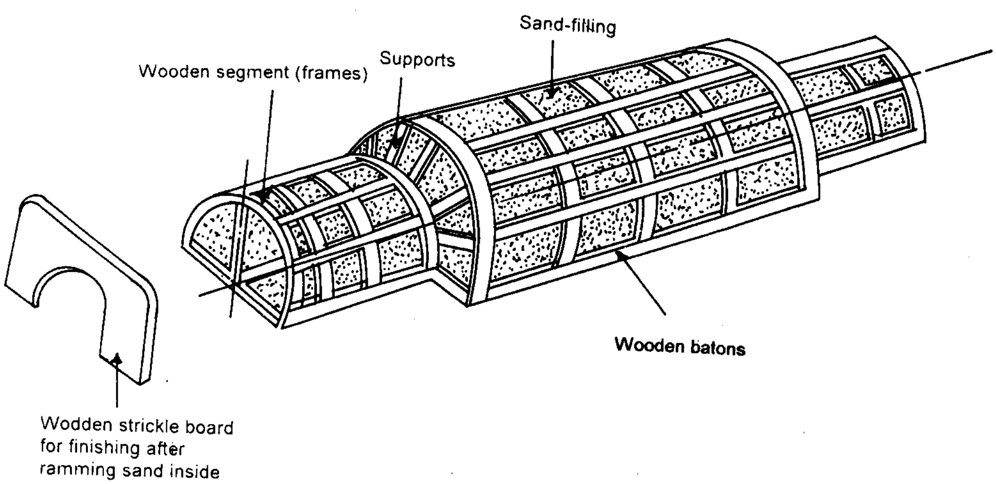


Fig. 2.11 Skeleton pattern (Half)

e. Skeleton pattern

When very large odd-shaped castings of only one or two quantity are to be made, a full pattern will be very costly and time consuming. To reduce pattern-cost, only a frame with supporting rib-sand flanges without covering the outer surfaces by wooden boards or planks is made. This skeleton-like pattern is then filled with strong molding sand-mix, finished properly by sticking to dimensions, given a good smooth coating and parting-sand to be made use of as a normal pattern for molding. Skill and careful handling are needed in using skeleton pattern, its main advantage being the saving on pattern-cost.
(See Fig. 2.11)

f. Forming mold by core-assembly

Molds of very large castings like slag pots, planing machine bodies, large housings etc., are made in pit molding without the use of conventional patterns. The mold is built up through external and internal cores using only a reference frame for bottom-core prints location in the specially made pit and templates. Even the (top) cope mold is made by using separate cores containing risers, sprue and gating called as cover-cores, assembled and fixed in a suitable position. This method effectively reduces the high cost of pattern and simplifies handling by separate smaller cores being assembled. This however requires highly skilled and experienced core-makers and core-setters.

iv. Other Pattern Equipment

Core-boxes

For making 'cores', separate core-boxes in wood or metal are needed. The design and construction of core-box depends upon the size, intricacy and quantity of cores to be produced from each box. Core-boxes for large quantities and machine-core making are made in metal. Wooden core-boxes are properly finished and painted to indicate core-print areas etc. They are provided with proper dowels and locking system of the halves rigidly, for hard ramming.

Templates, gauges

To prepare and check intricate and critical areas in molds/cores, special templates and gauges are made and supplied as a part of the pattern equipment. core-setting gauges help in properly setting and checking complicated cores during assembly in mold and closing. For mass production of castings, casting checking gauges and fixtures for inspection, special risers, gating and running system also form part of the pattern equipment.

v. Materials for pattern equipment

The basic requirements for pattern materials are

a. Easy availability
b. Easy manufacture/working
c. Dimensional accuracy attainable
d. Dimensional stabiity/rigidity during use over a period of time (working in moist molding sand)

e. Retention of surface finish against hard ramming of abrasive silica sand
f. Overall economy

vi. Pattern materials

The common pattern materials are
a) Wood b) Metals c) Plastics d) Polystyrene

a. Wood

The following advantages make wood the most common pattern material. Easy availability, economy and speed of making patterns easy working and handling due to lightness in molding, reasonable rigidity and surface finish by painting.

The disadvantage with wood as pattern material is mainly that it absorbs moisture from molding sand/atmosphere, (unless properly seasoned), causing distortion, warpages and dimensional changes later. Surface finish gets damaged in the long run causing poor quality molds. So, for large number of molds (above 1000) and for small/medium sizes of castings of high quality and intricacy, wood is not preferred. Due to depletion of forests, good hard wood has become quite costly now.

Types of wood for patterns:

Hard wood:

The best quality of pattern wood is obtained from teak and Mahogony which are hard, strong, durable and can be finished to a very smooth surface. For larger patterns and medium quantity (upto 100 pcs) these are the ideal choice.

Softer wood:

Deodar, pine, sal etc., are softer and cheaper than teak, easily workable but have less life and dimensional stability. For fewer quantity and less critical castings these are economical.

Seasoning of wood:

Wood is composed of large numbers of tubular cells. The cell walls of a fibre are held together by organic material. In green condition, the cell cavities and cell walls are full of moisture. In old and dry wood, the cell cavities are empty but cell walls contain upto 30% moisture. The variation in outside atmosphere due to seasonal changes causes changes in this moisture content, if it is below a certain range, it results in distortions/warpages. By natural seasoning over long periods or by artificial seasoning for about a week, during which the timber is subjected to hot, moist air in a controlled manner in special heating ovens, the internal moisture of wood can be adjusted to optimum value. This results in dimensional stability, resistance to fungus, higher strength and better working.

b. Metals and Alloys

For larger quantities of molds, better accuracy, finish and higher pressures in ramming as in machine molding, metal patterns are recommended even though costlier than wood. For special molding processes like shell molding, hot-box etc., where patterns have to be heated above 200°C during molding, metal pattern equipment is an automatic choice.

The metals commonly used for patterns are cast irons, aluminum and copper alloys, depending upon the quality requirements and quantity of molds to be produced. Cast irons are the cheapest, easy to machine and wear resistant. So they are used for larger sizes and longer production runs. The high specific gravity causing handling problems, low impact strength and low repairability are its disadvantages. Aluminium alloys are light and easy to work, but are less wear-resistant and so ideal for smaller production ranges. They are suitable for pattern-plates, risers etc. For highly critical castings in medium to large production range where patterns have to be heated, brass and bronze are the ideal choice, even though the costliest of the three.

c. Plastics

Different types of plastics like Epoxy resins which are chemically hardened as well as Polyester resins are used for making patterns. Plastic patterns combine the advantage of wood-like lightness, easy machinability and economy with the wear-resistance and dimensional stability of metals. Plastic patterns can be reinforced with fibreglass lamination or even metallic strips. For economy, we can have cheaper wooden inserts. Sometimes plastics are used as a wear-resistant coating on wooden pattern. Even though quite costly at present in India compared to other developed countries, more use of plastics in pattern equipment is predicted.

d. Polystyrene

'Polystyrene' or expanded 'Thermocole' is another pattern material which has the special property that gasifies on heating. For single quantity castings like prototypes, it is very easy to make a pattern is not taken out but either burnt off or metal is poured through gating directly into the mold without removing the pattern. As the polystyrene gasifies leaving negligible residue the casting formed is sound. These patterns are used also in special molding process called 'full-mold process', where no hard ramming of mold material is done and the pattern is not removed from the mold for pouring.

vii. Design of patterns

Proper design and construction of pattern equipment is an essential stage in the process of manufacture of any casting to quality standards and minimum cost.

Pattern lay out

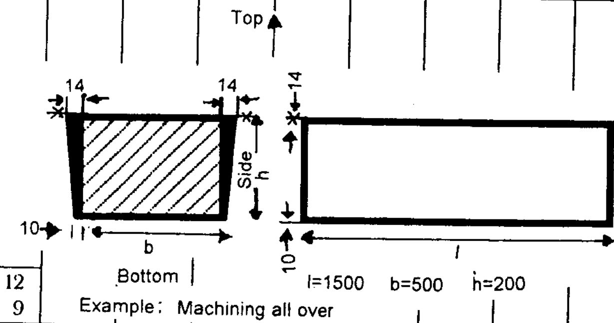
A pattern lay out is first made from the given casting drawing of the final machined component. Pattern lay out is drawn to full scale (1:1) on a plywood sheet or thick card board, selecting sufficient views needed to cover the entire object. The various allowances are then added in the different views.

a. Contraction (Shrinkage) allowance

Liquid metal which fills the mold-cavity entirely when poured, normally shrinks or contracts on solidification, reducing dimensions. To compensate for

Table 2.3 Machining Allowances (Steel Castings)

Dimension of casting in mm.	Position of casting surface while pouring	Width of the casting (Second higher dimension) in mm.														
		Upto 100	100-200	200-300	300-400	400-500	600-800	800-1000	1000-1250	1250-1500	1500-1800	1800-2300	2300-2800	2800-3500	3500-5000	Above 5000
Upto 200	Top side.	7 5	7 6													
201 to 300	-do-	7 5	8 6	9 6												
301 to 400	-do-	8 6	8 7	9 7	10 7											
401 to 500	-do-	8 7	9 8	10 8	11 8	11 8										
501 to 600	-do-	9 7	10 8	10 8	11 8	11 8	11 8									
601 to 800	-do-	9 8	10 8	11 8	12 8	12 8	12 8	12 9								
801 to 1000	-do-	10 8	11 8	12 8	12 8	13 9	13 9	13 9	13 10							
1001 to 1250	-do-	11 8	12 9	13 9	13 9	14 9	14 10	15 10	15 10	16 11						
1251 to 1500	-do-	12 9	13 9	13 10	13 10	14 10	15 11	15 11	16 11	16 12	16 12					
1501 to 1800	-do	12 9	13 10	14 10	14 10	15 10	15 11	15 11	16 12	17 12	17 12	18 12				
1801 to 2300	-do-	14 10	14 10	14 11	15 11	16 12	17 12	17 13	18 13	18 13	18 13	19 14	19 14			
2301 to 2800	-do-	15 11	15 12	16 12	17 12	18 13	19 13	19 13	20 14	21 15	22 15	22 15	23 15			
2801 to 3500	-do-			16 12	17 12	18 13	19 13	20 14	20 14	21 14	22 15	22 15	23 16	24 16	25 16	
3501 to 5000	-do-			18 12	19 13	20 13	21 14	22 15	22 15	23 15	24 16	25 17	25 18	25 18	26 18	27 18
Above 5000	-do-			20 13	21 14	22 15	22 16	23 16	23 16	24 17	25 18	25 18	26 18	27 19	28 19	28 20



this, the mold-cavity/pattern should be made correspondingly larger than the final casting dimensions. This additional allowance which is upto 2 percent over the casting dimensions depending on the metal poured, is incorporated in the pattern lay out in all dimensions.

Generally, pattern-makers use special measuring scales called 'contraction scales' which incorporate the contraction allowance directly in linear measurements while taking any dimension. For example, if the contraction scale for cast-iron casting measures 100 mm, it is actually 101 mm on standard scale, thereby incorporating an additional 1 percent in every dimension of the pattern made. common contraction allowances are approximately 1.0 percent for cast-iron, 1.5 percent for aluminium and brass, 2.0 percent for cast-steel, measured linearly.

b. Machining allowance

For fitting in assembly, the final casting needs to be machined on many external/internal faces. Accordingly, additional material has to be provided on all such faces requiring machining later, on the rough casting and so on the pattern. The amount of machining allowance depends on the size of the casting, the quality requirements and the nature of the casting metal. common machining allowances are indicated in Table 2.3.

c. Draft or taper

To facilitate easy withdrawals of pattern from the rammed mold, normally the vertical contact faces on the pattern are given a small taper or draft. The amount of draft depends upon the depth of the pattern which has to be drawn, the material and finish of pattern, and should be minimum to keep the casting dimensions closer to the final drawing sizes. Deeper patterns (500 mm) may have drafts even upto 8 mm. Draft is some times given as inclination in degrees (1 to 2) from the vertical faces. For deeper faces, it may be given for half height positive and other half, negative.

d. Camber warpage or distortion allowance

In long, thin, curved castings, the contraction stresses may cause certain dimensional changes which distort or deshape the overall configuration, during solidification in mold. In the production of such intricate castings, certain changes in dimensions are incorporated on the pattern from experience to compensate for the expected distortions and bring the casting to the shape nearest to the drawing shape. They are normally finalised by trial and error.

e. Core prints

Whenever a core is to be used to form the internal shape of a casting, it is necessary to provide proper location and support for the core in the mold. core prints are the projections provided on the pattern for that purpose. They are given vertically or horizantally, depending on the position of the core and molding convenience. Larger taper is given on core prints than as patterns for easy core-setting and molding. Fig. 2.16.

S. No.	Dia. or Max. thickness of core (D) mm	Size of core-print (P) mm
1	upto 10	15
2	11 - 19	20
3	20 - 30	25
4	31 - 50	30
5	51 - 80	40
6	81 - 120	50
7	121 - 180	60
8	181 - 250	70
9	251 - 350	80
10	351 - 500	90

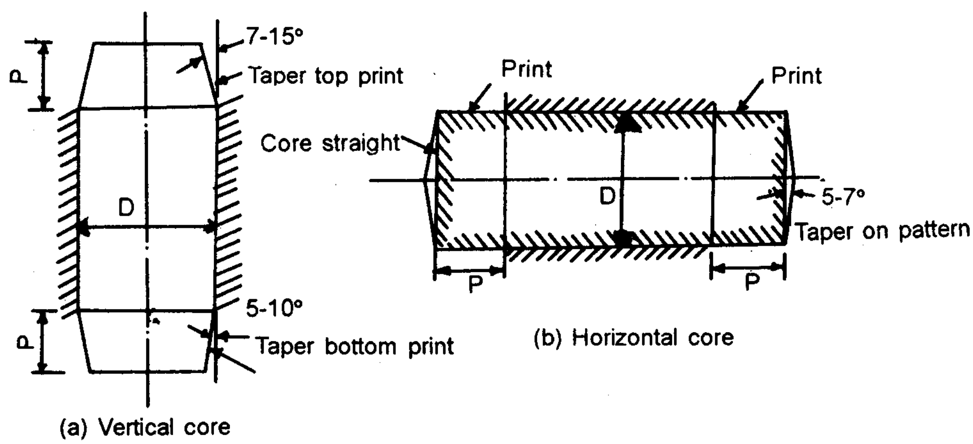


Fig. 2.16 Design of core prints

f. Parting line

The lay out also clearly shows the parting line used while molding the pattern that separates the cope (top) and drag (bottom) mold-halves, even when the pattern is not split. Pattern drafts are given according to the parting line. Generally, maximum possible part of the pattern should be taken in the bottom box (drag) to reduce metallostatic pressure on the cope. As the tendency for defects like sand-inclusions, blow-holes and shrinkage is to rise to the top faces, critical faces of casting (normally machined) are taken to the bottom, leaving non-critical faces to the top, while molding.

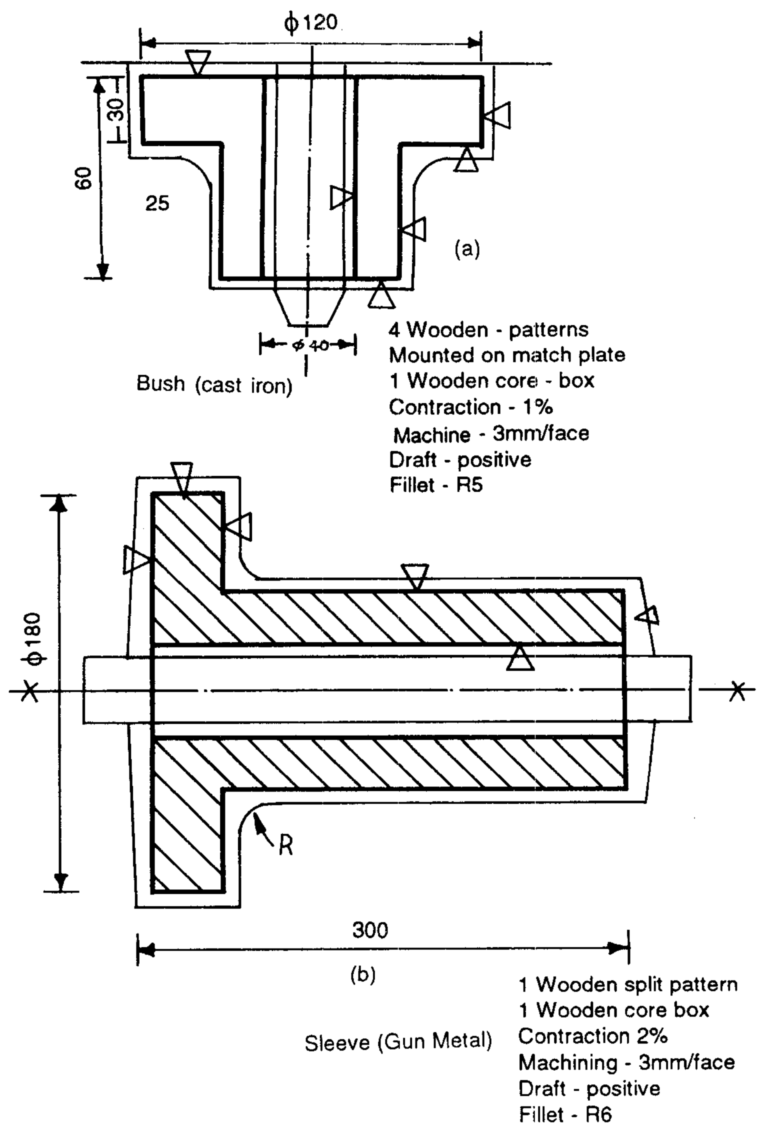


Fig.2.13 Pattern designs a, b

Examples of pattern allowances, design for lay out are given in (Fig 2.13, 2.14 and 2.15).

viii. Pattern construction

Once the lay out of pattern is complete with detailed dimensions and views of pattern and core-boxes, it is advisable to make a separate sketch indicating the construction details. Unless a pattern is very simple and small, it is never made out of a single piece of wood. A number of wooden pieces, either planks, batons or

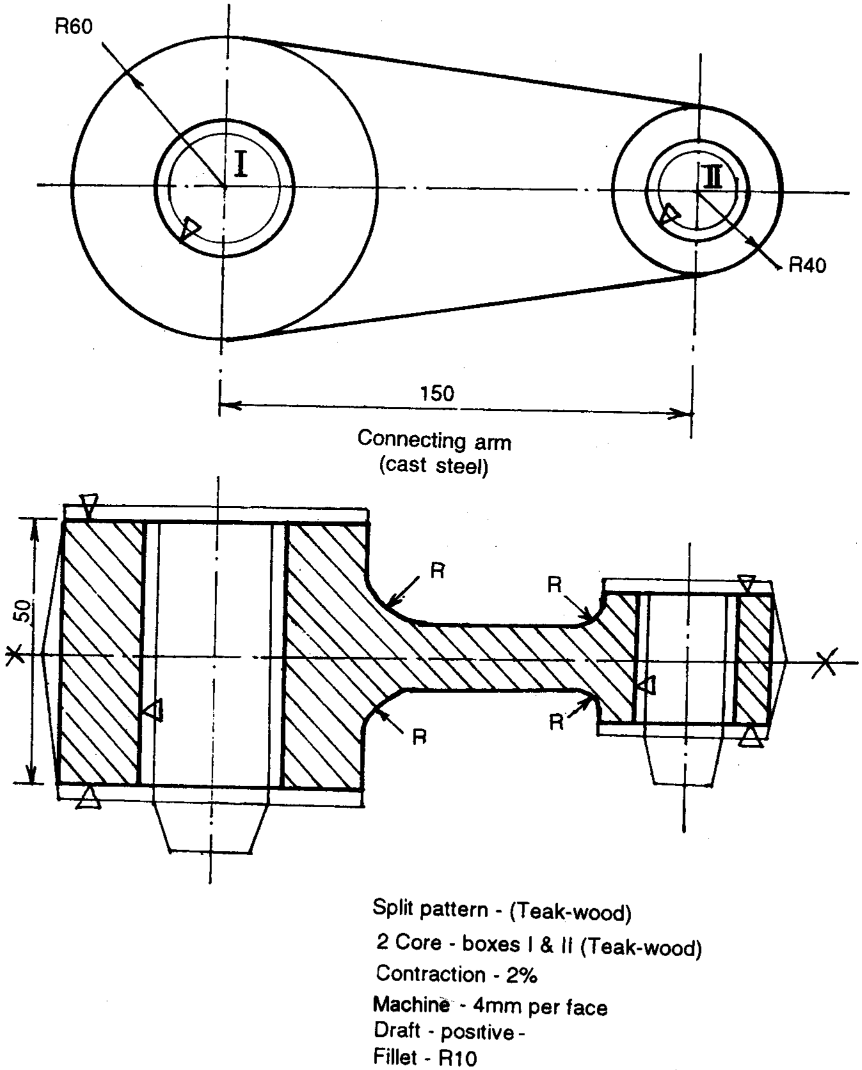


Fig.2.14 Pattern designs

sections of wood are jointed together, glued or screwed to form the full pattern. This helps in preventing warpage and gives strength as well as economy. For large patterns, a base frame is first constructed using heavier sections with good joints. Over this frame, wooden batons are fixed forming the outer surface. While joining, the directions of grains in wood are considered. The pattern designer decides the size, thickness of joining members, types of joining of different pieces and method

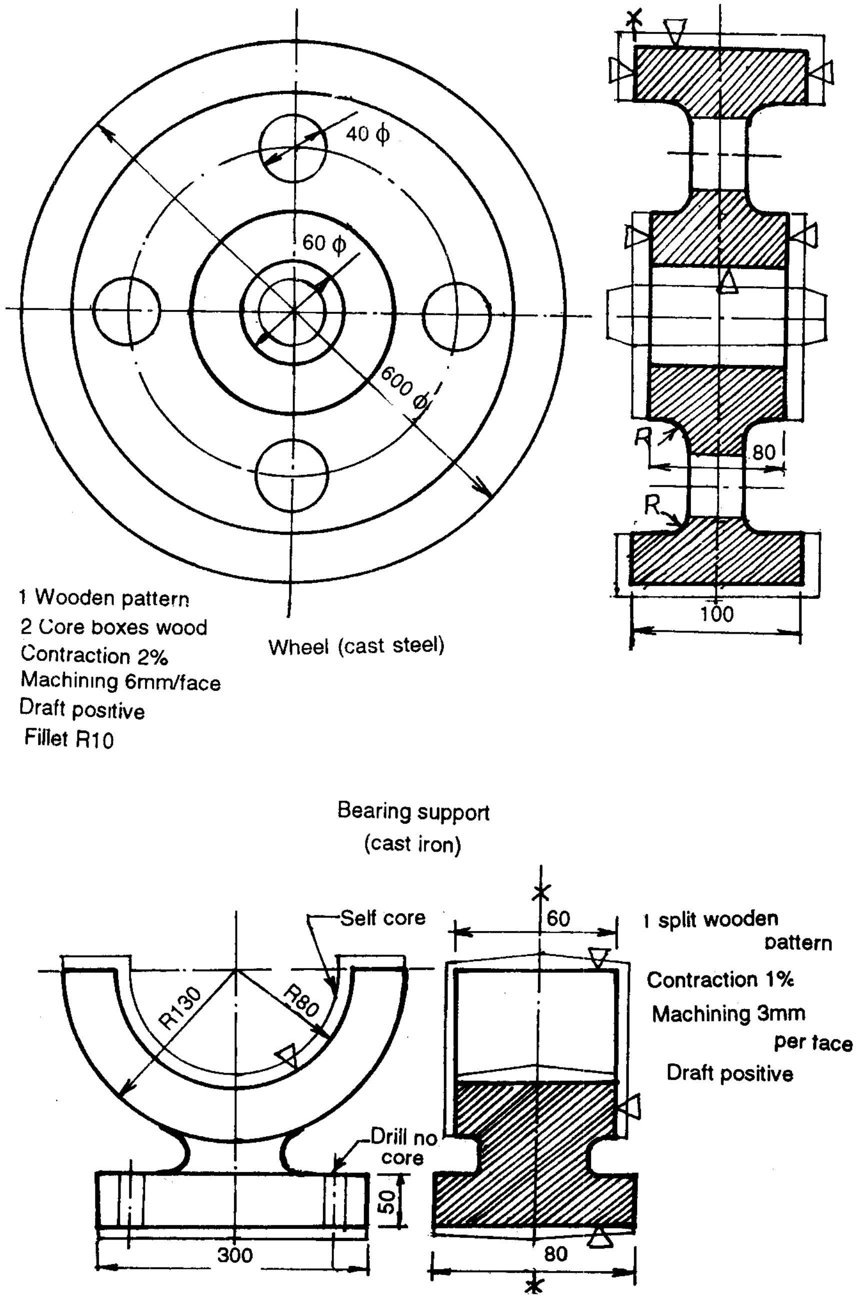


Fig. 2.15 Pattern designs

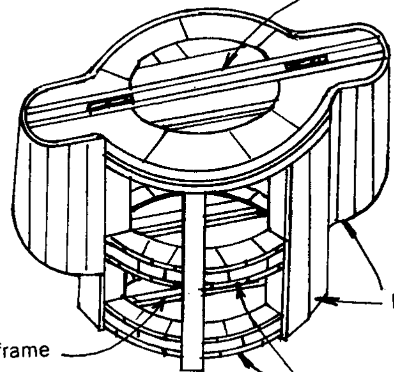


Fig. 2.12 Framed construction of pattern (Cut-view)

of finishing to final size, all being indicated by a proper sketch or drawing with bill of materials.(Fig 2.12)

From the details of pattern lay out and construction design sketches, the actual pattern is constructed. Properly seasoned and defect-free timber should be selected for the main frames and joined as per instructions. The individual pieces may be finished by machines or by hand as per the quality and cost. 'Loose pieces' are loose projections on the main body of the pattern, made for the convenience of molding casting projections, above or below parting line. During ramming, loose pieces remain in the mold and are withdrawn after the main pattern is taken out. 'Stop-offs' are reinforcing members used to strengthen thin and intricate patterns to avoid breakage during molding. The gaps where such stiffeners are used should be filled with molding sand and finished properly to prevent liquid metal to enter and form extra projections on the final casting. Once the body is built, it is finished mostly by manual methods, using suitable templates/gauges for curved profiles, to the final lay out dimensions. The surface of the pattern needs to be finished to a high degree of smoothness by sandpaper and putty, smooth and non-wetting surface.

