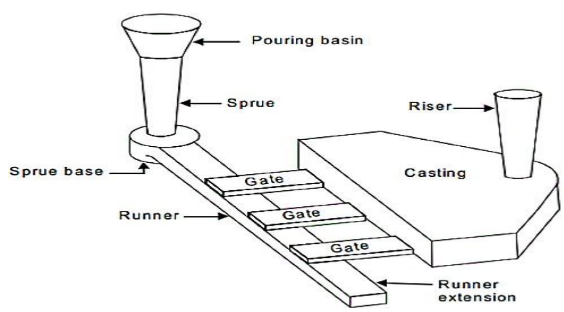
FEDERAL UNIVERSITY OF TECHNOLOGY OWERRI
DEPARTMENT OF MATERIALS & METALLURGICAL ENGINEERING

LABORATORY & ASSIGNMENTS WORKBOOK

For

(ENGINEERING WORKSHOP PRACTICE III)

ENG 201



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UNIT ONE

INTRODUCTION

This is a laboratory and assignments workbook. It is intended to assist students effectively carry out practical work as well as provide opportunity to do **assignments** and exercises that will enhance knowledge of the course in addition to attracting course marks.

Engineering Workshop Practice III (ENG 201) at the Federal University of Technology, Owerri is the third in the series of four compulsory workshop courses for engineering students. It covers the following three thematic areas, which shall also be the focus of this workbook:

- ***Introduction to Manufacturing Technology***
- ***Basic Foundry Technology***
- ***Joining Technology (Arc Welding & Design of Welded Joints)***

The author hereby acknowledge gleaning the information contained in this manual from several sources, particularly "**Fundamentals of Engineering Workshop Practice: Materials and Processes**", edited by O.E. Okorafor (2011) and published by M.C. Computer Press, Nnewi. This is the official Departmental Textbook for the first three Engineering Workshop Practice Courses in the University, namely; ENG 101, ENG 102, and ENG 201.

The principles or theory behind the assignments/exercises in this workbook are available in the above reference text, and will also be discussed in class during lectures.

December, 2016
Department of Materials & Metallurgical Engineering

UNIT TWO

INTRODUCTION TO MANUFACTURING TECHNOLOGY

2.1 Manufacturing Processes

Manufacturing or production connotes the making of products (goods and articles) from materials. Manufacturing plays a very important role in engineering because it changes the form of materials into the final products. When one thinks of how the various components of machines are produced, many techniques come to mind, for example; casting, forging, rolling, welding, machining, etc. Manufacturing processes or fabrication techniques are so varied that there is no simple and universally accepted criterion for classifying them. However, the various techniques may be categorized into the following groups:

a. **Deformation Processes, Forming Operations or Mechanical Working Techniques**: - In these processes, the material is plastically deformed (hot or cold) under the action of an external force, to produce the required shape. No material removal is involved but deformation. Examples include: *forging, rolling, drawing, deep drawing, bending,* etc.
b. **Machining Processes, Metal-cutting or Chip-forming Processes**: - In these processes, material is removed from a work-piece to get the final shape. Machining operations can be performed on castings, rollings and forgings in order to obtain the desired accuracy and shape. Examples are: *turning, milling, drilling, boring, threading, grinding, planing, sawing,* etc.
c. **Casting Processes or Foundry Techniques**: - Casting is a fabrication process whereby a totally molten metal is poured into a mould cavity having the desired shape; upon solidification, the metal assumes the shape of the mould but experiences some shrinkage. A number of different casting techniques are commonly employed, including sand, die, investment, etc. Casting techniques are employed when
    - the finished shape is so large or complicated that any other method would be impractical,
    - a particular alloy is so low in ductility that forming by either hot or cold working would be difficult, and
    - in comparison to other fabrication processes, casting is the most economical.
d. **Joining Processes**: - Here, two or more components or pieces are joined together to produce the required shape. The joint may be mechanical (e.g. *bolting, screwing, riveting*), metallurgical (e.g. *welding, brazing, soldering*) or polymeric (*adhesive bonding*).
e. **Powder Metallurgy**: - Here, particles of various sizes of metals, ceramics, polymers or glass, etc. are pressed to shape and then *sintered* to get the final product. Sintering is the coalescence of particles as a result of high temperature treatment called firing.
f. **Heat Treatment and Surface Finishing Processes**: - Heat treatment processes such as *annealing, normalizing, hardening* and *tempering* are employed to improve the properties of the product. Surface treatment processes are employed to improve the surface finish and/or impact certain properties. They include: *painting, sand blasting, shot peening, electroplating, polishing,* etc.