Pattern colouring

Patterns are given glossy, wear-resistant paint not only for ease of molding but also to provide useful information regarding the casting to molders. Information like the metal that is going to be cast later into the mold, critical areas of casting like machined portions which have to be taken special care during molding, core-prints which should be given provision for vents and fixing of cores as well as stop-offs are all indicated through proper colour code.

ix. Pattern life

The life of a pattern is the number of good molds that can be made using a pattern without major repairs. Table 2.4 gives an indication of the life of pattern in relation to its design, material and the molding process used.

Table 2.4 Average life of patterns in terms of molds that can be produced per pattern: (Depending on the pattern material, type and Molding method)

Sl. No.	Pattern Material	Pattern construction / Type	Molding Method	Number of Molds/Pattern
1.	Soft Wood	(A) Loose / Single piece	Hand Molding	upto 20
		(B) Mounted / Plated Pattern	Hand Molding	upto 50
2.	Hard Wood	(A) Loose/Single piece	Hand Molding	upto 50
		(B) Mounted / Plated Pattern	Hand Molding	upto 200
		(C) Mounted / Plated Pattern	Machine Molding	upto 500
3.	Aluminium or Epoxy Resin (Plastic)	(A) Mounted / Plated Pattern	Hand Molding	upto 2000
		(B) Mounted / Plated Pattern	Machine Molding	upto 5000
4.	Cast Iron / Bronze	(A) Mounted / Plated pattern	Hand Molding	upto 6000
		(B) Mounted / Plated Pattern	Machine Molding	upto 20,000

x. Cores

Types and procedure for core-making

Using pattern, mold is made in two halves, the cope and the drag. After withdrawl of the pattern, external features of the casting form in the mold. To form the internal shape of the casting, cores are used. A core is rammed in a specially made core-box using core-sand mixture.

Depending on the location, a core can be classified as a) horizantal, b) vertical or c) cover core. (Fig. 2.17) Core can be used to simplify molding external projections on casting. Fig. 2.18

While making cores, depending upon the size, it is necessary to provide steel or cast iron reinforcements inside to prevent breakage during handling and liquid metal pressure while filling. These metal inserts are called "core-irons" or "gaggers". Venting of a core is more critical than mold as liquid metal surrounds core during pouring, generating gases. Proper drying or baking to reduce gases and give strength is important.

xi. Closing

The following operations are involved in mold-closing:

a. Proper checking of the mold cavity for quality and dimensions

b. Positioning of cores in proper location guided by core-prints

c. Fixing the cores to avoid shift during pouring

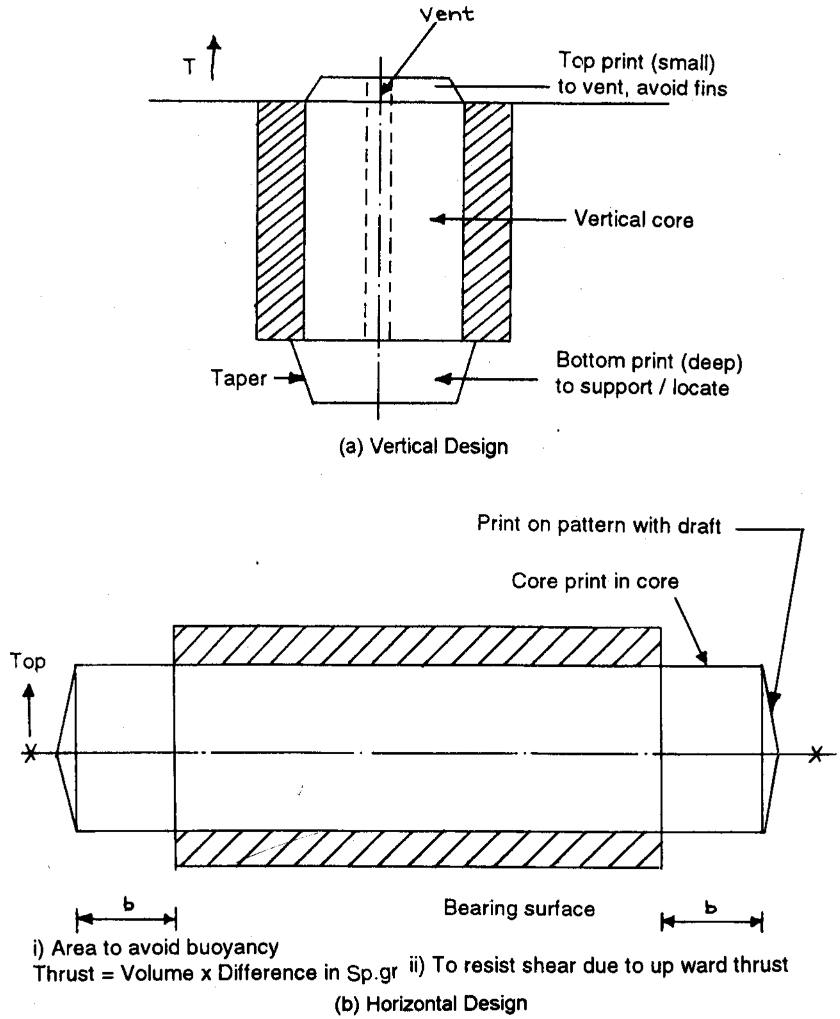
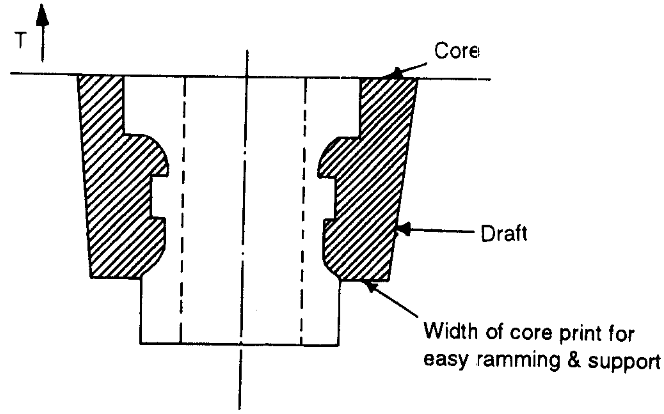
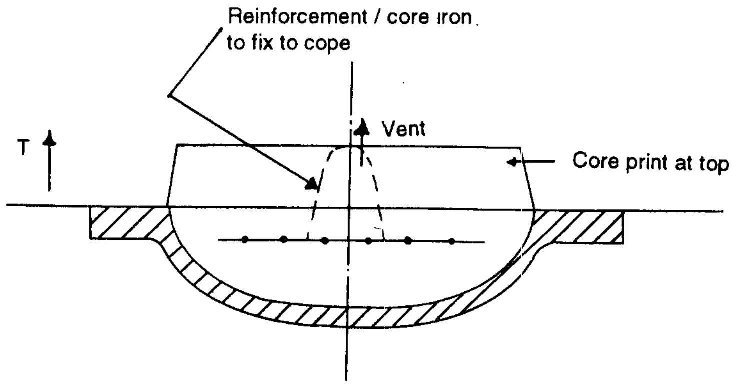


Fig. 2.17 Types of cores a, b

d. Inspection of critical wall-thicknesses, gating system
e. Checking proper matching of cope with drag
f. Connecting vents of core and mold
g. Checking gaps and sealing the parting face between cope and drag
h. Cleaning any loose sand in mold / sprue
i. Fixing pouring basin on sprue
j. Clamping the mold-halves or keeping weights to avoid leakage of liquid metal from parting plane due to cope-lift.



(c) External core (To simplify molding avoiding under cut/loose piece)



(d) Cover core

Fig. 2.18 Types of cores c, d

2.7 Sand molding processes

Sand molding processes are classified by the type of binder system in the molding sand and the method of hardening the mold.

i. Green sand molding

This is the most common molding process used for over 60 percent of total casting production. The molding sand containing bentonite, water and additives is rammed into the boxes and the molds are poured immediately (within 6 hours) after making green condition without the moisture drying. The sand is reusable and is the cheapest.

ii. Dry sand molding

The disadvantages of green sand molding for heavy and complicated castings like defects due to blow-holes, sand-inclusions etc., caused by moisture and low sand strength are eliminated in dry sand molding. In this, the molds containing higher moisture and clay initially, are dried thoroughly before pouring liquid metal. Due to the cost and time involved in drying, its used is limited.

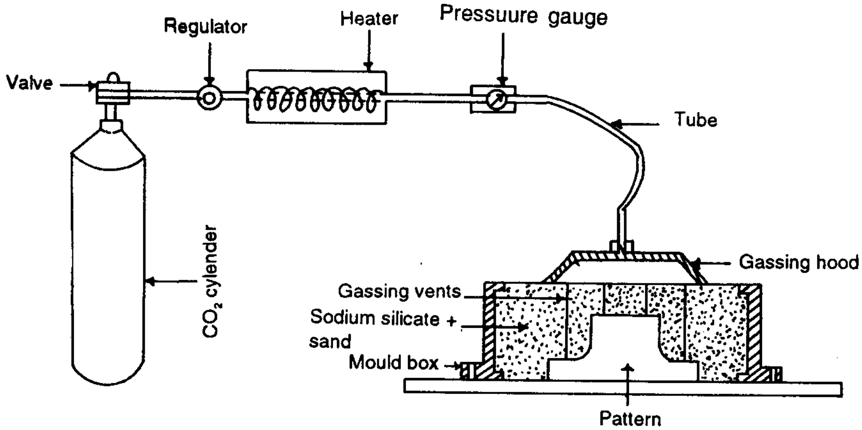


Fig. 2.19 Arrangement for gassing CO_2 process mold

iii. Chemical hardening using Sodium silicate and CO_2 gas

Clay-free sand mixed with sodium silicate is used for making heavy molds. The molds are hardened by passing CO_2 gas, making them extremely hard to resist the action of liquid metal. This is a cheap and fast process extensively used for molds and cores. Special additives to increase collapsibility improve its application. (Fig.2.19)

iv. Loam sand

This is a thick pasty mixture made from silica sand with high percentage of clay (including fire-clay) and water. This mix is packed and strickled with a metallic edge to form smooth surface. After the mold is made, it is dried well with burners and coated with mold-wash. Its use is limited to sweep molding of circular shapes in few quantities, as skill is needed.

v. Resin sands

Chemicals based on Urea and Phenol Formaldehydes are used as binders in molding sand. They have the advantages of dimensional accuracy, collapsibility and good surface finish even though they are costlier.

Air-set at cold-set sands use additional chemicals to oxidize and harden the mold at controlled rate without heating. They are ideal for medium size intricate castings even though the costliest. Thermosetting resins/chemical binders need heating to harden. Hot-box and shell molding processes use these cheaper resins but need costly metallic pattern/core-box equipment and heating devices. For small and medium intricate molds/cores these are used.

vi. Shell molding process

a. Sand mixture

The base sand is dry silica sand of 120-150 AFS fineness mixed with 1.5 to 5.5 percent thermosetting resin like phenol formaldchyde, Urea formaldehyde, alkyde or polyester. 10 to 15 percent hexamine is added to increase the hot tensile strength. Wax or release agent is added to increase the flowability of finished coated sand. Zircon, olivine or chromite can be used as base sands for higher strength and refractoriness but are very costly.

b. Pattern

Metal patterns, mounted on a metal plate with gating, risering and heating elements to heat pattern to about 150-200°C are provided underneath. Ejecting arrangements for the shell formed to strip clearly and uniformly without breakages is made by pins and guiding holes. A dump box is provided to place the sand mixture, and a tilting system with a timer is available to drop the sand-mixture on the heated pattern and 'dwell' or keep for a predetermined time cycle. Normally about 10 seconds are enough to form a shell of about 8-10 mm thickness. The hot pattern plate is given a spray of silicon parting solution for easy ejection of the shell. The dump box is brought back from its inverted position to original position after the 'dwell' period automatically.

c. Curing

The ejected shells are cured in an oven at 300-320°C for a few minutes for developing required strength and bench-life.

d. Pouring

The cured shells are clamped/glued together and often given backing with dry sand, gravel or metal shots to prevent cracking/distortion during pouring.(Fig 2.20 Examples or shells, castings)

e. Advantages

- Exceptionally good surface finish (less than 35 microns).
- Close dimensional tolerances (upto + 0.3 mm in 1200 mm).
- Extremely thin section can be cast.
- High production rates.
- Molds can be stored for a very long time.
- Requires only five percent of molding sand, saving on handling cost.
- Further machining, fetting and finishing cost are reduced or eliminated.
- No sand-based defects due to hard shell.
- No problem of blow-holes due to high permeability of thin backed shell (6 to 10mm).
- Even precision molds can be produced by unskilled workers.

f. Disadvantages

Disadvantages are high cost of pattern equipment, resins and small size of castings.

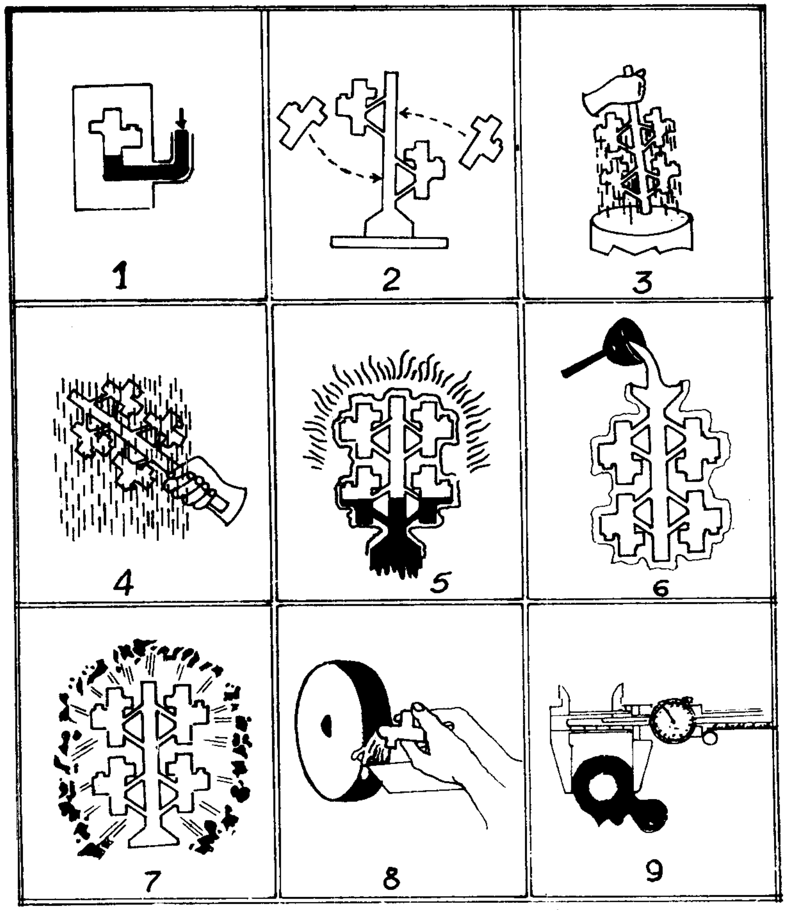
vii. Investment / Precision casting

This process involves use of special materials like wax for making patterns, which do not need conventional removal from mold. The mold is made around patterns by investing or applying coats of a refractory slurry having silica or zircon powder and ethyl silicate binder. It is preheated at 60° C to remove the wax pattern by melting out or dewaxing. The mold is cured at a high temperature of around 350° C, being a ceramic, it develops high strength. It is ideal for very small (less than 1 Kg) highly intricate castings avoiding costly machining operations. It is limited to tiny castings in special alloys in large quantities.

Fig. 2.20 Shell molding process

The details of the above processes including principles applications advantages and limitations are given in a tabular form for easy (Table 2.5) comparison in pages 58c and 58d. The corresponding sketches of the processes are given in Fig. 2.21

There are many other special molding processes for exclusive uses. Some of them like vaccuum hardening, expendable pattern, magnetic hardening, electro-slag technique are described in the chapter 10 under new materials and processes.



1. Wax injection into die to make pattern
2. Wax patterns attached to wad sprue
3. Coating of ceramic slurry
4. Sprinkling refractory material
5. Dewaxing by heating
6. Pouring mould
7. Casting knocking out
8. Grinding
9. Inspection

Fig. 2.21 Precision investment casting process

2.8 Practical aspects of molding

i. Economy

To achieve economy and higher productivity in molding, the following techniques are adopted:

a. Grouping of castings

Whether the patterns are single piece/loose or split, it is economical to group more than one pattern in a mold-box whenever space is available. Due

Table 2.5 Molding Processes Comparison

Sl. No.	Molding Process	Principle / Ingredients, Patterns and Equipment	Casting size / Alloy Range	Applications	Advantages	Limitations
1.	Green Sand	In silica (SiO_2) sand, bentonite (3 - 5%), water (3 - 5%) and additives (coal dust, dextrin) are mixed. Used in mixed condition readily. Normally wooden patterns used for hand molding of large sizes and metal/mounted patterns for machine molding of smaller sizes. Natural sands can be used for finer grain size.	Generally upto 1000 Kg (light / medim). Any metal alloy.	Most common process accounting nearly (70%) casting production of commercial use. Suitable for few pieces as well as mass production. Av. Tolerances: ±1.0 mm / 100 mm Av. Surface finish : 6-20 μm	Cheapest & most economical, very fast. Low investment as patterns & other equipment sand reusable.	Difficulty to get high quality due to sand defects like inclusions, gas defects like blow-holes etc., not suitable for critical/intricate/large castings. Low mold-strength.
2.	Dry Sand	In silica (SiO_2) sand, bentonite, fire clay (4 - 8%) water (5 - 8%), additives (graphite) are mixed. After maing he molds, they should be dried/baked at above 150° C for several hours in heating ovens. Special mold coat/paint needed. Wooden patterns and natural sands can be used, with larger grain size.	Only for heavy castings above 1000 Kg. Any metal / alloy.	Used mainly for large and critical castings like turbine casings, mill housings. Av. Tolerance : ±1.5 mm/100 mm Av. Surface finish : 10-30 μm	Long bench life of sand, high mold - strength free from sand/gas based defects. Good collapsibility. Sand reusable	Costly due to need of baking of molds. More process time needs hard ramming, poor finish (3 to 5 times of green sand).
3.	CO_2 -Sodium Silicate Sand	In clay-free silica (SiO_2) is mixed with liquid sodium silicate (3 - 4%). After making molds, CO_2 gas is passed through fine holes into the mold for chemical-setting. Metal/ wooden patterns with special paint, CO_2 gas cylinders and gassing tackles needed.	For medium to heavy castings above 200 Kg Any metal / alloy	As a replacement of dry-sand for critical and large castings. Av. Tolerence: ±1.5 mm/100 mm Av. Surface finish: 10-30 μm	Cheaper than dry-sand. Faster, no need of baking. Very high mold-strength. Does not need hard ramming, used also for Core making.	Poor collapsibility, high finishing/ fettling cost. Poor surface finish. Sand not reusable. Low bench life of mixed sand.

Sl. No.	Molding Process	Principle / Ingredients, Patterns and Equipment	Casting size / Alloy Range	Applications	Advantages	Limitations
4.	Resin Sand (Air-Set)	In clay-free silica (SiO) fine sand, furan resin (upto 2%) , oxidizing /setting chemicals (upto 0.5%) added to control setting time and bench life. Metal/Wooden/Polysterence patterns. No heating needed to harden, Air-setting.	For medium size casting (100 kg to 1000 kg.) any metal/alloy	For very critical & intricate castings like cylinder blocks, machine tool bodies, fully machine castings Av. Tolerence: ±0.5 mm/100 mm Av. Surface finish : 3-10 μm	Control of mold setting time. Close dimensional / surface finish /reduces machining cost. High mold strength. Good collapsibility. Does not need hard ramming. Can be machanised. Used aslo core making.	Resins are very costly (6 to 12 times cost of green sand) Some resins cause pin-hole defects. Sand not reusable
5.	Shell Molding (Hot-Box)	In clay-free fine silica (SiO_2) sand U.F./P.F. resin (upto 4%) is mixed. Mixed sand is dumped on heated metal pattern (200°C) to form a cake/shell about 5 - 12 mm thick in a few seconds. Excess sand dumped out, shell ejected and cured (350°C) upto 1/2 hour for good strength and bench life. Metal patterns with heaters / special mixing and dumpir.g equipment needed.	Small / medium castings upto 100 kg. Any metal / alloy	For highly intricate light castings of automobiles, machine tools, textile m/c, electric motors, Reduced machining, gears, impellers. Av. Tolerance: ± 0.5 mm/100 mm Av. Surface finish : 2 - 6 μm	Suitable for mass production (above 5000 pcs) of light castings as per pattern. High accuracy and finish No gas-enterapment as shell is thin, high permeability. No ramming needed. Easy to finish. Used for core making also. Good bench-life of shells.	Costly pattern eqipment and sand mix. Not suitable for few/large castings. Special care needed in pouring due to weak shells.
6.	Investment (Precision/ Lost-Wax) Casting	Wax patterns are 'invested' giving a thick coating with refractory ethyl silicate and other additives made into a thick slurry. The shells are heated to remove wax and form molds. The molds are further heated to above 500°C for strength and bench-life; assembled in form of trees around a sprue with runners, risers etc. Metal core-boxes for injectiing wax for patterns, special refractory liquids, mixing plants, dewaxing and curing equipments are needed.	Very small precision casting upto 5.0 Kg. Any metal/alloy, normally high alloy steels	For highly accurate, intricate, tiny components for watches, sewing machines, armament electronic & medical equipment, turbine blades etc. Av. Tolerance: ±0.10 mm/100 mm Av.Surface finish: 1 - 4 μm	For very small, mass production items, difficult to make by any other process. Avoids costly machining, high surface finish & close dimensional accuracy. Specially suited for costly high alloys only for 10,000 pcs & above per item. Very high casting quality as no blow-holes/sand-based defects.	Very costly. Not suitable for large sizes or for small quantities.

consideration should be taken while grouping for compatability of wall thickness, shape and quantity required to be cast. Normally, mounting split pattern on a match plate for small quantities increases pattern cost, but grouping more than one pattern on a match plate compensates the cost. The improvement in productivity of a plated pattern can be taken advantage of by this process. By combining many castings on a simple plate in a box saves the cost of sprues, runners and gating system, improving the 'yield' or utilization of liquid metal per casting. Normally in all foundries certain sizes of molding boxes are standardized and used. In such cases odd-sized patterns either for hand molding or machine molding can be grouped in a suitable available mold box giving better casting weight per mold, reducing over heads. (Fig 2.8)

b. Stack molding

For certain small, simple shaped castings like links, liners, grinding media, it is normal to have the mold assembled with more than one cope and drag, stacked vertically. A common sprue running through layers of molds helps in filling them. By this the number of filling/pouring operations are reduced saving pouring time, temperature and effort. It also improves the yield for small castings. Careful closing and sealing of boxes in the stack is essential to prevent the run-out of liquid metals at parting faces. Proper clamping of boxes and keeping weights at the top is important. Sometimes, mold-cakes made by CO_2-sodium silicate process (like cores) are stacked directly without using mold boxes, saving cost, for small castings. (Fig 2.22)

c. Boxless molding

For mass production of small casting in green sand, CO_2 or resin sand, high pressure molding machine produce molds which do not need boxes. Sometimes, simple mild steel plate jackets are slipped while pouring to prevent leakage. Boxless molding improves productivitiy, saves cost of molding boxes and their maintenance.

ii. Precautions during closing to avoid defects

a. While assembling cores in the mold, it is necessary to check the position of the vent in each core and connect it to the mold vent so that core gases can escape through the mold. Wax-ropes in core and fine grooves in parting faces of the mold should be properly connected.

b. To get proper wall thickness for inner/outer walls while using cores, chaplets of specific sizes can be used. They should be clean, rust-free and made of perforated plate to fuse properly in liquid metal.

c. Cores which might possibly float, should be secured to cope or drag properly by being tied with a wire to the gaggers or reinforcing bars in box. Even a large core may shift due to the buoyancy of lower specific gravity sand compared to liquid metal, during pouring. (Fig. 2.23)

d. To check any gaps existing between cope and drag faces or too much clearance between core-prints and mold when closed, an initial "top-bottom touching" exercise in done. Any parting powder upto 2 mm thickness can be sprinkled

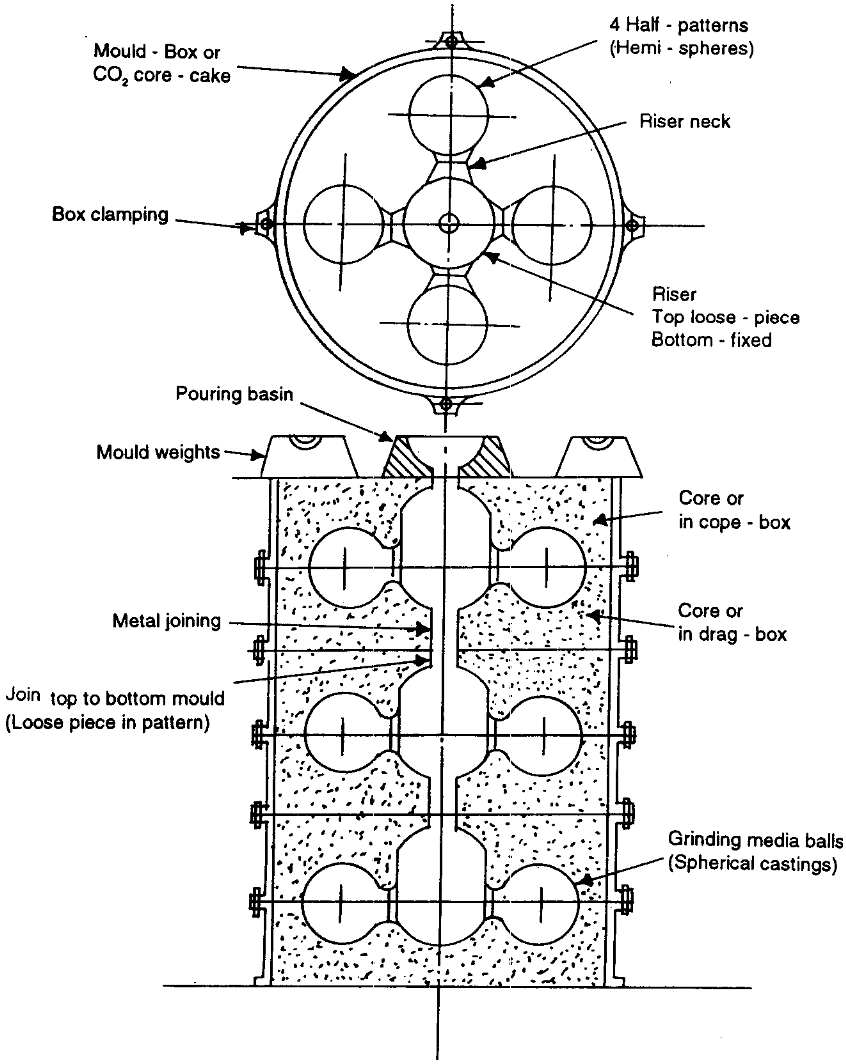


Fig. 2.22 Stack-molding (Grinding media)
(4x3 = 12 Balls per Stack in 6 Boxes/Cakes)

touching faces and checked by opening the mold for uniformity. Repairing may be done if needed before final closing. This will prevent leakages, fins, core-shifts etc.

e. Proper sealing of parting faces of mold while closing is important to prevent run-out/leakages. For small green sand molds, a thin layer of clay all around is sufficient. For large dry sand molds, an asbestos rope of different thicknesses is used alround.

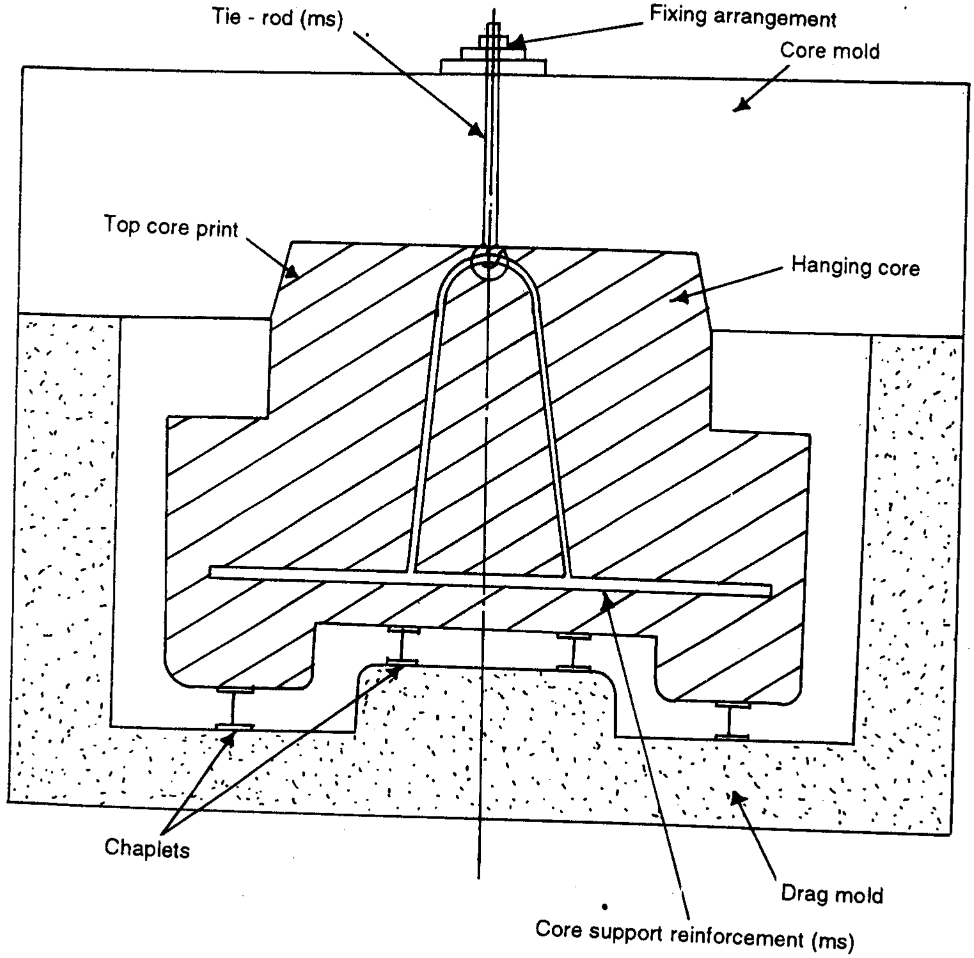


Fig. 2.23 Fixing hanging cores in cope

f. Smaller boxes should be clamped properly with C-clamps or bolts and nuts. For heavier boxes, weights are required to be placed on the cope to prevent lifting of the cope by liquid metal buoyancy. The weight needed depends upon the casting surface area in the cope bearing the upward thrust of liquid metal. The weights should not be placed directly on the sand part of the mold but be supported by external legs.

g. The mold cavity after closing should be thoroughly cleaned of loose sand particles by a vacuum suction pipe. All openings of sprue, risers, flow-offs etc., should be covered with lids/sheets till the time the ladle reaches the mold for pouring. This prevents dust particles in the foundry floor floating into the molds causing sand inclusions in castings.

iii. Mold/core coatings, paints or washes

Refractory powder-bases mold/core coatings are essential when a fairly coarse-grained molding/core sand it used to maintain permeability, simultaneously requiring good casting finish. This coating helps to prevent the physical metal penetration and chemical sand fusion at the mold surface, reducing rejections, fettling/finishing time and cost, considerably. Due to the very thin coating applied, permeability is not affected. For some reactive metals like magnesium, titanium or when the liquid metal chemically has a tendency to interact with the molding medium used (Austenitic maganese steel), coating of molds and cores cannot be avoided for achieving proper casting surface finish.

A good coating has a base refractory powder of 150/200 fineness. It may contain pure silica (SiO_2), graphite (carbon), zircon (ZrO_2), magnesite etc. It has a bonding system of suitable glue/resin to stick to the mold/core. To spread the coating uniformly over the mold/core surface a suitable carrier like water of spirit is used. Finally, it may contain special solvents which dry the coating fast on the surface.

A good coating should be properly proportioned with all the above ingredients and mixed well. It should have good suspension properties and the right rheological properties to give a homogenous, uniform thin coating. It may be applied by a brush, swab or spray using compressed air. It should be fast and easy to apply. Once applied the coating should dry it avoid gases in the mold. Different light-off (burn) or air-dry solvents are mixed in the coatings for this.

A large variety of coatings are available for the specific need of castings, the details of same are given in Table.2.6.

Table 2.6 Selection of a Wash Based on Metal Cast & Sand Binder Used

Binder	Non-ferrous	Iron	Steel	Mn Steel	Preferred carrier
Silicate	Graphite or special fillers	Graphite or Zircon	Zircon	Magnesite	Spirit
Oil sand	,,	,,	,,	,,	Water or spirit
Alkyd	,,	,,	,,	,,	Water or spirit
Shell	,,	,,	,,	,,	Water
Hot box	,,	,,	,,	,,	Water
Cold box	,,	,,	,,	,,	Water or spirit
Cold-set	,,	,,	,,	,,	Water

iv. Solid state shrinkage or contraction in castings

As the casting cools from solidification temperature to room temperature, there is reduction in dimensions (the opposite of thermal expansion). To compensate for this, extra allowance is provided in pattern dimensions. This allowance, given as a percentage of original dimension depends mainly on the metallurgical characteristics of the cast metal and to a lesser extent on the mold rigidity and casting geometry. The following table gives the normal range of pattern contraction allowance for common cast metals / alloys. Within the given range, the exact amount of allowance should be chosen on the basis of the considerations given below.

	Cast metal/alloy	Contraction %
1.	Grey cast iron	0.8 - 1.3
2.	S.G. Iron	1.0 - 1.2
3.	Malleable/White C.I.	1.5 - 1.8
4.	Carbon steel	1.6 - 2.0
5.	Hadfield Mn steel	2.0 - 2.4

Other considerations

a. Heavier castings with thicker walls have higher contraction compared to smaller castings with thinner walls

b. Simple-shaped castings with less risers contract more compared to complicated castings with more risers.

c. Softer molds in green sand contract more compared to rigid dry sand or CO_2 molds as casting cools.

d. Castings without core (free) contract more compared to castings with large/hard internal cores (obstruction).

Examples

Grey cast iron casting with thin walls in resin sand mold	- 1.0%
Grey C.I. heavy lathe bed in dry sand mold	- 1.2 %
Malleable C.I. pipe fittings in green sand	- 1.8 %
Carbon steel large gear wheels in CO_2 molds	- 1.9 %
C.S. die blocks in dry sand molds	- 2.0 %
Austenitic (Hadfield) Mn. steel liner plates	- 2.2 %

2.9. i. Casting defects caused by improper molding core sands

a. Poor surface finish, sand fusion, metal penetration

Basic reason is the improper selection of base-sand used in the sand-mix. Sands with low fineness, coarse grains, compound shape and low refractoriness having poor resistance to the high temperature of liquid metal, cause these defects. Selection of proper shape, fineness and distribution (3-sieve) with high silica content of base sand, especially for ferrous metals of high melting point reduces these defects. Mold and core paints, washes, coatings with pure silica or zircon base are very effective to control these defects.

b. Sand inclusions, sand wash, sand drop, loose sand entrapment

Sand mixtures with low compressive strength, poor rammed hardness and surface friability cause these defects by the abrasive action of liquid metal during pouring filling of mold cavity. Increasing binders, proper mixing and use of additives like dextrine and cereals, resin bonded coatings that give surface hardness can be used. Keeping green sand molds for more than 8 hours before pouring causes surface friability in dry areas.

c. Blow-holes

These are caused due to excessive moisture in sand-mix, gas forming additives in molding and core sands. Low permeability of base sand is to be investigated for ferrous metals. Control of the above aided by proper venting, avoiding excessive repairs and proper baking of oil-sand cores help to reduce this.

d. Swells, mold-burst, enlarged castings

Poor compressive strength of sand-mix aided by poor ramming on deep vertical faces in mold causes these problems. Increase of binder, proper ramming, good flowability for machine-molding sands help control this.

e. Poor collapsibility, difficulty in cleaning / fettling, hot-tears

Excessive use of inorganic binders to increase strength (sodium-silicate), too hard ramming, excessive gaggers for reinforcing mold and core (core-irons) cause this. Use of organic binders like resins, cushioning materials like wood-floor and saw-dust reduce this. Improper molding, core making and closing practices like excessive repairs, poor venting, not connecting vents of cores to mold vents in assembling, dirty shop-floor, allowing loose sand to float into molds before pouring, low air pressure in machine molding also contribute to these defects.

ii. Casting defects caused by poor pattern equipment

a. Wrong dimensions

Use of unseasoned wood causing distortion and warpage of patterns, improper pattern allowances like contraction, poor joining and weak construction of patterns as well as improper inspection of pattern/core-box are the likely causes.

b. Cross joint/mismatch

In the patterns mounted on plates or match plate pattern, accurate location and fixing of pattern-halves on cope and drag plates is very critical. Inaccuracy in mounting causes the defects. Sometimes worn-out molding box-bushes and closing pins also contribute to this.

c. Core-shift

Insufficient size of core-prints, failure to provide core-lock or register cause shifting of complicated cores during closing or under impact of liquid metal during pouring.

d. Poor surface finish

Poor finish of patterns/core boxes contributes to low quality mold and core causing not only rough surface finish of casting but also sand-insufficient draft causing mold breakages and consequent mold-repairs are also the reasons.

e. Low productivity in molding/closing

Improper design of pattern equipment while selecting parting line, type of pattern, parts to be cored, proper drafts on vertical faces, loose-piece design, marking/painting contribute much wastage of time and effort during molding, core-making and closing.

Considering the criticality of the casting and quantity required in the long run, (not necessarily at the time of receiving order alone), good pattern design and construction, even though appearing costly initially, contribute to improved productivity. This will reduce the overall cost in the long run, when the items are repeated over years.

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Questions

1. Explain the properties desired in a good molding sand.
2. Name the ingredients commonly mixed in the molding sands and the properties contributed by each of them.
3. What are the types or classification of molding sands?
4. How is clay content of molding sand determined in lab ? Explain the effect of clay content and temper water on (a) green compressive strength (b) permeability.
5. What is sand conditioning?
6. Write the tests and procedures to find the following properties of molding and core sands:
   (a) green compressive
   (b) permeability and
   (c) moisture content.
7. How is grain-fineness of base sand for use in molding specified? Mention the procedure to test fineness and its effect on
   (a) green strength
   (b) permeability and
   (c) surface finish.
8. "The quality requirements of core sand are much more stringent than that of molding sand" - justify stating reasons.
9. Explain the bonding action of clay in green sand.
10. What are the cushioning agents mixed in molding and core sands?
11. What are the tests performed on:
    (a) base sands
    (b) mixed sand in every batch
    (c) special tests

12. Select suitable sand mixtures with ingredients and properties for:
    (a) small iron castings
    (b) large, intricate special C.I.,
    (c) light steel castings
    (d) heavy steel castings,
    (e) pressure tight copper alloy and
    (f) aluminum alloys
13. What are the advantages of using mold/core washes, paints? Name a few commonly used mold coatings and their applications.
14. Compare the advantages and limitation of:
    (a) Green sand Vs. CO_2 sand
    (b) Green sand Vs. resin (air-set) sand and
    (c) CO_2 sand Vs. resin sand
15. Compare the process, applications and limitations of shell molding with investment (Precision) casting.
16. Differentiate between:
    (a) natural sand Vs. synthetic sand
    (b) facing sand Vs. backing sand and
    (c) base sand Vs. mixed sand
17. Select suitable molding process for the following, giving reasons
    (a) brass valves,
    (b) gear box casing,
    (c) watch cases,
    (d) large fly wheel
    (e) large steel valves,
    (f) paper mill rolls,
    (g) bell,
    (h) turbine blade,
    (i) tank chain link (track-pads),
    (j) car engine cylinder,
    (k) crank shafts,
    (l) precision tool-bit holders,
    (m) dental-tooth and pump impellers.
18. Name the common types of patterns giving their applications.
19. What are the activities in "pattern design" ?
20. Illustrate with examples, pattern allowances normally given.
21. Describe the stages in the construction of a good pattern.
22. Compare the advantages and limitations of wood as pattern material to metal and plastics.
23. What are the purposes for which cores are used? Describe the features of core-box construction.
24. For the following casting drawings, prepare pattern/core box lay out with complete instructions of pattern methoding. Refer: Fig. 5.5, 5.6, 5.11, 5.14, 5.16 to 5.21 (Chapter 5). (Hint: Redraw the views in full-scale, add allowances, draft, show parting line, core-prints. Assume suitable dimensions).
25. What is the purpose of coloring patterns? Mention the common pattern color code.

26. Compare the construction, applications and limitations of sweep patterns with skeleton patterns giving sketches.
27. Compare the advantages, limitations and applications of
    (a) wood,
    (b) plastics and
    (c) metal as pattern materials.
28. Mention the major casting defects that can occur due to improper pattern equipment.
29. Explain how proper location/support is done for cores in a mold. Mention the techniques of venting cores in a complicated mold.
30. Explain the role of molding / core sands in causing the following casting defects, stating their remedies:
    (a) sand-inclusions (sand-drop, sand-wash)
    (b) blow-holes
    (c) mold- burst (swell, bulge, enlargement)
    (d) hot-tears, hot-cracks
    (e) metal-penetration, sandfusion, rough surface and
    (f) poor knock-out, difficulty in cleaning/fettling (outside/cores)

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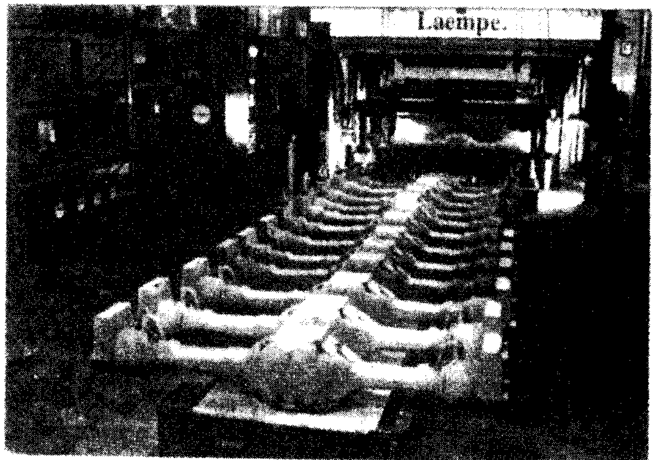
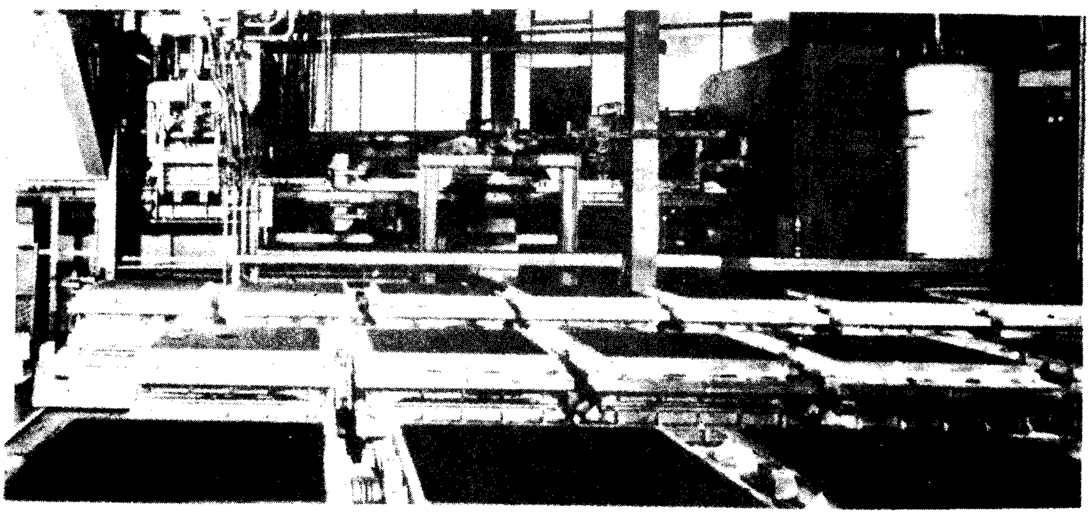
Liquid metal being tapped from electric induction furnace
(See text 4.2)

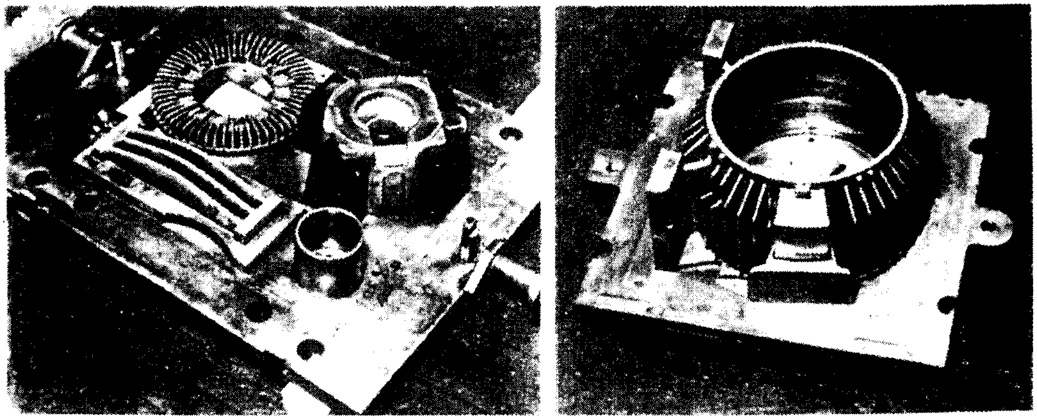
Drag molds with cores inserted. (See text 2.7)



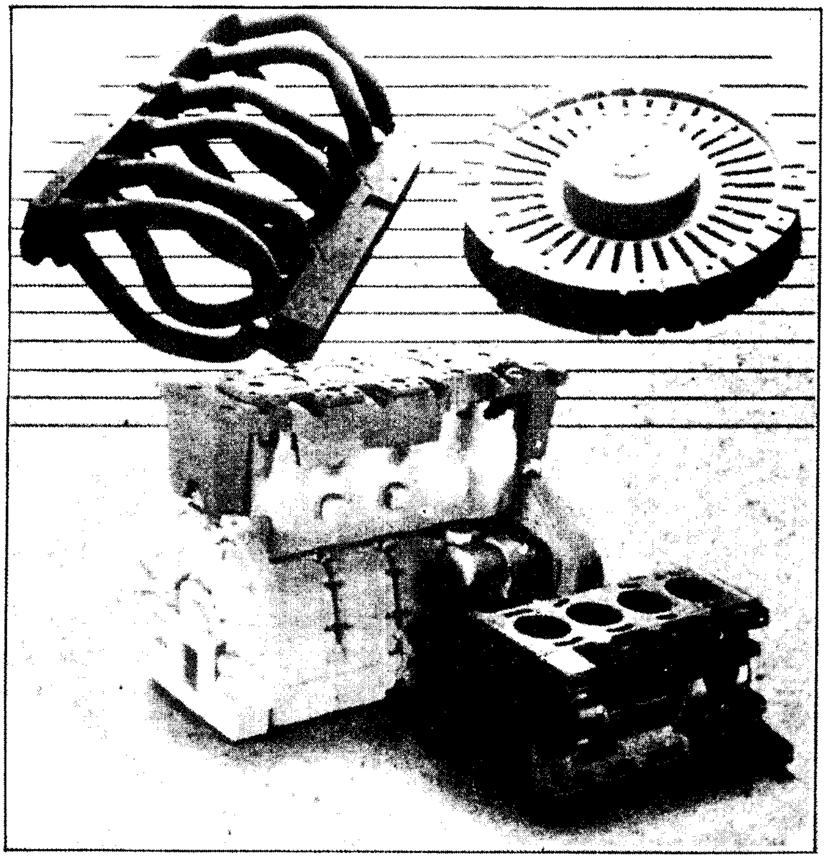
Cores for Auto castings. (See text 2.4)



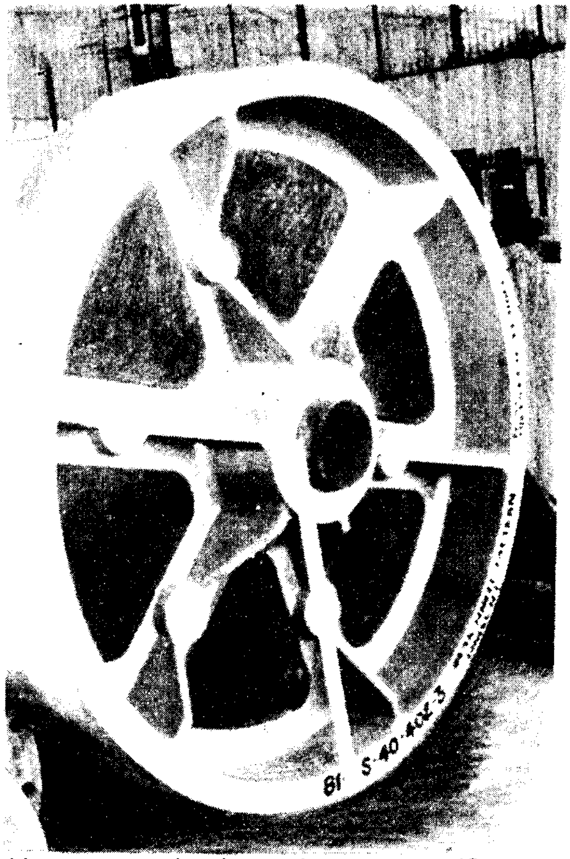
Modern molding machine with molds on conveyer. (See text 8.1)



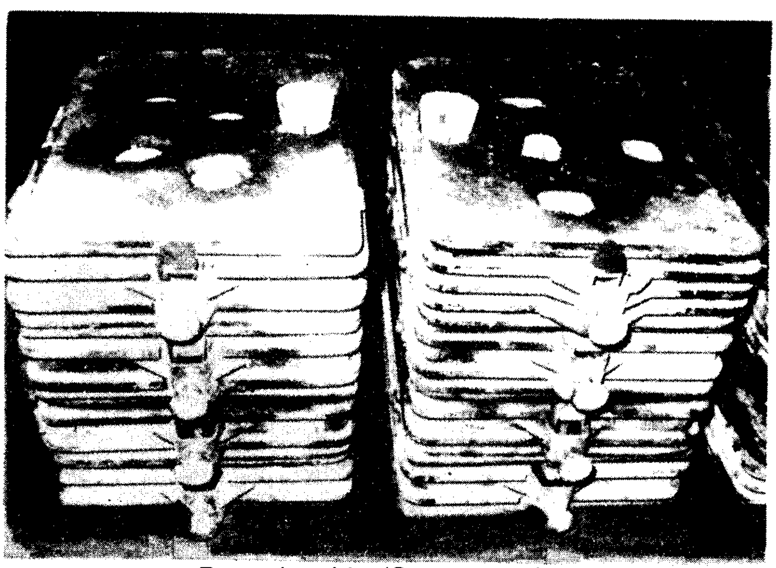
Metal patterns on plates for machine molding. (See text 2.6)



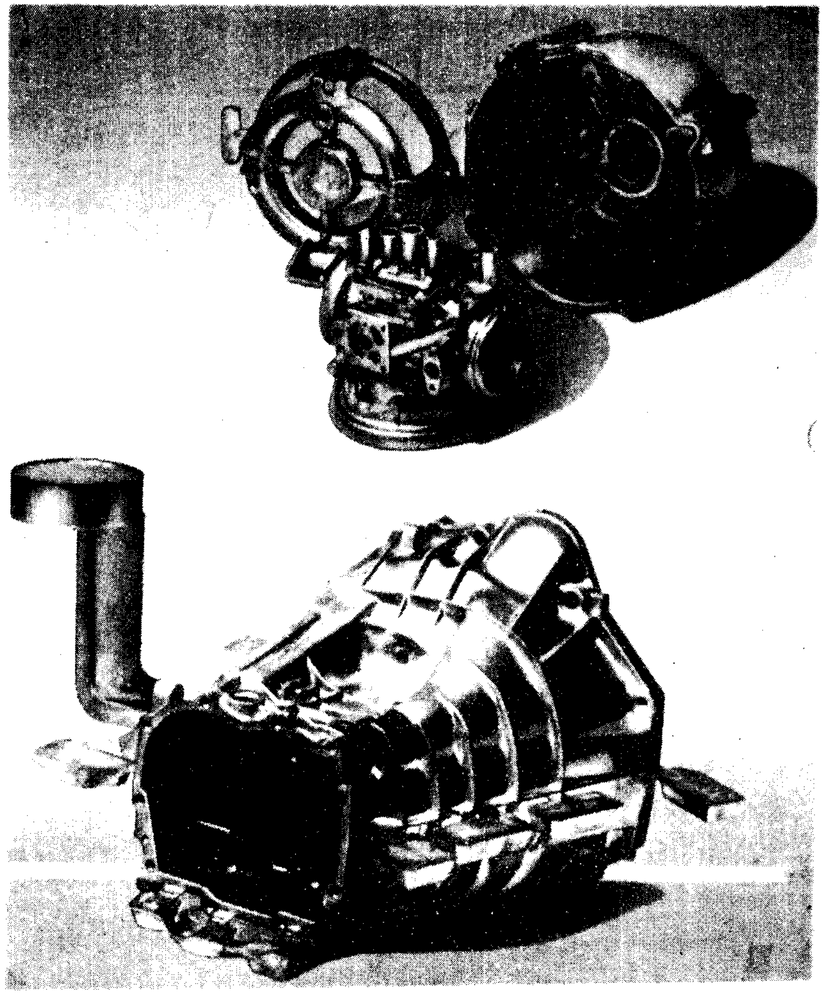
Cores and automobile cylinder block.(See text 2.4)



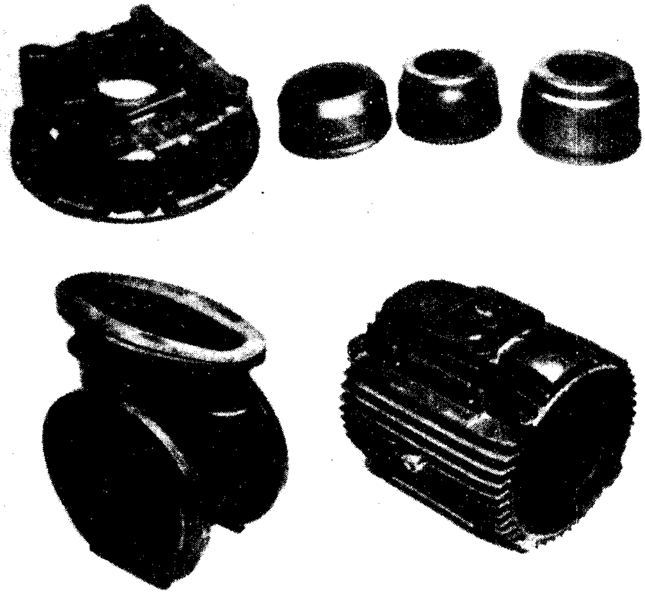
Typical large gear wheel - modern pattern. (See text 2.6)



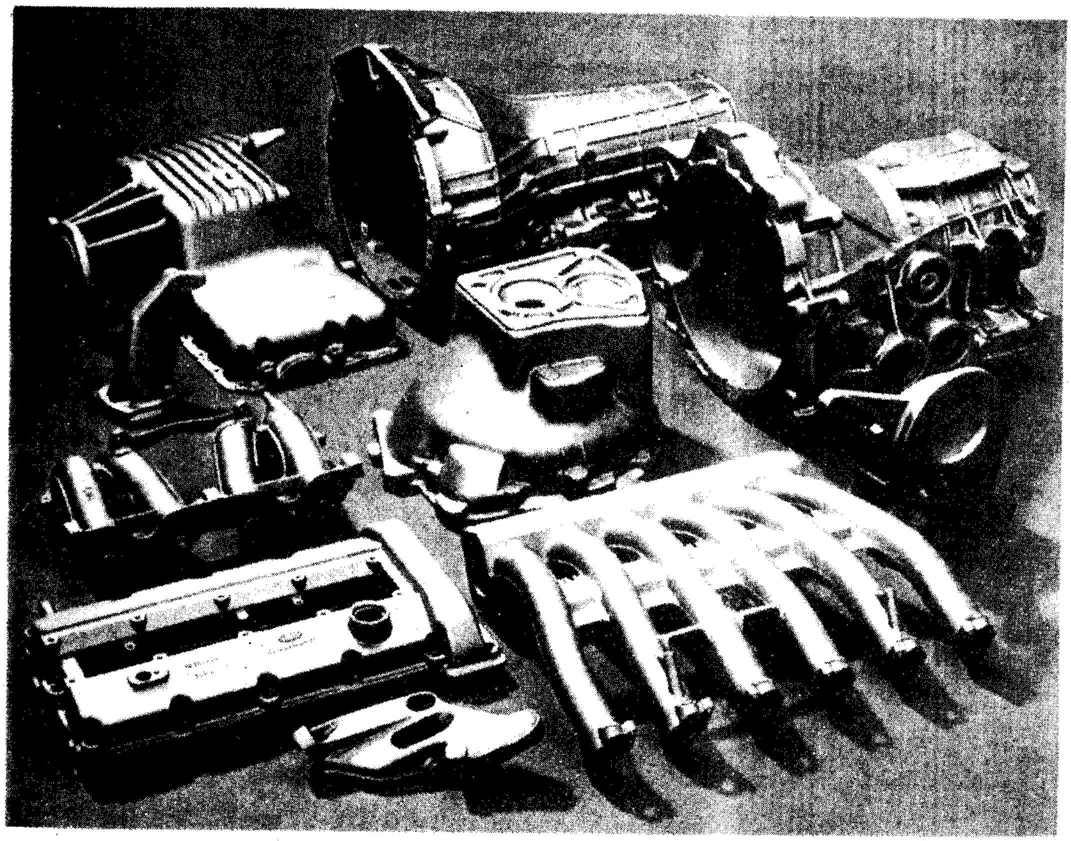
Poured molds. (See text 6.1)



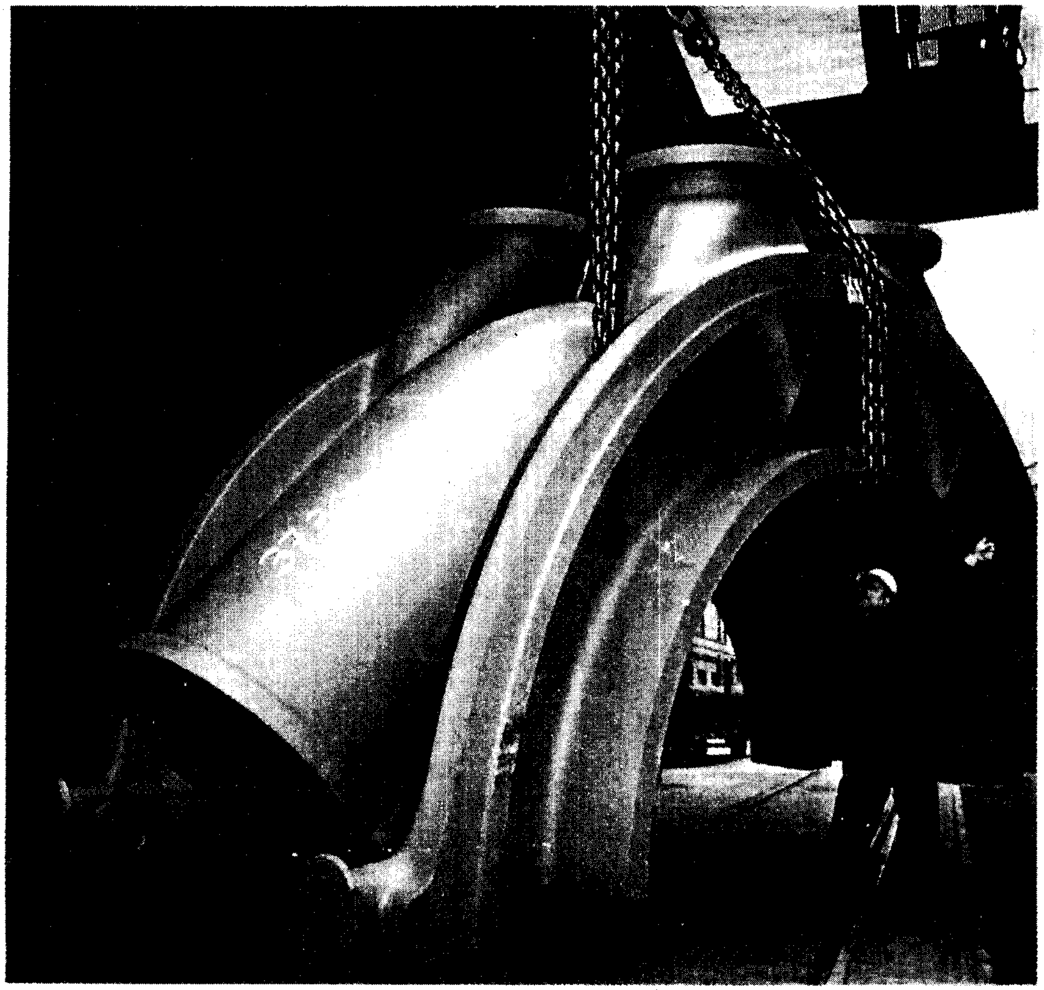
Intricate Die-castings with gating attached. (See text 3.1)



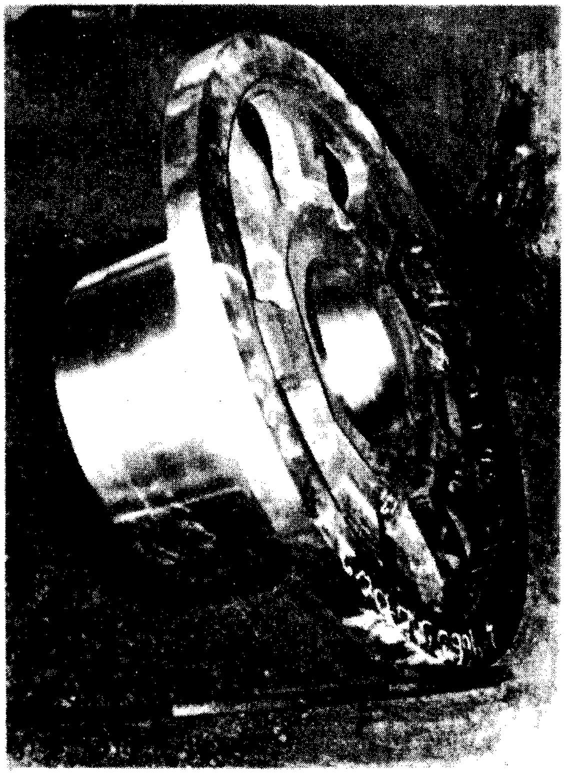
Typical grey iron castings. (See text 6.1)



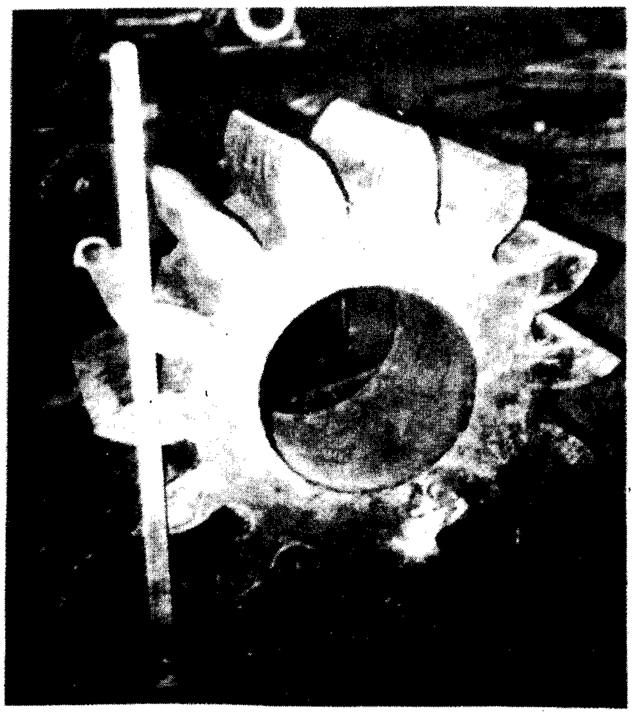
Typical non-ferrous castings. (See text 6.1)



Large Alloy steel turbine housing (3T tons) casting. (See text 7.1)



Rough machine steel casting. (See text 6.1)



As-cast pinion-steel casting for sugar mill. (See text 6.1)

3 MOLDING PROCESSES USING METAL MOLDS

In the processes of sand molding (Chapter 2) the molds once poured cannot be reused, which causes low productivity. Sand molding though cheap, contributes to rejections and rework due to casting defects like blow-holes, sand-inclusion, dimensional deviations, costly machining and generally lower quality in mass production. To overcome these problems, a variety of processes with permanent or metal molds have been developed. Generally, the initial cost of metal molding equipment is high and can be justified over large number of castings that can be cast per mold repeatedly. The other limitation is the die material for casting high temperature melting alloys.

3.1 Die casting

i. Permanent mold or gravity die casting

In this process, a metal die is used for mold. Cores can be made from metal or sand (non-reusable). Sometimes, cope mold is made in normal atmospheric pressure filling the mold by gravity. Castings are removed after solidification by separating the die. This process is relatively cheap and is used for mass production of medium size castings in non-ferrous alloys.

ii. Pressure die casting

Liquid metal is injected under pressure into metal molds in this process. The casting after solidification is ejected out by separating the moving part of the die from the fixed part.

In the cold-chamber process, a separate melting unit is used for melting liquid metal being transferred manually into the tundish of the pressure die casting machine. This is more flexible and cheaper (Fig 3.1)

In the hot-chamber process, a small integral melting furnace provides liquid machine, which is forced out of the crucible by a mechanical device into the die

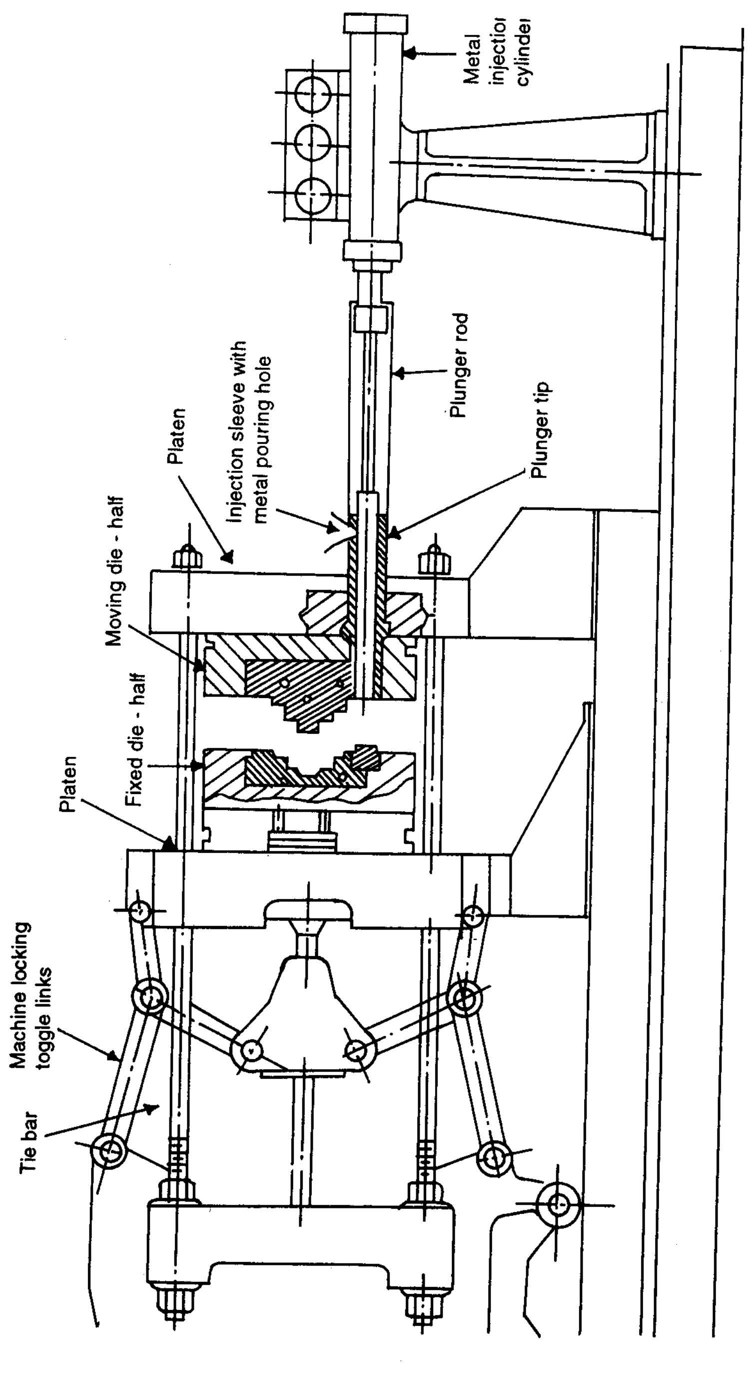


Fig. 3.1 Horizontal injection cold chamber machine for die casting

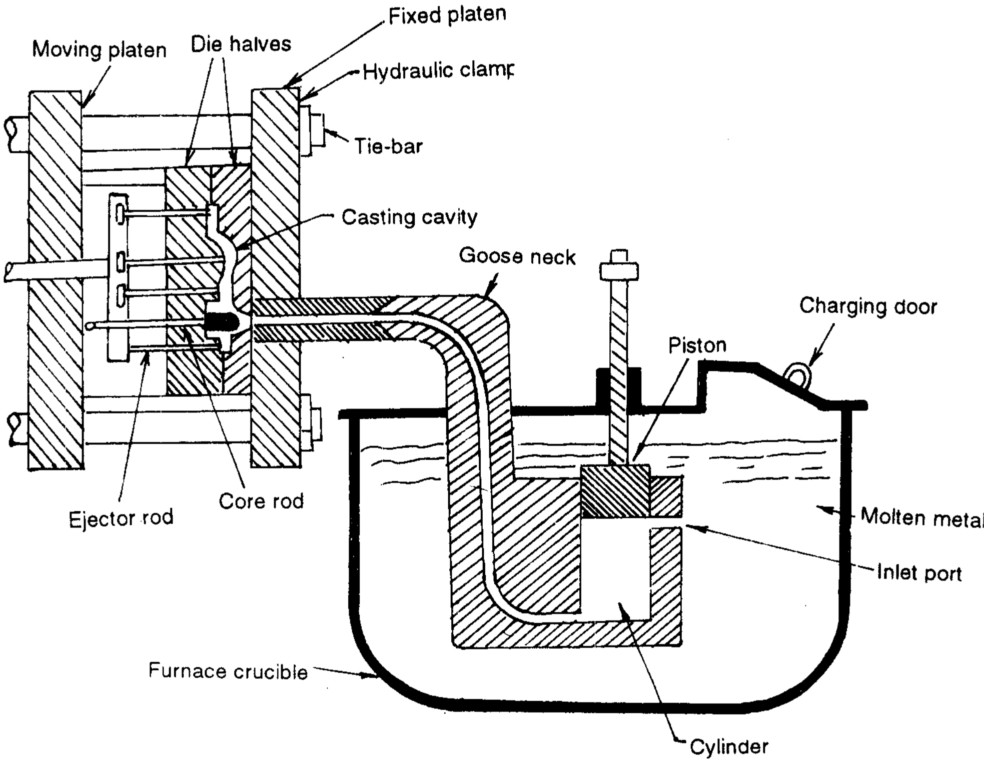


Fig. 3.2 Hot-chamber die casting machine

cavity. This system, though costlier, has very high productivity and is popular for mass production of automobile parts in aluminium alloys. (Fig. 3.2)

Pressure die casting being an important process with growing demand, detailed discussion of theoretical and practical aspects is given in the following pages.

a. Die casting process utilises two blocks of heat resistant metal machined to meet along the plane of the parting and having cavities machined accurately and smoothly to form opposite halves of the shape to be cast. The die casting process makes it possible to secure accuracy and uniformity in castings and machining costs are either eliminated all together or are reduced. The greatest advantage of the die casting process is the fact that parts are accurately and usually, completely finished when taken from the dies, (maximum accuracy possible 0.025).

b. Pressure die cast parts are used in automobile, electrical equipment, electrical motors, business machines, telecommunication equipments, building hardwares and home appliances. The main reasons for the popularity of the pressure die casting processes are as follows:

- yields thin walled castings with high tensile strength thus resulting in low raw material input.
- fast production cycles (500 to 1000 shots per hour).
- lower conversion cost, due to higher net casting weight for the liquid metal poured.
- intricate castings can be produced in incredibly short time with high, repetitive quality and dimensional accuracy.
- surface quality is excellent and features such as screw threads, locating flanges etc., can be readily incorporated.
- dies for pressure die casting can produce many thousands of castings without significant change in casting dimensions.
- die castings produce fine grained structure thereby having better mechanical properties.

c. Limitations of pressure die casting process

- casting size is limited.
- equipment is costly and hence large quantities are required for the process to be economical.
- commercial production is limited to non-ferrous metals.
- not an economical substitute for sand castings that require little or no machining.

d. Die casting machine features

Hot chamber machine:

- metal bath is an integral part of the machine.
- injection plunger and sleeve are submerged in the molten metal.
- relatively low melting point non-ferrous alloys are die cast since they do not pick up iron at higher temperature.
- generally used for zinc alloys only.
- pressure (280 to 700 Kg/Cm^2).
- metal injection into die cavity in minimum time.
- decrease in metal temperature is minimum.

Cold chamber machine:

- the molten metal is contained in a separate holding furnace.
- higher melting point non-ferrous alloys can be die cast.
- relative freedom from attack of molten metal in equipment.
- high injection pressure (560 to 2100 Kg/Cm^2).
- feeding problems are encountered.
- longer cycle time.
- possibility of metal defects due to loss of super heat.
- maintenance problems are less compared to hot chamber machine .

There are two types of liquid metal injection into the die depending on the direction of motion of the plunger - horizontal and vertical.

e. Die Temperature

The die temperature is important in terms of heat transfer. The main die areas to be controlled are those of the cavity face at injection and ejection. Face temperature at injection has a marked effect on surface finish of the casting whilst face temperature at casting ejection affects dimensional tolerances of the castings and formation of surface blisters.

The temperature gradient behind the cavity surface determines the rate and pattern of solidification. The cycle time, surface finish and internal soundness are directly related to the die temperature pattern.

Die temperature can be controlled either by regulating the flow of cooling media through the die or using a DTCT (Die Temperature Cycle Time) controller, allowing the temperature of the casting instead of the machine timing to control the die cooling cycle.

Dies used for aluminium die casting are water cooled in service and should be preheated to 175°C. Preheating should be done with water flowing slowly through the die to prevent serious damage that would result from introduction of cold water into a hot die. Preheating should be done with the slides removed since the slides tend to expand sooner than the guide reducing clearance.

f. General application of die castings

Gravity die casting: (upto 100kg weight per piece)

Aluminium alloy auto cylinder blocks, cylinder heads, wheel-hubs, motor housing, pump castings. Copper alloy castings of pump casings, housings, large impellers.

Pressure die casting: (upto 10kg weight per piece)

Aluminium alloys for scooter, motor cycle and car parts like carburettors, engine cylinder, covers, casings, intricate parts requiring high surface finish and internal dimensional accuracy. Zinc and magnesium light weight alloys for aero-space application, domestic gas cylinder control valves.

Copper base alloys:

Impellers, injection nozzles and burner parts.

g. Prevailing major defects in the die castings

Cold shuts:

A lapping of solidified metal that occurs due to incoming streams of metal divided into several separate jets that fill different parts of the cavity and meet again after traversing individual paths. During their separate travels these streams lose some heat and develop thin oxide films in their fronts. To ensure complete fusing it is necessary that these separate jets retain enough heat to fuse and that they come together under sufficient pressure and velocity to break up the oxide films.

Table 3.1 Minimum Wall Thickness for Die Casting

Surface Area	Sn, Pb, Zn.	Al, Mg	Copper
upto - 25	0.6 - 1.0	0.8 - 1.2	1.5 - 2.0
25 - 100	1.0 - 1.5	1.2 - 1.8	2.0 - 2.5
100 - 500	1.5 - 2.0	1.8 - 2.5	2.5 - 3.0
over - 500	2.0 - 2.5	2.5 - 3.0	3.0 - 4.0

All dimensions are in mm
The area of a single main plane to be produced at minimum wall thickness in Cm^2.

Table 3.2 Gate Velocity

Thinnest Wall Dimension in the Casting (mm)	Gate Velocity Range (m/s)
0.760	46 - 55
1.27 - 1.525	43 - 52
1.905 - 2.286	40 - 49
2.540 - 2.794	37 - 46
2.858 - 3.810	34 - 43
4.650 - 5.080	31 - 40
6.350	28 - 35

Use lower values for warmer dies and hot metal
Use higher values for colder dies and cooler metal

Table 3.3
Cavity Fill Time

Thickness (mm)	Fill Time (sec)
0.5	0.007
1.0	0.014
1.5	0.021
2.0	0.029
2.5	0.035
3.0	0.043
3.5	0.050
5.1	0.070

Select shorter fill time when

1) Die temp. is low
2) Thin wall sections are distant from the gate
3) Metal flow distances are long.

Select longer fill time when

1) Die temp. is high
2) Thick wall sections are distant from the gate
3) Metal flow distances are short.

Flash:

The thin web or fin of metal on a casting occurring at die or mold partings. air vents and around movable cores due to working and operating clearances of the die.

Excessive heat marks:

Excessively blackened portions on the surface of the casting, spoiling the surface finish.

Blisters:

A surface bubble or eruption caused by expansion of entrapped gas beneath the plating on the casting.

h. Die materials

For normal non-ferrous casting for use upto 10,000 pieces production cast iron die are used. Water cooling helps in longer life. Pressure cast dies upto 50,000 pieces are made in carbon steel, as they are under high pressure.

Special dies for extra life of above 100,000 pieces are made in die steels. Composition: 0.35/0.40% carbon, 5% chromium, 1.3% molybdenum and 1% vanadium, oil-quenched and hardened to 450 BHN.

i. Lubricants/Release agents for dies:

To prevent soldering of liquid metal to die, lubricants are needed. They give easy release and good casting surface. Graphite, mica, molybdenum disulphide, boron/silicon nitrides, aluminium flakes in fine powder form etc. , form base materials. The solid material is suspended in water or solvent organic oil with additives like wax or petroleum jelly as required.

For high melting point alloys like copper or cast iron, water cooling of the die is necessary.

3.2. Centrifugal casting

For casting circular and symmetric shapes like pipes, sleeves, rings etc., pouring liquid metal into a rotating mold is a cheap and high quality process. Depending on shape and size, the equipment may have rotation of vertical or horizontal axis. The metal mold is lined inside or coated with a refractory material and while it is rotating, controlled quantity of liquid metal is poured into it. The centrifugal force causes the formation of a uniform, dense and quality casting at the mold face. The casting can be easily removed from the mold on cooling, due to the contraction. Low finishing cost, high yield, and superior quality are the advantages. (Fig. 3.3 A, B) size and shape of casting are the limitations. See Table 3.4 for details.

Table 3.4 Typical data of HMT-Buhler cold chamber horizontal pressure die casting machine

Locking force	:	400 Tons
Die opening	:	600 mm
Die plate	:	920x980 mm
Free cycle time	:	7 seconds
Shot capacity max. (Aluminium alloy)	:	6.9 Kg
Power required	:	22.4 Kw

Arrangement for core pullout, hydraulic ejector, electronic controls etc.

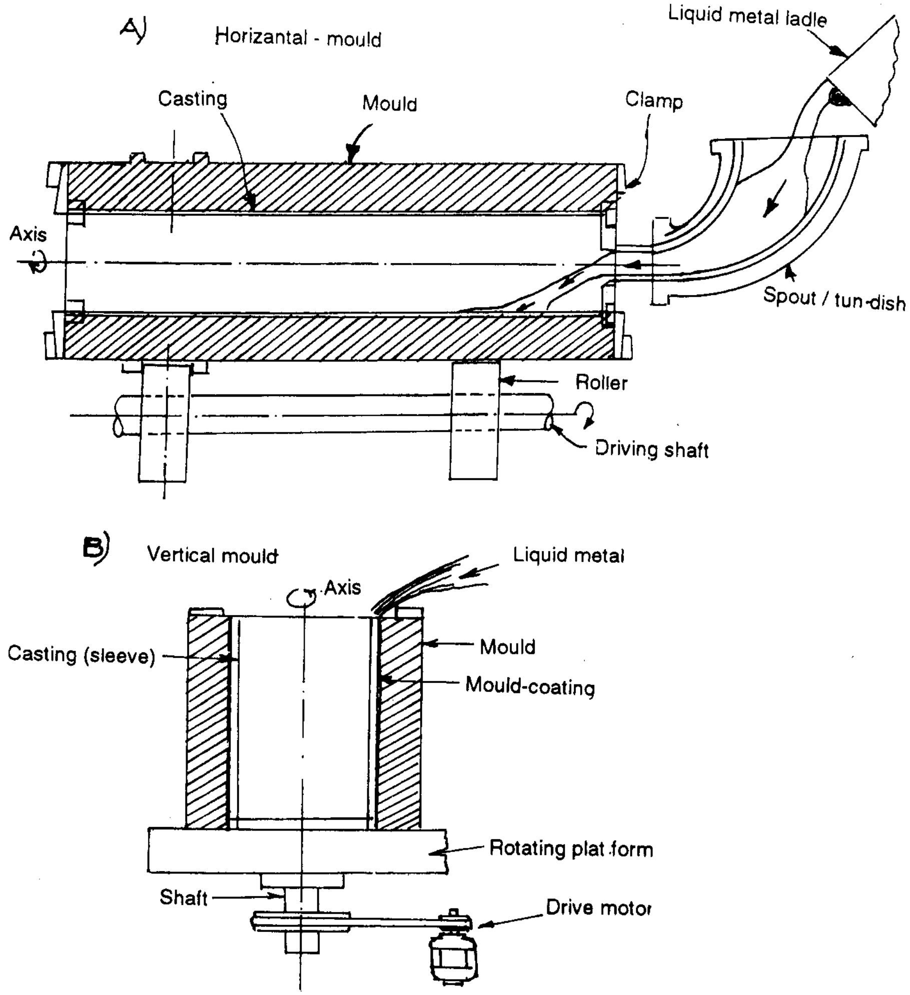


Fig. 3.3 Centrifugal casting

3.3. Continuous casting

Even though it is not a conventional process for making shaped castings, it is used to produce long sections of complicated profiles in both ferrous and non-ferrous alloys. They are later welded together in short lengths for making complicated castings. The principle is similar to continuous casting of liquid steel directly to form billets. Liquid metal from furnace is poured at controlled rate into a tundish through a long channel into a water-cooled copper mold. The mold contains an inner shape corresponding to the required section. The liquid metal solidifies in the mold and as it reaches solids temperature. The relative motion between liquid metal stream and the mold is the most critical parameter to get sound, shrinkage-free cast section. This process is being used for cast iron sections and other non-ferrous alloys of very complicated profiles in continuous lengths. (Fig. 3.4)

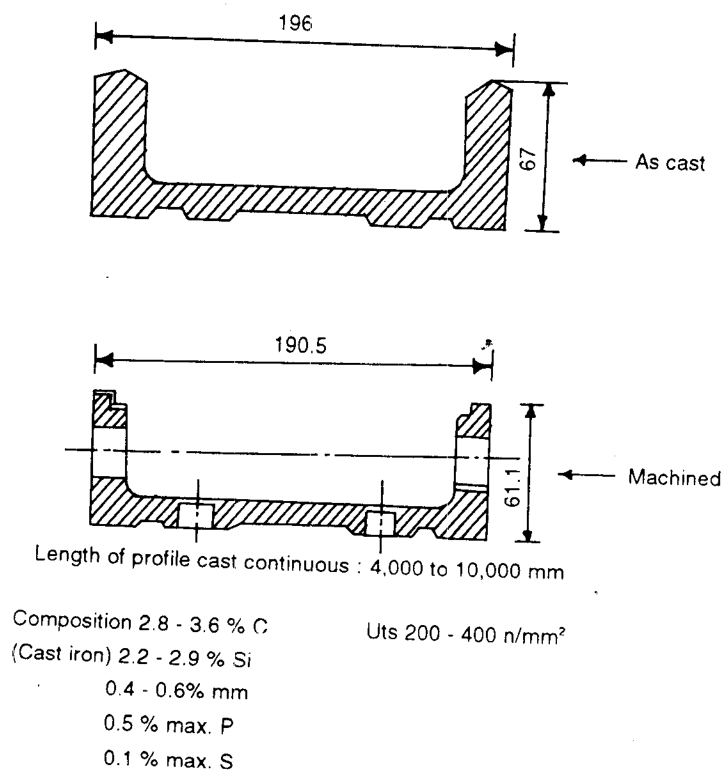


Fig. 3.4 Continuosly cast C. I. connecting beam For textile machines

3.4. Principles, applications of metal molding processes

The principles, applications, advantages and limitations of the above metal molding processes are given in a tabulated form for easy reference and comparison in Table 3.5

3.5. Selection of proper molding process

The selection of proper molding process for making a casting from among the sand-molding/ metal-mold processes depends upon the following factors:

a. Metal/alloy being cast ,
b. Size and weight of casting,
c. Quantity to cast per order, ,
d. Quality requirements such as freedom from defects, dimensional tolerances, surface finish etc., and
e. Overall cost/economy.

Examples of process selection for some common castings are given in Table 3.6

Table 3.5 Comparison of Molding process using metal molds

		Principle - Equipment	Casting Size Alloy Range	Applications	Advantages	Limitations
1.	Permanent Mold-Die Casting	Permanent metallic molds of cast-iron or alloy steels are used instead of sand molds (which cannot be reused) to receive liquid metal to be cast.	only for non-ferrous alloys Al, Cu, Mg etc.			Not suitable for high temperature ferrous alloys.
	(A) Gravity Die Casting	Liquid metal is poured into metallic molds under gravity (without external pressure) metallic or sand cores are used.	Castings upto 50 Kg. even C.I. is cast some times	High quality, accurate castings for textile, machine tool, auto parts. Tolerances 0.5mm/100mm Surface finish 2-5 μm Thin castings of 2 mm minimum wall thickness.	High casting quality surface finish, freedom from defects as sand is not used for molds. Many castings from same dies, economy in mass production.	Not suitable for medium/large sizes. Die making is very costly. Only for mass production.
	(B) Pressure Die Casting	Liquid metal is injected under pressure into metal mold (die). Special machines for closing the die, injecting metal, inserting, removing metal ccres and ejecting castings are needed. Some machines have a small furnace attached for ease of pouring.	only for non-ferrous alloys only for small castings upto 10kg	Very high quality, intricate shapes to avoid further machining. Scooter, car parts carburettors, fuel pump parts, electronic, compressor & machine tool parts. Tolerances : 0.2mm/100mm Surface finish upto 4 μm Thin castings, 1.0 mm minimum wall thickness.	Very high casting quality. No voids of gas/shrinkage. High casting yield. Ideal for mass production of small non-ferrous castings.	Not suitable for ferrous alloys. Only for small, mass production castings. High cost of equipment & patterns (dies)

		Principle - Equipment	Casting Size Alloy Range	Applications	Advantages	Limitations
2.	Centrifugal Castings	A permanent metal mold (with refractory coating) is revolved horizontally or vertically. Liquid metal is poured into it at a controlled rate to form the required wall-thickness adjacent to mold face by centrifugal action. The casting is ejected out on solidification. Metal molds, coatings, equipment for rotating the molds, special pouring arrangements are needed.	For cast iron upto 1000 kg in different sizes. Not used for steel casting	For circular shapes like pipes, rings, rims, hollow cylinders etc. C.I. water pipes are most commonly used. Tolerance: 1.0mm/100mm Surface finish : 1-5 μm	Good quality casting as defects are thrown to surface by centrifugal action. High yield, cheap for mass production.	Limited only to circular shapes. Not suitable for steels Mostly for mass production.
3.	Continuous Castings	Molten metal is poured through a long channel to solidify in a water cooled metal (cooper) mold. The mold is moved at a controlled speed to synchronise with solidification of full section. Special pouring tackles, water cooled metal molds, mold moving machines, handling equipment for very long products are needed.	Used mostly for steels for simple shapes like bars, billets, plates. Different special continuous shapes in C.I. non-ferrous are now being made	Mainly for round/simple shaped long products like rods, squares, strips (avoiding reheating re rolling of ingots). Special shapes of non-ferrous section can be cut and formed to final useful shapes.	Cheaper than normal rolling/rerolling, high quality/soundness. Cheap in mass production.	Severe limitation of shapes, sizes, only continuous long products. Costly equipment, only for mass production.

Table 3.6 Examples of selection of mlding process

Sl. No.	Item	Metal	Weight (size) Kgs.	Order Quantity	Molding Process
1.	Lathe-bed	Cast iron	600 Kg	10	Hand molding, CO_2 process, resin-sand core, teak-wood pattern, core-boxes.
2.	Man-hole covers	Cast iron	15 kg	200	Green sand molding, match-plate pattern, teak-wood pattern/core box size 500 X 300
3.	Liner plates	Mn. steel	80 kg	50	CO_2 process, match-plate pattern, teak wood pattern/core box, oil-sand core, Zr mold and core wash.
4.	Valve bodies	C.I./steel	1-5 kg	500	Machine molding, green sand, shell-core, metal pattern/core boxes, mold & core wash.
5.	Large gear wheel/blank	C.I./steel	2000 kg (Dia.2m)	2	Sweep pattern and molding tackles, loam/chamotte sand, CO_2 cores, Dry/bake mold and cores, graphite wash.
6.	Gear-box housing	Steel	2000 kg (2m X 1.5m)	2	Pit-molding, core-assembly, CO_2 process for mold and cores, part-pattern.
7.	Large housing for blast-furnace damper	Steel	5000 kg (2m X 2m X 2m)	1	Skeleton pattern, pit molding, CO_2 process, Zr mold and core coating.
8.	Chain-links for tanks	Mn. steel	2-4 kg (200X150)	1,000	Shell molding, heated metal pattern and metal core boxes.
9.	I.C. engine car cylinder body	C.I./S.G. Iron	200 kg Intricate	1,000	High pressure sand molding by machine, air-set/resin sand mold and shell cores and metal pattern.
10.	Piston rings	C.I.	100-200 mm dia	10,000	Centrifugal casting, vertical axis, metal mold with refractory coating cast as a long sleeve and parting slices.

Sl. No.	Item	Metal	Weight (size) Kgs	Order Quantity	Molding Process
11.	Scooter carburettor	Aluminium alloy	1	10,000	Pressure die-casting, metal die, highly intricate, hot-chamber.
12.	Motor body (generator)	Aluminium alloy	8.0	2000	Gravity die casting, metal mold for drag and sand mold for cope, shell resin sand core.
13.	Watch cases, turbine blades	Stainless steel	0.2 0.5	10,000	Precision investment casting, wax pattern, highly intricate and tiny.
14.	Armament lever	High alloy steel	0.1	10,000	Precision investment casting, wax pattern, highly intricate and tiny.
15.	Special shaped sections	Al, Cr, Cu, steel	500	continuous lengths	Continuous casting with water cooled copper mold
16.	Cutting tool tip	H.S.S Tungsten carbide	0.1	1,000	Precision investment casting or by powder metallurgy
17.	Cement kiln tyre	steel	5,000	2	Sweep molding, CO_2 cores, top in box dry mold, graphite/Zr. coating.
18.	Bearing sleeves	Cu./gun	10	5,000	Gravity die casting, metal drag, sand / metallic cope, shell / resin core.
19.	Ball-mill balls Grinding media	Alloy steel	0.3-5.0	10,000	Green sand stack molding, match plated metal pattern, machine molding mold coating.
20.	Turbine housing	Alloy steel	6,000	2	Pit molding, CO_2 / resin sand, teak wood pattern and cores, mold and cores to be dried / coating.

Questions

1. Compare the advantages of metal-molds over sand-molds, and the limitations.
2. With a neat sketch, give the principle of operation and applications of :
   a. gravity die casting b. pressure die casting and
   c. centrifugal casting
3. What are the types of commonly used die casting machines? Explain their principle, advantages and limitations.
4. Sketch a common cold-chamber type pressure die casting machine. Give its specifications and applications.
5. What are the common metals used for metal molds / dies. What is a release agent in die casting?
6. What are the different types of centrifugal casting methods? Give their advantages and applications.
7. Sketch a centrifugal casting machine used for making large cast iron water pipes and explain its principle.
8. Explain the salient features of continuous casting with a sketch. Can it be used for normal shaped castings?

❄ ❄ ❄

4 MELTING FURNACES & TECHNIQUES

Melting of the metal/alloy to be cast is a very important stage of casting manufacture.

- Almost 50% of the capital investment of the foundry is normally made in melting and associated equipment.
- Out of the total production cost of a casting, almost 50% is contributed by the cost of melting and associated materials.
- The final quality of casting primarily depends on the melting equipment and melting techniques adopted.

4.1. Classification of melting equipment

i) From the type of fuel used:

a) Coal/Coke-fired b) Oil-fired
c) Gas-fired d) Electric power

See Table 4.1 for comparison of fuel types.

ii) From the furnace construction

a) Lift-out/Bail-out Crucible b) Tilting
c) Rotary d) Cupola/Shaft

4.2 Common melting furnaces employed in foundry

i. Coke-fired crucible furnace with lift-out or bail-out crucible

The crucible is kept in a pit surrounded by coke, (Fig. 4.1) supported on grate bars. Air is blown from bottom. Space is provided for cleaning ash from the bottom compartment. Metal is charged into the crucible and a flux or other material is given as cover. After melting is completed, the crucible is lifted out by tongs manually and transferred to molds for pouring.

Table: 4.1 Comparison of Fuels for Melting

No.	Item	Coke	Oil	Gas	Electric
1.	Initial cost (For 1 ton per hour melting Rs. in lakhs)	Very low (Less than 0.5)	Low (1.0)	Low (1.0)	Very high (20.0)
2.	Running cost of fuel	Low	Very high	Very high	High
3.	Maintenance cost of equipment	Low	Low	Low	High
4.	Capacity to achieve high temperature	Good	Low	Medium	Very good
5.	Rate of heating	Low	Medium	High	Very high
6.	Control over temperature	Nil	Good	Very good	Very good
7.	Control on melting process /composition/ refining	Very difficult	Good	Good	Very good
8.	Generation of pollutant (Smoke, particle dust, unburnt gases, fumes	High	Very high	Low	Medium
9.	Availability	Difficult to get good quality (high ash)	Difficult (imported)	Very difficult	Available
10.	Applications	Small scale melting units for non-ferrous and ferrous of ordinary quality	Medium scale non-ferros melting of ordinary quality	Only by large units having own gas-plant	Medium and large scale units for ferrous and non-ferrous high quality castings.

The advantages and limitations of this furnace are:

a. Used for small quantities of cast iron or non-ferrous melting upto 100 Kg. batch.
b. Very cheap as investment is the lowest.
c. Low thermal efficiency and long cycle time.
d. Not for high quality alloys.
e. Pollution due to dust and fumes.

ii. Oil/gas-fired tilting type furnace:

This is a furnace employing an inbuilt crucible, heated by the flame from furnace oil or a fuel gas like producer gas or natural gas. The crucible is kept elevated with tilting-trunnions. After melting, the crucible is titled, emptying liquid metal into carrying ladles for transfer to molds for pouring. (See Fig. 4.2)

a. This is used for special cast irons and non-ferrous metals for medium capacity approximately 50 to 500 kg. batches.
b. Fast melting rate.
c. Higher thermal efficiency than coke with proper burner-blower system.

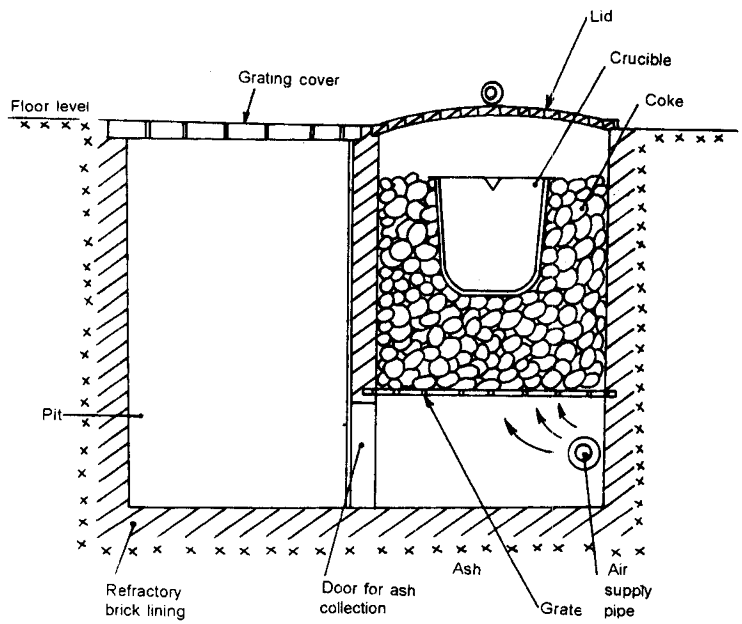


Fig. 4.1 Coke-fired pit type crucible furnace (manual lift-out of crucible)

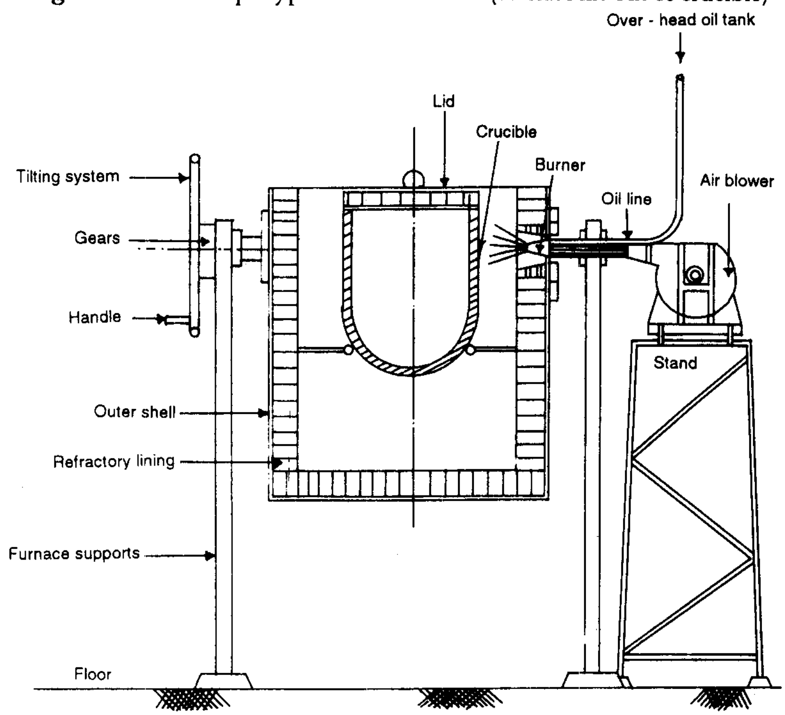


Fig. 4.2 Oil-fired tilting type crucible furnace

d. Cleaner melting.
e. Control on melting technique possible to achieve good quality.
f. Investment higher than coke-fired but much lower compared to electric melting furnace.

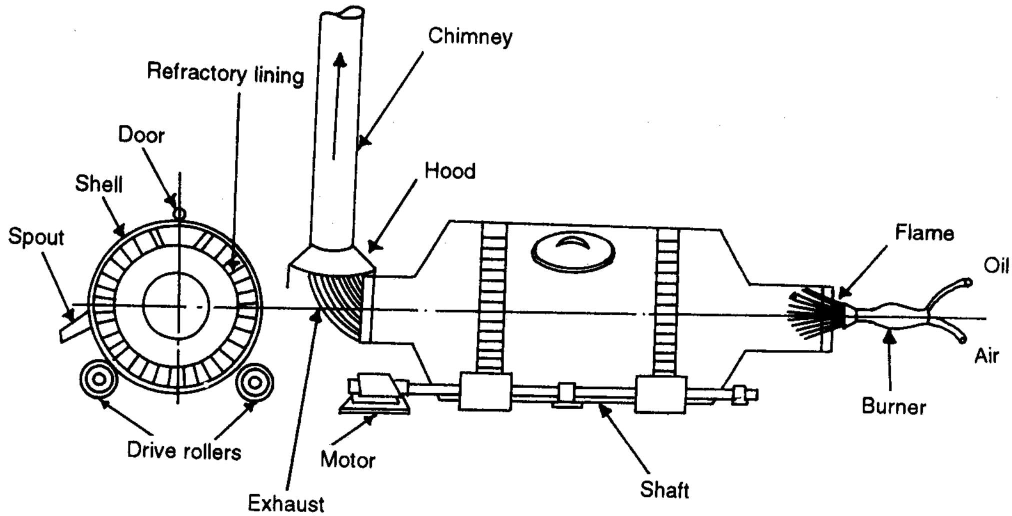


Fig. 4.3 Oil fired rotary furnace

iii. Oil/gas-fired rotary furnace:

Rotary furnace consists of a cylindrical steel vessel, lined with refractory bricks, supported horizontally on rollers. Flame from oil or gas burner is given from one end and hot gases exhaust from the other. The entire cylinder is slowly rotated through a system of gears and pinions (10 to 30 R.P.M). Charge of metal and flux is dumped from a charging door at centre and suitable tapping system is provided once the metal is molten. This is used for special cast irons as well as commercial grades of carbon steel castings of small and medium sizes (10 to 100 kg). It is not very popular due to the cost of installation and maintenance. (See Fig. 4.3)

iv. Direct arc electric furnace

This consists of a cylindrical shell with hemispherical bottom made of thick mild steel plate. The roof is a dished dome having three openings for three graphite electrodes. A door is provided in the front side for observation, minor charging, slagging etc., while a tap spout on the opposite side, opening into a pit, holds the pouring ladle. The furnace shell is lined in the sides, bottom and roof with refractory bricks and rammed mass to protect it from the internal heat. The shell can be tilted by a toothed rack, controlled through hydraulic piston, cylinder and motor, 45^0 towards pit and 15^0 back for slagging and pouring. The furnace roof which sits on the shell during melting can be lifted and swung aside by the hydraulic ram to facilitate open charging. Three electrode arms which hold electrodes by water-cooled copper clamps, are mounted on masts outside. The electrode's vertical movement for control of arc length and temperature, which is the heart of the operation, is done by a thyristor and motor drive.

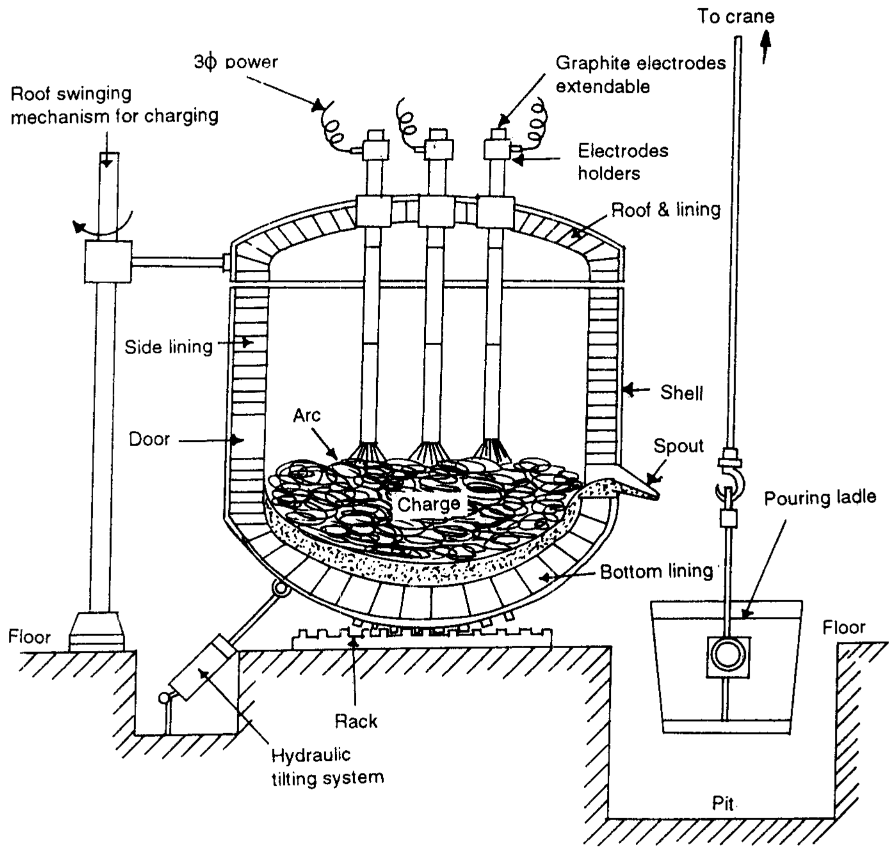


Fig. 4.4 3ϕ Direct arc electric furnace

The auxiliary systems consists of high tension transformers and circuit breakers which receive power directly from a 11 KV sub-station and convert it to needed voltage at the furnace, transformers to change 'tap' or current settings to electrodes and regulators to move electrodes automatically, control panels, water cooling pumps, piping for roof ring, electrode holders etc.

Normal quality steels with single-slag operation can be made using cheaper acid-lining refractories at side and bottom. High quality steels with double-slagging need costlier basic refractories at bottom and side. The roof is normally lined with acid (Silica) bricks.

As melting proceeds, the graphite electrodes striking the arc at bottom, get consumed. Fresh lengths are added from the top by joining nipples provided with threads.

The sketch showing the major parts is given in Fig: 4.4. Typical specifications and important aspects of maintenance are given in Chapter 8.1

Advantages of arc furnace melting:

a. High melting temperature and fast melting rate.

b. Cheap, low-quality scrap can be used in charge, for economy.

c. Good control over temperature and furnace atmosphere for high quality melting for carbon and low alloy steels.

d. Possibility to refine melt to reduce sulphur and phosphorous.

e. Popular for melting large quantities (5 to 50 tones)

Disadvantages of arc furnace melting:

a. High fluctuations in the line voltage in initial stages of melting.

b. Need of comparatively high maximum demand of electric power.

c. High melting losses of costly alloys. Not recommended for high alloy steels.

d. Cost of graphite electrodes which get consumed during operation.

e. More maintenance cost compared to induction furnace.

f. Pollution due to fumes, smoke and noise.

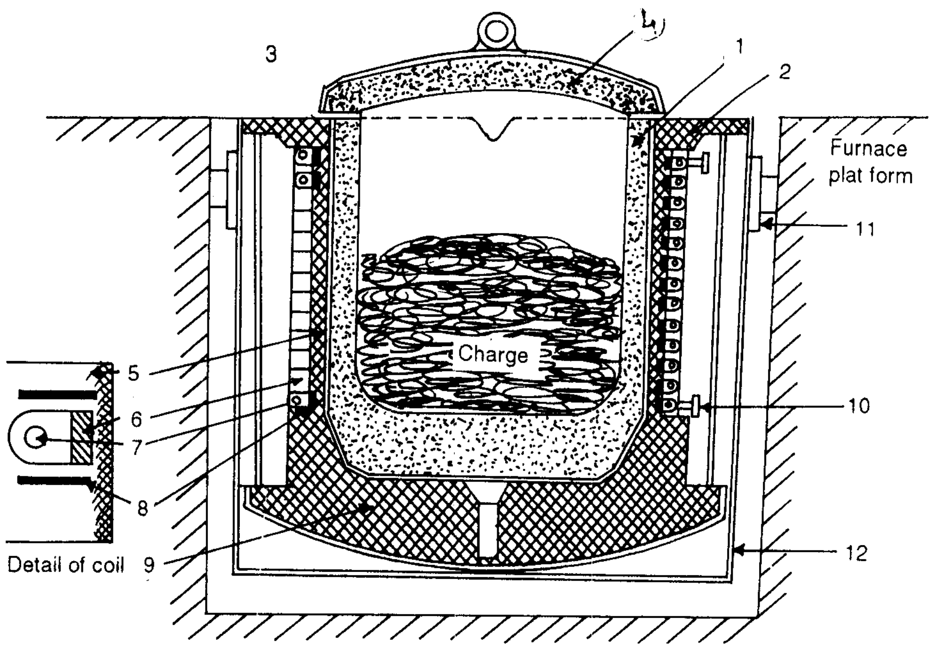
v. Electric induction furnace

This furnace has a crucible formed from ramming refractory mass around a mild steel former. Electric power is supplied by an induction coil placed around the crucible concentrically, protected from heat by refractory and insulating material. The coil is made of thick copper tube, inside which cooling water is circulated. The crucible and coil are packed in a rectangular box/shell. The box is placed at a raised level in a platform and has tilting mechanism for pouring liquid metal into ladles held at the normal foundry floor.

Heating of charge placed in the crucible is done by electromagnetic induction effect of the current passing through the coil around it. The normal supply frequency of 50/60 Hz Ac can be used for melting cast irons. It is however difficult to melt smaller pieces of scrap at the start without a molten heal or large pieces. Medium frequency of 200 to 5000 Hz is more popular as the furnace can be started cold, has modest stirring of liquid metal and is used for melting steel, cast irons and even non-ferrous alloys. High frequencies like 10,000 Hz are used for small special melting of precious metals and super alloys.

A sketch of the induction furnace is given in Fig: 4.5 and typical specifications and maintenance are discussed in Chapter 8.1.

The auxiliary systems of the furnace include frequency convertor which is the heart of the unit, a solid state electronic device to convert the mains frequency to the required higher frequency, furnace box tilting arrangement, water-treatment plant and pumps to circulate water in the coil for cooling, control panels and capacitors to improve the power-factor which is otherwise negative. These furnaces in capacities 15 to 2000 Kg are very popular for foundry melting.



1. Working rammed lining
2. Castable Refractory Ring
3. Ms lining former
4. Furnace lid with lining
5. Coil Grout refractory
6. Coil current carrying portion
7. Cooling water opening
8. Insulation between turns
9. Castable refractory bottom
10. Inlet for cooling water
11. Trunnion for tilting of furnace
12. Outer ms shell / box

Fig. 4.5 Tilting induction furnace- electric

The advantages of induction furnace over arc furnace are

a. For the same size (volume), induction furnace has a much faster melting rate compared to arc furnace.

b. Energy consumption per ton melted is much lower.

c. Metal losses during melting are much lower making it ideal for melting high alloy steels and non-ferrous alloys.

d. Homogenous alloying due to automatic inherent stirring.

e. No requirement of costly consumable graphite electrodes.

f. Simpler mechanism and lower maintenance cost.

g. Lower pollution and better working conditions.

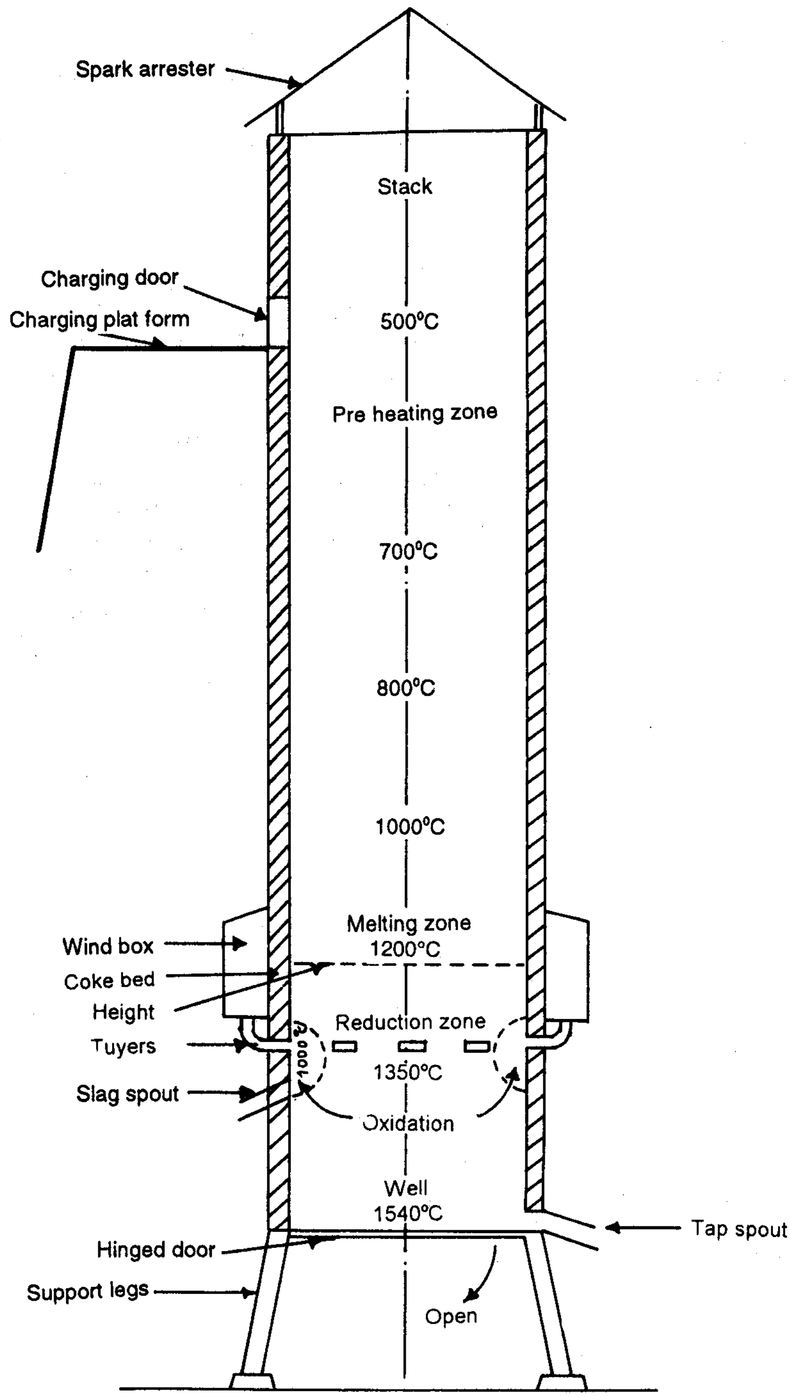


Fig. 4.6 Cupola zones / temperatures

The disadvantages of induction melting are:

a. Refining of metal in the furnace is difficult.

b. Needs higher quality low-impurity scrap/ charge, making it costly.

c. Need of specially treated water, for coil-cooling which is critical.

d. Negative power factor due to inductive load needing usage of costly capacitor banks.

vi. Cupola

Cupola is universally used for melting ordinary/grey cast iron in foundries due to its cost of construction, installation and operation. It cannot be used for melting any metal other than the cast iron.

a. Principle

Metallic charge consisting of pig iron and scrap is melted using coke and oxygen in air as fuel. Lime stone ($CaCO_3$) in the charge works as flux to separate impurities in the form of slag from liquid cast iron. It can be termed 'continuous' as charging of material is continuous from top charging door while tapping of liquid metal is done from bottom tap hole at intervals. The basic chemical reactions are:

Oxidizing:	$C+O_2$	$\rightarrow CO_2$
	$2C+O_2$	$\rightarrow 2CO$
	$Si+O_2$	$\rightarrow SiO_2$
	$2Mn+O_2$	$\rightarrow 2MnO$
	$Fe+O$	$\rightarrow FeO$
Flux/slag:	$CaCO_3$	$\rightarrow CaO+CO_2$
	$(SiO_2, MnO, FeO)+CaO \rightarrow Slag$	
	$Mn+FeO$ (slag)	$\rightarrow MnO+Fe$
	$SiO_2+X\,FeO$	$\rightarrow FeO.SiO_2+Fe$ (slag)
Carburisation:	$3Fe+C$	$\rightarrow Fe_3C$ (Absorption of C as cementite)
	$C+FeO$	$\rightarrow Fe+CO$

b. Description

Cupola is a mini-blast furnace. It has a long cylindrical shell made of mild steel sheet and lined inside with fire-clay refractory bricks. It has a door at the top for charging and a spark arrester to prevent sparks and unburnt fuel particles from flowing into the atmosphere. The bottom has a circular door hinged for emptying the contents of the furnace. The structure is supported on steel legs grouted into ground. Air/oxygen for combustion is provided by a blower through a wind box for uniform pressure around the cupola which enters through a number of rectangular openings called 'tuyers'. Provision is made at the bottom of the hearth to tap liquid metal through a tap hole and spout which is normally kept closed by a refractory 'bot' and opened when needed. Just below the tuyer level is a slag hole and spout to remove slag, once liquid metal accumulates fully in the hearth or crucible. (Fig 4.6)

Table: 4.2 Cupola Design/Major Dimensions

Sl. No.	Dia. inside lining at hearth (mm)	Melting rate (tons)	Ht. of Tuyer bottom from floor	Ht. bottom (mm)	Ht. of charging door from bottom (mm)	Wind-box (mm) width	Wind-box (mm) height	Chimney height from door (mm)	Tuyers			Air pipe
									Nos.	width	height	dia (mm)
1.	500	0.7-1.3	750	650	2000	160	600	2000	4	130	85	175
2.	600	1.5-2.0	750	700	2500	180	650	2500	4	160	95	200
3.	700	2.0-2.5	850	750	2500	200	700	2500	4	200	100	225
4.	800	2.5-3.0	850	800	3500	240	750	2500	6	210	110	250
5.	900	3.0-4.0	950	850	4000	270	800	2800	6	220	120	275
6.	1000	4.0-5.0	950	900	4000	300	850	3000	6	240	130	300

Table 4.3 Cupola Operating Parameters

Sl. No.	Inner Dia (mm)	Coke Metal ratio	Charge (Kg)			Air Blast		Blower HP/KW	Bed coke Ht. above tuyers (mm)	Shell plate (mm)	Lining thickness (mm)	Hearth ht tap-slag hole (mm)
			Metal	Coke	Lime stone	Volume (m^3)	Pressure (WG. mm)					
1.	500	1 : 6	120	20	7	20-25	275	5/3.8	800	5	125	300
2.	600	1 : 7	160	25	8	30-40	325	7.5/5.6	850	6	125	325
3.	700	1 : 7	210	30	10	40-50	400	12/9.1	875	8	125	350
4.	800	1 : 7	280	40	12	50-60	450	16/12.2	900	8	175	375
5.	900	1 : 7.5	360	50	15	60-70	500	20/15.2	925	10	175	425
6.	1000	1 : 7.5	450	62	22	70-85	550	30/23	950	10	175	450

c. Design of cupola

Cupola is designed on the basis of its melting capacity. The important parameters to be decided are: metal to coke ratio, inner diameter, volume/pressure of air-blast, blower capacity, tuyers, hearth height, bed-coke height and charge mixture.

Inner diameter at hearth:

This is the controlling factor which determines the melting capacity. Approximately 1Kg of metal can be melted per hour in 2 Sq. cm of hearth area while using a metal to coke ratio of 7:1 (depending on the quality of coke).

Eg.: For 1000Kg/hour melting capacity,
hearth area required = 2x1000 = 2000 Sq.cm($\pi d^2/4$)
Inner diameter of cupola (d) = 50 cm (20")

Metal to coke ratio:

To melt metallic charge of pig iron and scrap, coke is used. The quantity of coke needed depends upon its calorific value, fixed carbon and ash content as well as the inner diameter of the cupola with sufficient air supply. Normally with inferior Indian coke (more than 20% ash) 1Kg of coke is needed to melt 6 to 8 Kg of metal, whereas with high quality low ash coke, about 10 Kg of metal can be melted. Good quality coke (less than 20% ash) can give 6 to 7 tonnes of metal melted per hour per square meter of hearth area. Normal metal to coke ratio with Indian coke can be assumed as 7:1.

Air for combustion:

Proper quantity of air at suitable pressure is essential to complete the melting of metal in cupola and supply at proper temperature. Normally about 8.5 cubic meters of air at atmospheric pressure is needed for complete combustion of 1Kg of coke (including line losses). Thus for a metal to coke ratio of 7:1 and 1000 Kg per hour melting capacity, a cupola needs:

$$8.5 \times 1000/7 = 1220 \text{ M}^3 \text{ of air}$$

At 300 mm water gauge pressure, this is approximately 20 to 25m^3 per minute of air. A normal centrifugal blower of 5 H.P motor is needed for delivering this. Tuyer area is chosen, depending on the quality of coke, normally 1/6th of hearth inside area. This is divided into number of tuyers uniformly positioned around the circumference, varying from 4 to 10 depending on the size of the cupola. (Tables 4.2, 4.3 for Design data)

4.3 Melting procedures

Melting procedures, practical aspects of melting control, refining and special techniques for cast iron, S.G. iron, steel and common non-ferrous casting alloys are described in the following pages.

The melting furnaces considered are (a) for cast irons - cupola, (b) for steels-electric arc and induction furnaces and (c) for non-ferrous metals oil-fired furnace.

i. Cast iron melting - cupola operation

a. Cupola operation

At least 4 to 8 hours before starting, the cupola is checked for inside lining damages and repaired using refractory mass/bricks. The bottom door is closed and a sand-bottom made sloping towards the tap-hole. The tap-spout is cleaned and hole closed with fire-clay bot.

Dry firewood, rags etc., are placed on the bottom, above which bed-coke is charged to the required height. The coke-bed is burned using low air-blast from the blower till it is uniformly red in color. The height is checked from the charging door and replenished with coke.

Metallic charge consistingof pig iron.foundaryreturns, steel scrap etc., with coke and lime stone (flux) are dropped from the top charging door in given size and quantity continuously. The blower is kept low for about 30 minutes for soaking the initial charge. Then a full blast of air is given to melt continuously.

Observation through the tuyer windows shows droplets of liquid metal falling into the hearth. After reasonable time when the slag is observed at slag hole it is removed and liquid metal is tapped out into ladles by opening the tap-hole which is plugged after that.

Charging from tap continues till all the molds required are poured. Tapping takes place at suitable intervals.

After completing the operation, the air-blast is put off and the bottom door is opened, discharging the balance contents. It is necessary to clean the inside of lining in hot condition only, as, after cooling metal and coke sticking to it cannot be removed without damages to the lining.

ii. Calculations in cupola design and charge-mix

Eg: A ton per hour melting capacity cupola has a hearth area of 2000 Sq.cm. The total tuyer area = 2000 ÷ 6 = 330 Sq.cm. Assuming 4 tuyers, area of each tuyer is 81 Sq.cm. This can be made into a rectangular opening with 105 x 80 mm (width x height). Hearth height from tap-hole to slag-hole is calculated to accommodate the maximum volume of liquid metal and slag for the desired melting rate.

Eg: For 1 tonne/hour melting rate, (for cast iron of specific weight 7.2 Kg/1000cc)
volume of hearth = $1000 \times 1000 \div 7.2$ c.c
cross-sectional area = 2000 Sq.cm.
therefore, hearth height = $(1000 \times 1000) \div (7.2 \times 2000) \simeq 70$ cm. (approximately)
Keeping space for coke and extra for slag, hearth height = $70 \times 4.0 \simeq 300$ cm

All other dimensions are decided by practical considerations. For normally used cupolas with melting capacities for 1 ton to 5 tons per hour, the recommended design/dimensions are given in Table 4.2. Bed-coke height is calculated from the tuyers height and kept at a minimum of 600 mm to 1000 mm depending on melting rate.

Charge:

Charge mix is decided on the basis of melting rate, inner dia of Cupola and quality of coke (metal to coke ratio).

For example, for a 2 ton/hour melting rate (ID = 600 mm) cupola, 200 Kg metallic charge (pig iron + scrap), 35 Kg coke (7:1) and 10 Kg lime stone (30% of coke) can be used.

Refer Table 4.3. for normal operating parameters for Indian conditions.

Calculation of charge mix to suit final composition of liquid metal (C.I.) tapped:

During the melting operations, elements like C, Si, Mn undergo some loss or gain from the original charge. Accordingly the required charge can be calculated for a required composition. The method of calculation is illustrated by the following example:

Composition of charge materials:

Sl. No.	Charge material	% of charge	Element		Mn	Sulphur	Phosphorous
			Carbon	Silicon			
1.	Pig iron	40%	3.4	1.8	0.8	0.08	0.5
2.	Foundry return	50%	3.2	1.5	0.6	0.08	0.5
3.	Steel scrap	10%	0.2	0.5	0.8	0.04	0.05

Chemical analysis for 100kg charge:

		C	Si	Mn	Si	P
1.	Pig iron (40)	1.36	0.72	0.32	0.032	0.200
2.	Foundry return(50)	1.60	0.75	0.30	0.040	0.250
3.	Steel scrap (10)	0.02	0.05	0.08	0.004	0.005
	Total (100)	2.98	1.52	0.70	0.076	0.455
	% loss or gain	+15%	-10%	-15%	+0.1%	-
	Quantity - loss/gain	+0.45	-0.15	-0.10	0.001	0.455
Final composition after adjustment		3.43	1.37	0.60	0.077	0.455

Problem: Charge mix for least cost.

Calculate the charge mix and the lowest cost given the following data and restrictions:

	Charge material	Sulphur(%)	Cost (Rs/Tonne)	Proportion
(a)	Pig iron	0.04	7200	X
(b)	Foundry returns	0.09	6000	Y
(c)	Steel scrap	0.04	5000	Z

Restrictions:

(i) Maximum of 10% steel scrap per charge can be melted

(ii) Final sulphur content should not exceed 0.07 percent, (ignore melting losses).

Working:

For least cost, maximum permissible quantity of cheapest material, steel scrap should be used.

Assuming a final charge of 100 Kg.

$$X + Y + Z = 100 \quad (1)$$

$$\text{Maximum steel scrap } Z = 0.1\ (X+Y+Z) \quad (2)$$

$$= 0.1 \times 100 = 10 \quad (3)$$

$$\text{therefore} \quad X+Y = 90 \quad (4)$$

Final sulphur content:

$$X \times 0.04 + Y \times 0.09 + Z \times 0.04 \leq 0.07 \times 100 \quad (5)$$

From (3) $0.04\,X + 0.09\,Y = 7.0 - 0.4 = 6.6$ (6)

Solving (4) & (6)

$$0.04X + 0.04\,Y = 90 \times 0.04$$

$$0.05\,Y = 3.0$$

$$Y = 60,\ X = 30,\ Z = 10$$

So the proportion for least cost is :

30% Pig iron
60% Foundry return
and 10% Steel scrap.

Cost per tonne of charge:

$$0.3 \times 7200 + 0.6 \times 6000 + 0.1 \times 5000 = \text{Rs. } 6{,}260.$$

c. Common metal quality tests

Apart from routine chemical analysis and liquid metal temperature using optical/immersion pyrometer, one of the common shop-floor tests is wedge or chill test. This simple test consists of a small mold having a cavity corresponding to a wedge. Liquid C.I. to be tested is poured into it and the resulting wedge, after cooling is broken with a hammer. The triangular cross section shows typical bright, lustrous area at this edge and normal grey area at the wider side. The depth/width of chill (bright) is indication of C.I. with more steel scrap addition and vice-verse. Experienced melters use this test to get much useful information of melting technique/charge and improve as needed during operation.

Inoculation at spout:

In normally tapped C.I., the graphite flakes are not favourable with large sizes and non-uniform distribution. The inoculation process consists of adding a very small quantity (0.1%) at the spout into the flowing liquid metal stream during tapping, nucleating solid particles of alloys like calcium silicide to improve the microstructure considerably, resulting in finer and evenly distributed graphite flakes. This is found to increase mechanical properties like tensile strength considerably from 30 to 100%, reducing the harmful effect of chilling, like hard unmachinable areas.

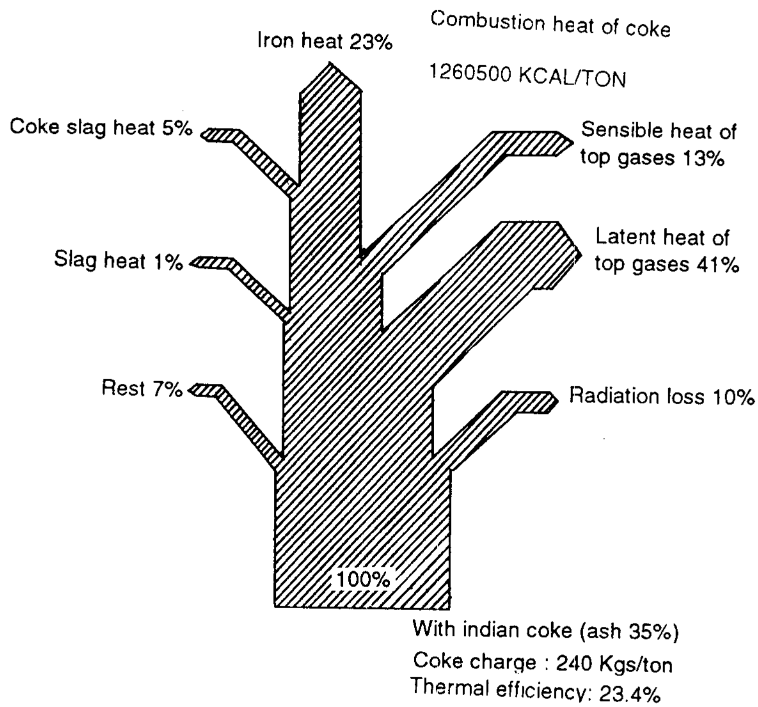


Fig. 4.7 Heat balance of cold-blast cupola

d. Common problems with cupola melting in India

a. Due to poor quality of coke with high ash content (over 25%), low tapping temperature, high coke consumption and high slag volume.

b. Difficulty in operation resulting often in 'bridging', solidification of solid charge with semi-liquid metal, just above tuyers resulting in stopping of further melting.

c. Difficulty in making higher grades of C.I. with more steel scrap and low fluidity in complicated thin cooled castings.

d. Low thermal efficiency (Fig. 4.7)

e. Hot-blast cupola

The major problems stated above with normal cold blast cupola in India can be effectively solved by using simple hot-blast arrangement. In this, the air-blast into the cupola is preheated to 150-250°C using the heat energy of the exhaust/flue gases.

Almost 40% effective heat is normally lost through hot semi-burnt flue gases. Part of this heat can be recuperated and used to preheat the air-blast entering the cupola. One of the simple methods is to use a heat exchanger in

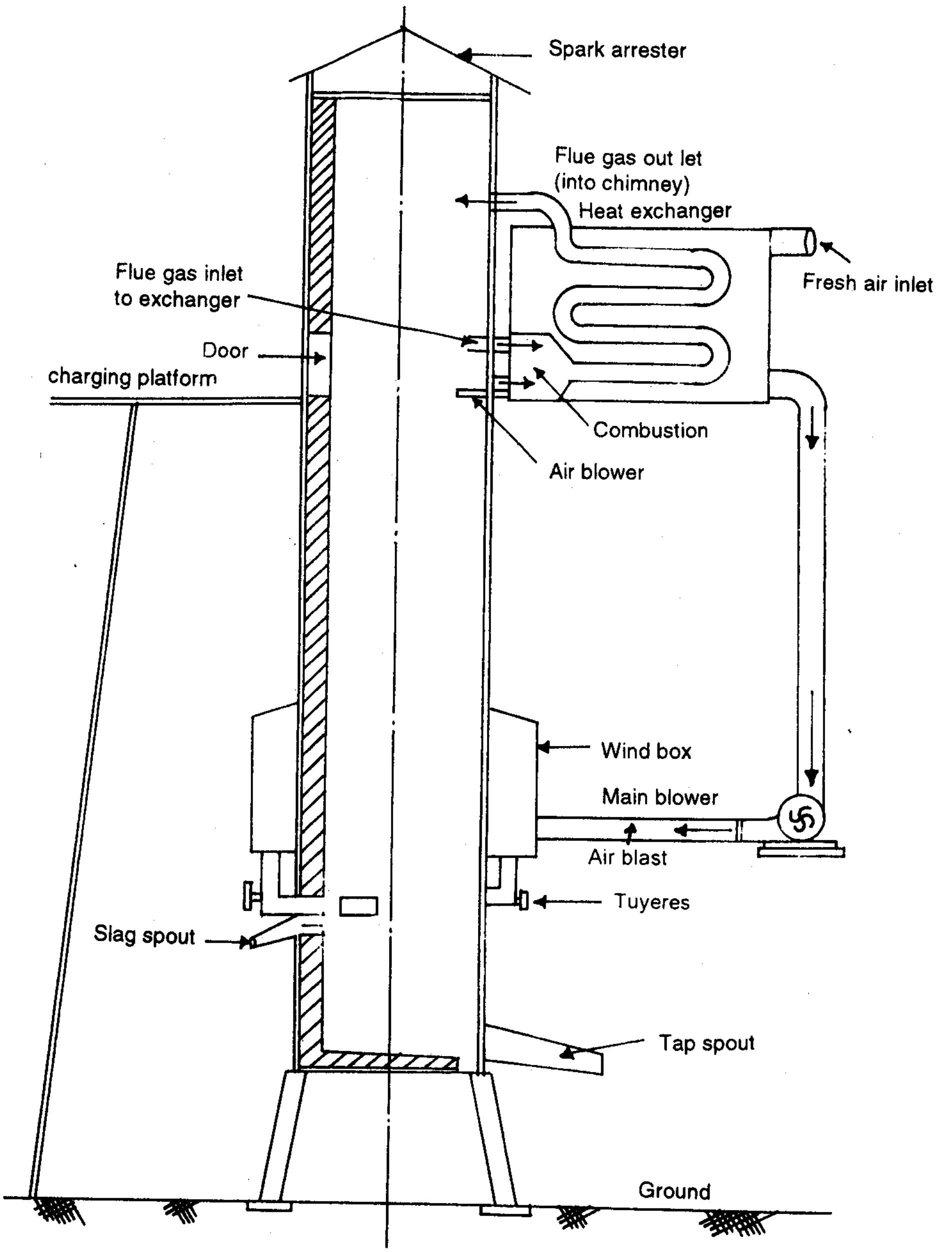


Fig. 4.8 Layout of hot-blast cupola

which un-burnt CO/flue gases tapped near the cupola charging door are allowed to complete combustion using additional air, heating the exchanger.

The cold air from the main blower enters the heat exchanger from top and is conveyed through blast piping to cupola wind box after absorbing the heat, from bottom. This installation is low in initial cost as well as maintenance due to non-mixing of contaminated flue gases with cold air (Fig 4.8).

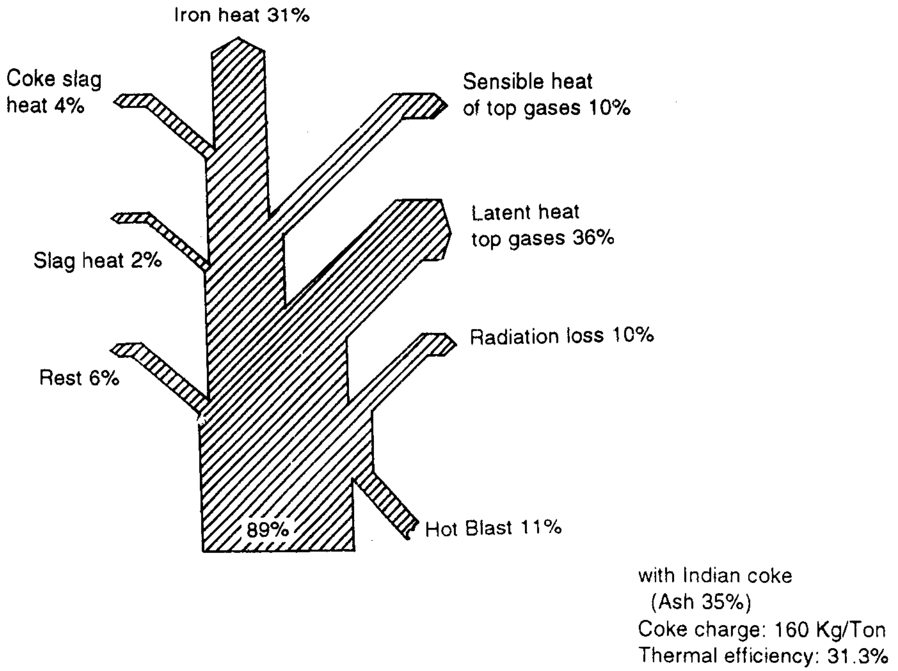


Fig. 4.9 Heat balance of hot-blast cupola

Advantages of hot-blast cupola:

- With same coke to metal ratio in the charge, there is a 30 to 50°C rise in spout/tapping temperature. This helps in producing thin walled critical castings of high quality.
- This can accommodate use of low quality low priced coke to a higher proportion without affecting melting and causing bridging.
- Saving in coke upto 25% of charge is found possible. Coke to metal ratio can be increased from normal 1:7 to 1:10 saving coke considerably.
- Can use higher percentage of high melting point steel scrap which not only reduces charge cost but gives higher strength cast irons.
- Increase in melting rate.
- Reduction in harmful sulphur content due to higher melting temperature.
- Reduction in loss of silicon.
- Reasonable cost of installation making it possible to recover investments in a short period. Governmental assistance and subsidies are available on installation of hot-blast system to reduce coke consumption, energy saving and to improve efficiency/productivity.
- Higher thermal efficiency (Fig. 4.9).

f. Water-cooled cupola

This is an improvement on normal cupola. In this, a water chamber (jacket) is provided around the hearth area outside the shell where arrangement for cooling water circulation is made. The main purpose is to reduce the inner lining thickness in this important zone by which the inner diameter/melting area is increased without any other change in cupola. Depending upon the diameter, this method can increase the melting capacity of cupola from 5 to 20 percent. But considerable risk is involved as improper design of cooling can cause the shell to puncture in operation.

g. Divided blast cupola

In large sizes of cupola (over 1000 mm dia), distributing tuyers in two or more rows instead of in a simple row around the shell is found to give better distribution of air and uniform melting. Ease in operation and better liquid metal output were observed with such design of tuyers/wind box/piping.

h. Inoculation of cast irons

Inoculation of grey cast irons is essential to produce high quality castings with consistent properties of machinability, reduced section sensitivity and higher strength, by controlling the graphite structure through minimising the undercooling. By the addition of the inoculant in very small amounts (0.05 to 0.3%) into liquid metal before pouring, (a) chill (iron-carbide) or high hardness, problems of machinability in this section are eliminated, (b) randomly oriented, uniformly distributed, type 'A' graphite in a predominantly pearlitic matrix is formed which is the most desirable microstructure for good strength, (c) section sensitivity is reduced, giving uniform properties in thin and thick section of the casting and (d) the 'cell count' or nucleation centres is increased to improve mechanical properties, preventing segregation of impurities.

Inoculating agents:

To achieve the above properties without causing slag/dross, pinholes or unsolubility, many chemicals are used. Most of these are based on ferro-silicon having 45-70% Si. They are supplemented by aluminium (0.5-1.5%) and calcium (0.5-2.0%). Sometimes other materials like cerium, strontium, manganese, magnesium etc., are also added in small quantities.

Practical aspects of inoculation:

- Inoculants should be added as late as possible into liquid metal before pouring.
- They should be added to clean metal free of slag or dross.
- It is preferable to add it continuously to the liquid metal stream when the ladle is 1/3 full and complete the addition where the ladle is 3/4 full.
- Lower carbon equivalent melt needs more inoculation.
- Thinner wall castings and melt with lower than 0.04% sulphur need it.
- Higher proportion of steel scrap in charge require this.

- Iron melted in electric furnaces, specially arc furnaces need it more than cupola-melted cast iron.
- Longer holding period and higher pouring temperature (above 1450°C) need more inoculation.

  Many proprietory processes such as 'Meehanite' are available for making high quality cast iron using inoculation, used extensively for critical machine tool bodies, diesel engine cylinder blocks etc.

ii. Melting of S.G. Iron

Cast irons offer a large range of the mechanical properties of strength, hardness, machinability, wear resistance, low friction coefficient, corrosion resistance damping capacity etc. Other plus points of cast irons are the foundry properties like high yield, fluidity, low shrinkage, casting soundness, ease ot production etc., which make the material very suitable for making cast components out of it. The continued and well spread use of cast irons depend upon these outstanding properties.

In general, cast iron is an alloy of iron, carbon (upto about 4.0%) and silicon (upto 3.50%).

S.G. Iron (Spheroidal graphite, nodular or ductile cast iron):

S.G. Iron is a bridge between grey iron and steel with combined properties of both. It is a specially prepared iron treated in molten condition with a small percentage of magnesium, cerium or other agents that causes a large portion of its carbon to segregate as spheroids of graphite rather than as flakes. Spheroidal type of graphite gives ductility. (Table 4.4)

Magnesium is by far the most effective and economical element to promote spherodization of graphite. The content of sulphur and oxygen in the base iron determine the amount of magnesium to produce S.G. Generally a minimum retained magnesium content of 0.015 is considered adequate.

The base iron temperature at treatment is considerably above the boiling point of magnesium. To reduce the volatility of the reaction, magnesium is usually alloyed with other elements. A number of alloys have been developed for this purpose. Magnesium recovery is usually higher when the lower magnesium content alloys are used. Recovery also depends upon the method of addition of magnesium alloy to the melt, the most common methods of adding magnesium being:

a. the open ladle method
b. the plunging method and
c. the mechanical feeder.

a. The open ladle method

It consists in first placing the magnesium alloy at the bottom of a treatment ladle and then tapping the melt on to the alloy. The violent reaction of magnesium vapour with the liquid iron is confined to the ladle, due to the narrow and deep design of ladle.

Table 4.4 Different common types of S.G. Irons

Type*	Brinnel hardness No.	Characteristics	Applications
80-60-03	200-270	Pearlitic matrix high strength as cast, of responds easily to flame or inductor hardening	Heavy duty machinery, gears, dies rolls for wear resistance and strength
60-45-10	140-200	Essentially ferrite matrix. Excellent machinability and good ductivity	Pressure castings, valves and pump bodies, shock resisting parts
60-40-15	140-190	Fully ferrite matrix high ductility and low transition temp.	Naval / ship parts
100-70-03	240-300	Uniformly fine pearlite matrix, normalized and tempered or alloyed. Excellent combination of strength, wear resistance and ductility	Pinions, gears, crane shafts, cams, guides track rollers
120-90-02	270-300	Matrix of tempered martensite, alloyed to provide hardenability. high strength and wear resistance.	

* the type number indicates, the min. tensile strength, yield strength and percent of elogation (ASTM)

Carbon %	Silicon %	Manganese %	Sulphur %	Phosphorous %
3.0 - 4.0	1.8 - 2.8	0.15 - 0.90	.03 Max.	.10 Max.

The open ladle method results in minimum loss in melt temperatures and is a flexible method at low equipment costs.

In one method called "sandwich" method, the magnesium alloy is placed into a recess in the refractory bottom of the ladle. The alloy is then covered by a steel plate, iron chips, steel punchings, ferro-silicon or an inert material.

b. Plunging method

This involves placing the magnesium alloy into a container positioned within a vented graphite or refractory bell fastened to a refractory-covered plunging rod. The bell is then plunged into a ladle filled with molten iron. Greater degree of control over residual magnesium can be obtained by this method.

c. Mechanical feeder method

In this method magnesium alloy is continuously added to the melt coming out of the cupola of fore-hearth. This allows continuous and uniform treatment and magnesium recovery is also generally greater than the obtained by other methods.

Metallurgical considerations:

Greater degree of control over manufacturing process is required in case of S.G. Iron, than is needed for grey cast iron, because production of S.G. Iron is a process highly sensitive to process variations.

The graphite shape developed in ductile iron has been shown to be dependent on pouring temperature, casting section size, amount of effective magnesium added, post inoculation and base analysis of the iron. As a general rule, poorer graphite shapes are developed with low pouring temperature, heavy sector size, insufficient magnesium addition, lack of inoculation, and low carbon equivalent.

iii. Steel melting in foundry

Carbon and alloy steels are used extensively for casting critical components subjected to severe working conditions involving high tensile loads, corrosion, abrasion, heat as well as impact, creep and fatigue stresses. Cast steels differ from wrought steels used in rolling, forging etc., in their wider ranges of composition, less impurities and higher casting temperature. In addition, due to the variety of specification handled in foundries, careful segregation and control of charge materials (comprising foundry-returns) is needed. Generally, the size of melting units used for making cast steels range from 100 Kg to 20 tons, the most common range being 500 Kg to 5000 Kg. The preferred melting units in steel foundries are three-phase direct arc furnaces and medium/high frequency core-less induction furnaces. Smaller sizes furnaces are more suitable for jobbing foundries whereas larger furnaces (above 10 tons) are preferred by mini-steel plants.

a. The important metallurgical factors involved in steel melting in foundries include

- High melting/pouring temperatures and high energy requirements.
- Necessity of high quality refractories of melting units and ladles.
- Effect of impurities in molten metal on mechanical properties.
- Absorption of harmful gases like H_2, N and O_2 during melting/casting.
- Effect of alloying elements on structure and properties
- Need for careful control over melting losses.
- Large range of solidification temperature.
- Low fluidity of liquid metal (compared to other cast metals)
- High volumetric contraction during solidification.
- Development of high thermal stresses during solidification.

Good understanding of the above aspects helps achieve substantial cost reduction, high productivity and quality in foundry steel melting and casting.

b. Melting of carbon steels in arc furnace

Reactions and theory:

The basic lined arc furnace with double-slag techinque yields the best quality carbon steels with the lowest level of impurities.

Oxidation period:

The purpose of oxidation is to decrease phosphorous content in the metal to below 0.04%, removal of gases like nitrogen and hydrogen, removing non-metallic inclusions and moisture in charge materials.

The conditions required for reduction of phosphorous are:

- sufficient supply of oxygen, to give high FeO content in slag
- good basicity of slag
- low temperature of metal pool

$$2P + 5FeO \rightleftharpoons P_2O_5 + 5Fe + 47{,}850 \text{ K. Cal.}$$

$$3FeO + P_2O_5 + 4CaO \rightleftharpoons (4CaO\ P_2O_5 + 3FeO) + 130{,}100 \text{ K.Cal.}$$

Maximum removal of phosphorous occurs with about 40-60% CaO and with low temperature. With increase of metal temperature, the removal reduces and even reverses.

Carbon-boil:

During melting, oxygen from FeO reacts with carbon in the charge to form Fe and CO. CO being insoluble escapes stirring the molten metal causing "boiling". Proper boiling requires sufficient FeO and C in charge, good contact with gas, rising temperature. Boil helps in removal of impurities, hydrogen and nitrogen.

During oxidation, before dephospherization is complete, other alloying elements may be oxidized and lost to slag. According to the affinity for oxygen, the order of alloying elements is Ca, Mg, A1, Ti, Si, Mn, Cr, Va, P, W, C, Fe. All the above will be oxidized by FeO.

On the other hand Ni, Mo, Cu have lower affinity for oxygen than Fe.

Accordingly care has to be taken for adding alloying elements during oxidation or during reduction period.

Slag composition required before oxidation period, after melt down:

CaO	-	40-50%
SiO_2	-	10-15%
FeO	-	10-20%
MnO	-	5-15%

After finishing oxidation period, the slag should have

CaO	-	40%
SiO_2	-	22%
FeO/Fe_2O_3	-	15%
MnO	-	10%
MgO	-	7%

Reduction period:
The purpose of reduction period is to:

- deoxidise the metal $FeO + C \rightarrow Fe + CO$
- removal of sulphur
- alloying high-oxidizable elements
- obtain proper composition of steel
- obtain proper tapping temperature.

Sulphur reduction condition:

- high basicity of slag
- abundant fluffy slag
- low FeO content
- high temperature

  $CaO + FeS \rightarrow FeO + CaS$ (into slag)

c. Melting procedure (Practical instructions)

Charging:

Place/light scrap/(turning &, boring) 10% at furnace bottom, over these keep heaviest pieces under electrodes, charge lime stone (2% of total CaO), charge smaller risers and returns. Keep sufficient coke to get about 0.5% Carbon. Top it again with light scrap. Keep coke-pieces under electrodes.

Melting down:

Start with lower current and after the movement of electrodes becomes steady, increase current for faster melting. When 80% is molten, switch off power, lift electrodes, poke the charge around furnace walls into the central pool. Switch on the power and complete melting.

Oxidation:

After full melt-down add iron ore or scale for boil. Oxygen from bank of cylinders can be used through a pipe at 8-12 Kg/cm^2 pressure into liquid metal to cause vigorous oxidation. The initial copious red fumes will gradually subside as carbon goes down below 0.1% when oxygen can be switched off. Thus oxygen lancing reduces decarburization to a few minutes, saving precious heat-time and power consumption. Ofcourse, it causes additional wear of refractory lining. Limestone is added to the bath along with CaF_2. Temperature reaches about 1600-1630°C at the end of oxidation.

Slag of oxidation period containing impurities and phosphorous is totally removed to get a mirror-like metal surface.

Reducing period:

Crushed coke/graphite electrode pieces are charged on liquid metal. Fluorspar, limestone and coke can be further added on the surface to cover. The slag should be fluffy and white in colour with the small of acetelyne (carbide slag).

Deoxidation using FeSi (to get 0.5% Si in final analysis) should be given below slag layer. After required tapping temperature is reached, final analysis is checked and slag is fully removed. (See Table 4.5, 4.6)

After tapping metal into the ladle, deoxidation is finished by adding about one Kg. of aluminium for a one ton of steel (sometimes partly in the furnace and partly in the ladle).

iv. Alloy steels: Alloy addition procedure

The ferro-alloys should be perfectly dried and preferably preheated to about 600°C at furnace.

a. Nickel, Cobalt, Copper

These alloys can be added along with the charge.

b. Molybdenum

Added after melting down before carbon boil.

c. Tungsten

Added before starting reduction period. Thorough mixing of metal pool from bottom is essential.

d. Vanadium

Added in reduction period after Fe-Si addition, about 15-30 minutes before tapping.

e. Manganese

Added at start of reduction period after getting good fluid slag.

f. Chromium

Added after Fe-Mn addition in reduction charge to be nearer to electrodes.

g. Titanium

Added just before tapping, after slag-off and lifting of electrodes.

v. Melting procedure for austenitic manganese steel in arc furnace

Austenitic manganese steel containing 1.1-1.4% carbon, 11-14% manganese is one of the most common alloy steels melted in steel foundries. These steels can be economically melted using about 60% returns (rejections, runners, risers and used liners) and 40% mild steel scrap. After melt down, oxygen lancing can be done to reduce carbon level by 10 to 15 points. Ferro-silicon, fluospar and lime are added to make white slag. After checking analysis, adjustments of carbon and manganese can be made finally using high carbon or low carbon ferro-manganese. The slag is maintained throughout the heat till tapping. The procedure helps in manganese recovery of over 90% and also avoids build-up of hydrogen and nitrogen which result in pin holes in castings poured. Other precautions of proper drying of ladles, use of dry refractories, clean melting practice etc., are common.

vi. Effect of furnace utilization on total power requirement

The power consumption per ton of steel melted reduces significantly with increasing number of continuous heats taken in arc furnace. Studies on nominal two ton basic electric arc furnace have given the following results.

Average power in KWH per tonne of steel:			Energy saving %
For only 1 heat (first heats)	---	890	-
2nd heat (second heats)	---	753	15%
3rd heat (third heats)	---	670	25%
4th heat (fourth heats)	---	630	30%

It is highly necessary to plan continuous operation of arc furnace, for minimum 3 heats at a stretch to obtain optimum power consumption.

vii. Induction furnace melting

The charge for induction melting has to be carefully selected avoiding rusty scrap, impure alloys and improper sizes for accommodation in the crucible. Turnings and smaller piece, can be charged at the bottom of the furnace and the balance on the top.

As melting proceeds, further scrap can be added along with suitable alloy additions. The high speed of melting and smaller surface area cause negligible loss of alloys during melting. At the same time, there is no method to remove sulphur or phosphorous, if obtained higher, from the charge. After final melt-down, composition is adjusted through calculated additions, deoxidation is done by ferro-silicon and aluminium, (partly in furnace and partly in ladle), slag is removed and metal is tapped. The new induction furnaces offer much savings in power, higher volume of production, easier melting procedure, better homogenous mixing of alloys due to inductive stirring, cleaner melting, less fluctuation in voltage in the system and less loss of alloying elements compared to arc furnace melting. However, for high quality low alloy, high strength steels with stringent composition control, arc furnaces continue to be in use, mainly due to the non-availability of reliable charging scrap and ferro-alloys. In Indian steel foundries, induction furnaces in varying sizes upto 2 tons capacity are very popular, the larger sizes above 2 tons being mostly arc furnaces. One of the popular- make medium frequency induction furnace has the following characteristics:

Power rating - 450 KW, frequency - 1000 Hz, melting rate for steel @ 780 Kg per hour and power consumption - 640 KWH/Ton.

The recent trend in foundries indicate shift towards induction melting and holding furnaces. See Fig. 4.10 for specimen melting log sheet.

viii. Shop floor rapid tests for metal quality

a. Liquid metal temperature

The sampling spoon is coated with slag on top of molten metal, filled with metal from furnace. The time required in seconds for the formation of skin over bright metal surface is a measure of superheat.

If a slag coated sampling spoon with metal is taken out and poured slowly - if no skull is stuck with the spoon, it indicates sufficient temperature to tap.

Crucible No:........................

Standing W. O	Mat Description	Code	Heat No.	Date	Month	Year	Shift
.... 0001/0							

Shift Foreman	Code	Ladle man	Code	Ladle cap	Type of Nozzle	Dig.	No of Heats

Charging Materials - Scrap			Composition											
Kind	Code	Kg	Prescribed											
Scrap No.														
Scrap No.					C	Mn	P	S	Cr	Ni		Si	Cu	Temp.
Scrap No.			Actual	1										
				2										
				3										

	Code	Kg	Prodn. Process		Code	Hrs	Min	Power consumption		
G.I.			1	Repairs				Meter reading	Kwh	
G.I.			2	Idle time				1 Switched on		
Total kg.			3	Idle time				2 Melted		
Metallic Charge			4	Switched on at				3 Completed		
Kind	Code	Kg	5	Melted till				Consumption in melting		
			6	Completed at				Cons. final completion		
			7	Melting period (5-4)						
			8	Finish period (6-8)						
			9	Idle time				Total consumption		
			Total prodn. time					Mat. for repairs	Code	Kg
			Summary			Kg				
			Scrap & pig iron							
			Addition							
Total Kg			Total charge							
			Melting losses							
Tapping temperature			Molten metal supplied to M.S.					Melter		
Consumption Kwh/t								Foreman		

Remarks:-

Fig. 4.10 Melting sheet for medium frequency furnace

b. *Absorbed gases in metal test for deoxidation*

A small cylinder shaped mold with rounded bottom, rammed in green sand is poured with metal from the furnace, near the furnace itself. If the metal contains any dissolved gases, the top part of the sample would take a convex shape (like a cauliflower). If there are no absorbed gases, it will shrink and show concave shape. Variation of the test include use of graphite mold, sprinkling of exothermic powder on top immediately after pouring metal etc.

A small cylindrical mold with a deep notch at centre is used for testing gas content of metal in same foundries. Immediately after pouring, the cylinder is fractured (at the notch) by hammering. Heavy gas absorption shows clearly as smooth cavities at the centre.

All the above shop-floor tests have to be developed and used with care and experience for rapid and cheap estimation of liquid metal quality before tapping. Even measurement of temperature with Immersion or Radiation Pyrometers, though costly, need to be standardised before relying on experience blindly.

ix. *The essential quality control tests for metal include*

a. Chemical composition (C, S, P, Si, Mn and alloying elements)

b. Mechanical properties (U.T.S., elongation, bend, impact, hardness etc.)

c. Metallurgical Tests (microstructure, grain size etc.)

The important point in conducting the above tests is to cast proper test-specimens and test-bars in the same ladle-melt, to provide suitable identification (non-tamperable) with the melt and store them properly for future use. One of the systems followed is to insert into the test-piece mold, prepunched number of heat on a small mild steel strip, so that it gets welded permanently into casting.

x. *Practical problems during heat and remedies (arc furnace)*

a. *Not getting stable arc/no arc under some electrodes*

- lift the electrodes and slip coke powder/pieces under them.

b. *Furnace bottom getting/melted (red hot)*

- (the cause is loose charge under electrodes, insufficient metal under them till bottom plate), keep heavy risers under electrodes while charging.

c. *Solidified metal at furnace bottom*

- (chilling due to stoppages during melting/higher melting alloys of earlier heat), after tapping, cover the sticking metal with coke/high carbon scrap.

d. *Insufficient oxidation of carbon and phosphorous*

- heavy, viscous slag of high MgO content, remove slag and make fresh fluid slag and keep temperature low by reducing current.

e. *Low activity of reduction slag*

- (due to excess air in furnace), add coke + FeSi and close furnace door. Make fresh slag if required.

Table: 4.5 Liquidus temperature determination

Carbon %	Liquids temperature°C
0.20	1520
0.25	1515
0.30	1511
0.35	1507
0.40	1503
0.45	1499
0.50	1495
0.55	1491
0.60	1487
0.65	1483
0.70	1480

Table 4.6 Depression of liquidus by 0.01% of alloying element

Element	Depression°C
P	0.300
S	0.250
Mn	0.050
Si	0.080
Cr	0.015
Ni	0.040
Mo	0.020

Table 4.7 Melting loss/gain of elements for cast iron and steel

Melting Furnace	Lining	Loss (-)/ Gain (+) % (Percentage)							
		C	Si C.I.	Mn	P	S	Cr	Ni	Mo
Cold blast cupola	Acidic	8	-10 to 20	-15 to 30	-	10	-15 to 20	upto 10	upto 10
Hot blast cupola	Acidic	+8	-10	-10 to 20	-	-5	-10 to 15	upto 5	upto 5
Electric arc	Acidic	-5 to +5	-5	-15 to 30	-	upto 30	upto 20	upto 10	upto 10
Electric mains frequency induction	Acidic	5 to 15	-3 to +5	-10 to 20	-	-		-	-
Steels									
Electric arc	Basic	-5 to 10	-5 to 10	-10 to 15	upto 20	-20 to 50	upto 10	upto 5	upto 5
Electric induction	Acidic	-15 to 20	-15 to 20	-5 to 10	-	-	-	-	-
High frequency	Basic	-10 to 15	-10 to 15	-8 to 10	-	-	-	-	-

Melting procedures for common cast non-ferrous alloys

xi. Aluminium alloys

a. The charge materials, chemicals should be free from moisture, oil, corrosion products and should be preheated befor. changing. The calculation of charge should be done considering the melting loss of each element in the type of melting furnace for final desired analysis.

b. The furnace crucible should be clean an red-hot for charging.

c. Aluminium alloys get readily oxidized and from dross. Using proper covering top with flux and chemicals helps to reduce this. Different proprietory chemicals are available for different alloys.

d. Melting should be done under steady conditions without agitation or stirring to reduce gas pick up.

e. Once melting is complete, degassing using solid chemicals like hexachloro ethane which evolves chlorine or by purging with nitrogen or organ gas is done to remove the dissolved hydrogen. Hydrogen is evolved from moisture.

$$3H_20 + 2A1 \rightarrow 6H + A1_20_3$$

Hydrogen absorbed by liquid metal causes serious porosity in castings during solidification. Degassing should be done in the temperature range of 730 to 750°C.

f. Liquid metal, after degassing, is treated with sodium containing chemicals to improve mechanical properties (modification).

g. Liquid metal once ready, should not be super-heated, agitated or kept long in the furnace which will cause drossing and gas pick-up. Dross should be skimmed properly before pouring.

h. Alloys containing magnesium should be melted carefully as it is highly reactive. Special fluxes and chemicals like sulphur are used to inhibit the reactivity and prevent spontaneous ignition, melting loss and dross.

xii. Copper alloys

(a) and (b) are the same same as for aluminium alloys.

c. Copper alloys have a tendency to absorb hydrogen which form serious pin-hole defects in castings and cause pressure leakages. To prevent this, initially oxidizing atmosphere (with about 0.50% free oxygen) is maintained in the products of combustion in furnace.

d. Fluxes like borax, bottle-glass powder and charcoal are used to cover the top layer of liquid metal to reduce drossing and oxidation of alloying elements.

e. After initial melting down in the oxidizing condition, a reducing stage is provided by chemicals/fluxes containing 0.02% phosphorous, lithium, borax etc. This will help reduce oxygen absorption in copper.

f. During the reduction period, alloying additions such as zinc, lead and tin are added to get the desired chemical analysis. Grain refiners may be added to improve mechanical properties.

g. Flushing or purging with nitrogen gas or through chemicals is helpful for gas removal, especially in electric induction melting.

h. Liquid metal once ready, should not be stirred, over-heated or retained in the furnace. It should be quickly transferred to ladles and poured into molds with minimum turbulence.

i. Use of a clean, hot furnace, spoons, skimmers, ladles and moisture free charge, chemical addition and covering to prevent gas pick-up are important to prevent pin-hole porosity, the most serious defect in non-ferrous alloys.

4.4 Refractories for furnace/ladle

i. Refractories for furnace/ladle lining

To protect the outer metal shell from the heat and chemical reaction of molten and slag and to prevent loss of heat to outer atmosphere, lining made from refractory shaped bricks and ramming mass is provided inside. In addition, a good refractory should resist the wear and abrasion of the charge metallics dropped inside the furnace, have high/ softening temperature, it should be chemically inert and have low coefficient of thermal expansion to prevent spalling when the furnace is heated and cooled in cycles.

The types of refractories commonly used are classified as acid, basic and neutral. Their properties, applications and cost is given in Table 4.8.

Table : 4.8

S. No.	Property	Acidic	Basic	Neutral
1.	Refractoriness (fusion temp)	below 1750°C	above 2500°C	above 2000°C
2.	Composition	Silica (SiO_2) (quartzite) Fire clay (Al_2O_3, SiO_2, H_2O) Mullite	Magnesite ($MgCO_3$) Chrome-magnesite Dolomite $Ca(MgCO_3)_2$	Chromite (CrO) Graphite (Carbon) Silliminite, Zircon (ZrO)
3.	Chemical resistivity	Not attacked by acidic slag but reacts with basic flux (lime)	Does not react with basic flux or slag	Does not react with acid/basic flux/slag
4.	Resistance to thermal shock, abrasion, spalling	Low to medium	Magnesite-medium Cr-Magnesite-high	High
5.	Cost	Cheapest, easily available	Costly (Dolomite is cheaper)	Very costly
6.	Applications	Cupola, acid lined Arc, induction, lower quality steels, low control of S & P, for roofs, sides not in contact with liquid metal/ slag and ladle linings, Heat-treatment ovens.	Basic Arc furnace, induction melting, high quality steels with low S & P, for hearth and sides in contact, with liquid metal and slag, and as base powder for mold & core paints/ wash.	As layer seperating top acidic and bottom basic lining and as base powder for mold wash.

ii. Ladles for pouring liquid metal

For transporting hot liquid metal from melting furnace to molds, ladles are used. Ladles are fabricated from mild steel sheet/plate and provided with refractory lining to protect the outer shell and insulate liquid metal from losing heat.. Depending upon the size, shaped/ calcined refractory bricks or rammed lining mass, mostly silica and fireclay ($A1_2O_3$, SiO_2, X H_2O) is used. Different handling and pouring systems, depending on the amount of liquid metal contained, are provided, from simple manual tong-lifting, tubular handle hand-shanks to special tackles for overhear-crane handling and tilting. Ladles are classified on the basis of pouring system:

a. Lip-pouring with manual lifting for small sizes (hand shanks) (Fig 4.11a)

b. Lip-pouring with crane lifting and tilting machanism (Fig 4.11b)

c. Tea-pot ladles with slag-trap (Fig 4.11c) and

d. Bottom-pouring ladles for crane lifting and tilting mechanism (Fig 4.11d)

Lip-pouring ladles are cheap and easy to operate. They are commonly used for ferrous and non-ferrous metals other than steel. Hand shanks are used for single-person manual pouring upto 30Kg and by two persons with long handle upto 80Kg. Larger ladles are equipped with tilting mechanism using worm gear and large wheel-handle for smooth and controlled operation. Tea-pot ladles prevent slag and dross entering molds, especially for dross forming alloys. Lining of tea-pot, ladles is complicated and they have low life. For pouring steel with fluid floating slag at with temperature, bottom pouring ladles are used. A special steel stopper-rod assembly, covered with refractory sleeves, having at bottom a highly refractory nozzle (graphite or magnesite) opening is used to control, close and open the bottom hole of the ladle through a system of levers. Good design, quality nozzle and stopper control skill are essential with these ladles. Otherwise, costly and dangerous leakage of liquid metal run-out during pouring occurs. Bottom-pouring ladles are costly to install and operate but are essential for high quality pouring without slag and dirt inclusions. It is essential to preheat ladles thoroughly.

4.5 Selection of melting furnace

i. Criteria for selection of suitable melting furnace

Melting is the costliest operation in foundry. The choice of melting furnace is the most vital decision affecting the cost, quality and profitability of the unit. Some of the important criteria to be considered are as follows:

a. Quantity of output/melting capacity/rate of melting [Table 4.9],

b. Cost of melting per ton of liquid metal initial and running cost,

c. Control over composition/quality of melt,

d. Melting temperature needed,

e. Metallurgical feasibility and

f. Pollution.

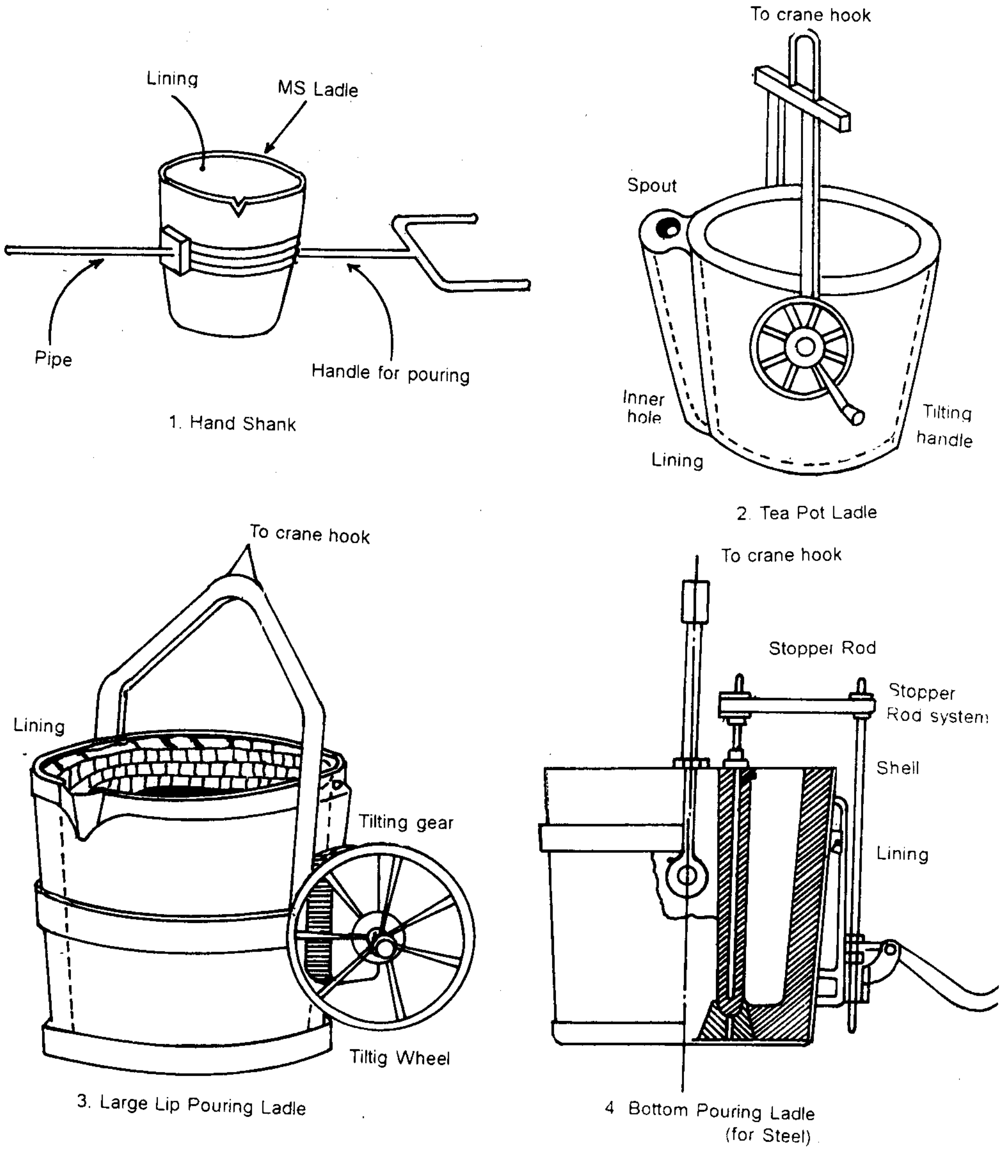


Fig. 4.10 Ladles for liquid metal

a. For deciding the production capacity of a foundry, decision of the size of furnace is important. Too small a size will affect the output and economy, but selecting too large a furnace will reduce its utilization and productivity. The liquid metal needed for pouring the match with molding, fettling and other operation's capacity. When small castings are made, large furnace size results in too long pouring and consequent problems. The general tendency of foundries is to install excess furnace capacity as it appears relatively cheaper per ton of

Table 4.9 Comparative Study of Different Melting Furnaces

	Furnace	Energy Consumption	Auxiliary Equipment requirements	Refractory Material	Exclusive disadvantages	Fxclusive advantages	Application
1.	Pit furnace	800 Kg/Coke/tonne	Blower	Graphite crucible	Limited usage	Very low capital investment	Cast Iron non-ferrous
2.	Rotary furnace	250 Ltr. oil/tonne	Blower and rotating arrangement	Fire bricks ramming mass	Limited usage less controls on composition	Less expensive cast iron melting with low investment	Cast-irons non-ferrous
3.	Cupola furnace	200 Kg/coke/tonne	Blowers	Fire bricks and fire clay	No control on composition	Can give large quantity of metal	Cast-irons only.
4.	Indirect arc furnace	1200KWH unit/tonne	Rocking mechanism phase balancer	Bricks/ ramming mass	Limited usage due to single phase power requirement	Good for very small non ferrous and ferrous foundries	
5.	Direct arc furnace	725 KWH/tonne	Transformers, water cooling system and metal handling equipment	Bricks / castable etc., basic / acidic	Heavy capital investment, power fluctuations, high pollution	Metal purification is possible	Steel
6.	Mains frequency furnace induction	600 KWH/ tonne	Water cooling system and big underground room, capacitors	Ramming mass acidic	Cannot melt steel	Lower capital investment compared to medium frequency furnace, low pollution	Cast iron S.G./ Alloy iron non-ferrous
7.	Medium frequency induction furnace	550-600KWH/tonne	Water cooling system, capacitors	Ramming mass, acidic/basic	Higher capital, investment refining is difficult	Remelting of different alloys without ingredient loss, low pollution	Steel / Alloy steels

melt. For efficient operation, smaller capacity furnace is better as it can work continuous without shut-down, saving power, refractory and with higher melting rate than idle excess capacity. Sometimes two separate melting units, one with large and the other with smaller capacity are installed for more flexibility and utilization, even at a higher initial cost. Electric furnaces are faster and give higher melting rate compared to coke or oil-fired furnaces.

b. Melting cost depends on the initial cost of furnace and auxiliary equipment as well as running costs. Cupola is relatively cheap for melting cast iron compared to electric furnace. Similarly for nonferrous melting, oil-fired furnaces are economical. Installation cost of electric furnace is high as it includes essential transformers (11KV supply, 1500/200KVA), frequency converters, water treatment plants, capacitor banks apart from the electronic control system. Running costs of electric arc furnace are high due to consumption of electrodes, refractories for lining, burning losses, higher power tariff (maximum demand and power units) and maintenance. But for melting carbon steels, cheaper scrap can be used in arc furnace compared to induction furnace reducing running cost. However for high alloy steel melting, induction furnace with lower melting losses of costly alloying elements is preferred.

c. Quality of liquid metal implies control over exact chemical composition of final melt, refining to remove harmful elements, removal of dissolved gases, freedom from slag and other impurities and capability to deliver good liquid metal at the required temperature. Obviously, it is not possible to achieve all these in cheaper furnaces like cupola or oil-fired crucible types. For critical alloys and castings, even though expensive, electric furnace is the only choice. For melting high quality steels, basic lined arc furnace with double slag technique is normally used for reducing sulphur and phosphorus to low levels. For less critical applications, other than steels, non-electric furnaces can be used.

d. Even though all melting furnaces develop high temperature, for ferrous metals the capacity to raise temperature fast is essential. Electric furnaces with control over power/ current input are the best. Hot-blast cupola is ideal for cast iron. For low melting non-ferrous metals, oil-fired furnaces with good burners are economical and adequate.

e. Certain alloys need specific control over furnace atmosphere during melting to avoid burning losses, oxidation of costly metals like zinc, magnesium. Similarly chemical reactions with flux, lining and slag are to be controlled while refining low alloy steels. Some alloys absorb gases like oxygen, hydrogen, nitrogen during melting. Selection of melting furnace should consider these metallurgical characteristics of the alloy to be melted.

f. With stringent legislation of pollution-control over furnace emissions, coke-fired ordinary cupolas, oil-fired furnaces and to a certain extent even arc furnaces are being replaced by quieter and pollution-free electric induction furnaces in many developed countries, even for melting non-ferrous metals. Consideration should be given for the cost of pollution and emission control equipment, while selecting a melting furnace.

ii. Examples of furnace selection

a. For normal grade cast iron castings upto 100 Kg piece-weight, 600 to 1000 tonnes production capacity per year: cupola with 600 mm inner diameter, 1.5 to 2.0 tons per hour melting rate. It can be converted to hot-blast with a little additional cost.

b. For high grade alloy cast irons, S.G. iron upto 100 Kg piece-weight, 1000 tons s per year capacity: electric induction furnace, mains frequency (50 c/s) with 500 Kg crucible, 350 KW power pack, twin crucibles to save lining time.

c. For normal grade aluminium alloy castings upto 10 Kg piece weight, 50 tons per year capacity, oil-fired lift-out crucible furnace with 25 Kg crucible for special high grade alloys with magnesium etc., for gravity die-casting, a medium frequency induction furnace is needed.

d. For copper alloys of normal quality, 50 Kg piece-weight and 100 tonnes per year capacity, oil-fired tilting-crucible furnace of 100 Kg capacity is sufficient. For critical pressure tight castings in brass etc., electric induction furnace, medium frequency (1000 Hz), 150 KW rating, with tilting system is preferred.

e. Low alloy and high quality carbon steel castings upto 1500 Kg piece-weight, 2000 tonnes per year output need electric arc furnace 3000 Kg size, 11 KV, 250 MVA, maximum current 5000 Amps, 600 KWH power consumption per ton of metal melted, with basic lining, matching auxiliary equipment for charging etc., is needed.

f. High alloy steels (stainless, heat-resistant etc., with nickel, chromium etc.) casting size upto 100 Kg piece weight, 300 tons annual production - medium frequency induction furnace (1000 Hz) 200/300 Kg crucible, 250 KW power pack, tilting system with assured high quality charge (scrap) is recommended.

4.6. Casting defects due to improper melting

i. Improper chemical analysis

Incorrect charge calculations including wrong estimates of melting losses, metal recovery, excessive losses due to improper fluxing and slagging operations, improper covering of nonferrous melt cause this defect. This leads to rejections by unsuitable mechanical properties and microstructure. Heat treatment cycles have to be modified to achieve final properties even if there are minor deviations in chemical composition of certain elements.

ii. Gassy metal / hydrogen pickup / pin-hole porosity

Wet and oily scrap, undried ladles, spoons, stirrers of liquid metal unclean melting causes formation and absorption of hydrogen into liquid metal. As casting solidifies, the absorbed hydrogen loses solubility and forms cavities inside casting, trapped by solid outer skin of casting. These defects get revealed during machining. Copper alloys have special tendency to absorb hydrogen.

iii. Oxygen absorption

Excessive oxygen from furnace atmosphere following oxidation during melting causes this. Oxidation also causes loss of costly metals added in the charge, apart from oxide inclusions. Proper deoxidation procedure should be followed in melting. Copper alloys should be melted in the later stages under reducing conditions. For costly alloys, vacuum melting provides the most effective solution.

iv. Slag inclusions

Improper fluxing and slag removal slag particles to be mixed in the metal being poured. Careless pouring, lip-pouring for alloys with fluid slag cause slag particles to enter casting. Use of filters of ceramic / high melting materials, strainer cores in pouring basin and runners effectively reduce this. Slag inclusions in critical castings cause failure and so are rejected.

v. Cold-shut, misrun, unfilled castings

Low pouring temperature, delay in pouring due to many molds being poured, loss of heat from ladle due to improper top covering, failure of ladle opening in bottom-pouring cause premature solidification of metal during pouring mold. These cause the variety of defects mentioned above, which can lead to total rejections in intricate walled castings.

vi. Sand fusion, metal penetration, rough surface

Excessive pouring temperature of liquid metal causes damage to casting surface by attacking mold surface. Controlled pouring, use of refractory mold / core coating/ wash/ paint reduce these defects.

vii. Sand erosion, sand inclusions

Uncontrolled high pouring rate from ladle into mold leads to erosion of mold/ core. The sand particles loosened get trapped in casting causing rejections.

Proper control of melting, refining, tapping temperature followed by proper design, preheating and operation of ladles can reduce these defects.

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Questions

1. How are melting furnaces classified?
2. Compare the performance of the following fuels used in melting furnaces: coke, furnace-oil, electricity.
3. Draw a neat sketch of a coke-fired pit furnace. Explain the procedure for melting aluminium alloys in it.
4. Draw a neat sketch of a tilting type oil-fired crucible furnace and explain the procedure for melting copper alloys in it.

5. Draw a sketch of cupola, showing different parts and zones. What are the steps of operating it to melt cast iron?

6. Explain the importance of (a) bed-coke, (b) air-supply and (c) metal to coke ratio in the performance of cupola.

7. Explain the reasons for the following in cupola operation: (a) bridging (b) low metal temperature and (c) low melting rate.

8. State the important parameters for the design of a cupola. Design a cupola to give 2.0 tonnes of liquid metal per hour.

9. Calculate the final composition of cast iron with the following charge:

	Item	Composition %				Proportion
		C	Si	Mn	S	%
1.	Pig iron	3.4	1.8	0.8	0.05	40%
2.	Foundry return	3.2	1.3	0.6	0.08	50%
3.	Steel scrap	0.2	0.8	0.5	0.04	10%

10. Given that the rate per tonne of the charge materials is as below, find the charge-mix for lowest cost, considering:
    a) more than 10 % steel scrap cannot be melted,
    b) sulphur content of final C.I. should not exceed 0.07% and
    c) cost per tonne of pig iron is Rs. 7000, foundry returns is Rs. 5500, steel scrap is Rs. 5000.

11. "Hot-blast cupola is the most ideal furnace in Indian conditions for efficient melting of cast iron" - justify.

    Or

    Show the lay out of a hot-blast cupola. What are its advantages in Indian conditions.

12. With a sketch explain the parts, principle and operation of an electric induction furnace.

13. Draw a sketch and explain the principle of electric arc furnace.

14. What are the operations in melting and refining steel in Direct Arc furnace. Give the reactions involved in dephospherisation and desulphurisation.

    Or

    Why is double slag process used in melting high quality steels in Arc furnace? Explain the reactions involved.

15. Compare the applications, advantages and limitations of electric Induction and Arc furnaces.

16. Select suitable melting furnaces for the following, stating reasons:
    a) Aluminium alloys, less than 100 Kg. batch
    b) Copper alloys - 100 to 500 Kg. batch
    c) Grey Cast Iron - 1000 Kg. per hour
    d) S.G. / Alloy C.I. - 500 Kg. per hour
    e) Carbon steel - 10,000 Kg. batch
    f) Low alloy steels - 2000 Kg. per heat
    g) High alloy steel - 500 Kg. per heat

18. Mention the types of refractories commonly used for lining of melting furnaces. State their advantages and limitations.

19. Compare acid refractory lining with basic for melting furnaces.
20. Explain the reasons, originating from melting practice for the following defects and suggest remedies:
    a) pin-holes or gas-holes
    b) improper chemical composition
    c) slag inclusions
    d) cold-shuts (too low tapping temp.)
    e) low mechanical properties
    f) burn-on, sand-fusion, metal-penetration (too high temp.)
21. What are the shop-floor tests commonly done to assess the quality of liquid metal before tapping ?
22. What are the common types of ladles used in foundry?
23. Describe with a neat sketch a bottom-pouring ladle. Where is it used?

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5 SOLIDIFICATION, GATING, RISERING AND CASTING DESIGN

One of the most important stages of manufacture of castings is the formation of solid casting from liquid or molten metal phase when poured into mold cavity. The various complex transformations that occur during the process including physical, chemical, metallurgical and geometric changes, influence the quality and cost of the final product - a casting. The understanding of "methoding" or the design of the system which ensures this optimum casting quality to be achieved is very vital in metal casting process. 'Methoding' or 'technology' involves designing pattern equipment and molding process, gating system through which liquid metal is distributed into mold cavity and risering or feeding system which ensure freedom from shrinkage and other solidification oriented defects in the final casting. Obviously this field has attracted research at very high level in different institutions all over the world and as it has grown out of practical data, many empirical methods are also in use.

In general gating system is very critical for cast irons and dross-forming non-ferrous alloys but not so critical for carbon steel castings. On the otherhand steel castings need extensive risering or feeding system for optimum quality. Most of the principles of feeding of steel can be adopted for aluminium and copper alloy castings also. For grey cast iron, feeding is not critical.

Recent developments in methoding practice include various computer programs developed for design of gating and risering systems like "FEEDER-CALC" by FOSECO, "CRUSADER" by British Steel Casting Research and Trade Association, "Computer program for methoding" by Ruddle, U.S.A., "Micro methoding" by Melton and Clegg for non-ferrous alloys etc., which have found wide acceptance industries abroad. Even in India a few leading steel foundries have developed their own computer programs for methoding.

The other important development in feeding practice is the use of feeding aids to improve efficiency of feeding and reduce liquid metal requirements, appreciably reducing energy, material and manufacturing cost. This also helped in standardizing