It should be noted that there are various specialized fabrication methods for processing ceramics, polymers and composites. Again, the manufacturing technique influences the choice of material and vice versa; because certain materials cannot be formed via certain manufacturing processes. Furthermore, some manufacturing processes are economical for small quantity production whilst others become viable only when mass production is considered. The course ENG 201 is concerned with Casting Processes (Foundry Technology) and Joining Processes (particularly Arc Welding Technology).

BASIC FOUNDRY TECHNOLOGY

3.1 Meaning and Types of Foundry

A foundry is a work establishment (i.e. a workshop) where ferrous and non-ferrous metals are first of all caused to be liquid or molten by application of heat and then allowed to cool in a mould to yield a solid mass known as a **casting**. The furnaces used in melting and the tools and accessories as well as the shop floor on which castings are made constitute the **foundry**.

The floor of a foundry is usually not made with concrete; but filled with moulding sand (usually laterite).

Foundries may be classified as ferrous and non-ferrous. Further classification based on the nature of products and processes may be adopted, giving rise to:

a. <u>General or Jobbing Foundry</u>: that is one in which a small number of a variety of castings are produced. That is, jobs are done as they come or as job orders are placed. There is no specialization in any type of product.
b. <u>Specialized or Production foundry</u>: which is usually a highly mechanized plant where very large number of a limited variety of castings may be made in order to achieve a low unit cost of production. There is specialization in a number of products and mass production is involved.
c. <u>Captive Foundry</u>: which is a subsidiary of a large manufacturing organization and the castings from this type of foundry are consumed solely by the parent organization in their finished products. Examples are the captive foundries of machine tools manufacturers and motor-car manufacturers.

Very often foundries are mixtures of jobbing and production, i.e. a section is dedicated to jobbing while the rest is on mass production basis. The Nigerian Foundries Lagos has both jobbing and production lines.

3.2 Casting Methods and Processes

The technique of melting and cooling a metal to give a desired product is known as casting. So, thee term *casting* is both the process and the product. Metal casting or founding is a liquid shaping process in which the liquid is made to conform to a desired geometry in a **mould** and then allowed to transform to a solid. It takes advantage of the ability of a liquid (in this case, the molten metal) to conform to the shape of a container (in this case, the mould) into which it is poured.

Casting is classified not only by the metals cast, but also by the methods and materials used for making the mould. There are several ways of producing castings from molten metal and of these, castings made of sand moulds are the most common. Casting methods or processes include:Green sand moulding, CO_2 moulding process, Shell moulding, Shaw moulding process or ceramic moulding, Investment casting or lost wax process, Gravity and pressure die casting [metal moulds]. Centrifugal casting, Plaster moulding, etc. In ENG 201, we shall be concerned more with sand casting.

3.3 Foundry Moulding Sands

Sands are defined as granular particles of diameter 0.05 – 2.00 mm that result from the disintegration (weathering) or crushing of rocks. The most widely used foundry sand, silica sand, is composed mainly of quartz (SiO_2) grains. However, sands based on zircon, chromite, olivine and ground ceramic minerals are also employed in the production of castings. In foundry practice, a wide range of sands is used which vary in purity, structure, refractoriness and also in grain size, shape and distribution.

3.3.1 Classification of Sands

Foundry moulding sands are generally classified into two broad categories: **naturally bonded sands** and **unbounded sands** which are **synthetically bonded**. The naturally bonded moulding sands are combined with clay minerals in nature; i.e. the binder is natural with the sand as is mined from the sand pit. They require no additives except water. Naturally bonded sands occur with a wide range of grain fineness and clay contents depending on their source. The unbounded sands are clay-free high silica sand. They are prepared for use in casting production by being bonded with the required amount and types of binders, additives and water. In effect, they are raw materials for the production of **synthetic sands** used in CO_2 and shell moulding processes. Binders for synthetic sands include sodium silicate or water glass (Na_2SiO_3), clay (e.g. bentonite) and other resins.

3.3.2 Kinds of Moulding Sand

Molding sands can also be classified according to their use into number of varieties which are described below.

Green sand - Green sand is also known as tempered or natural sand which is a just prepared mixture of silica sand with 18 to 30 percent clay, having moisture content from 6 to 8%. The clay and water furnish the bond for green sand. It is fine, soft, light, and porous. Green sand is damp, when squeezed in the hand and it retains the shape and the impression to give to it under pressure. Moulds prepared by this sand are not requiring backing and hence are known as green sand molds. This sand is easily available and it possesses low cost. It is commonly employed for production of ferrous and non-ferrous castings.

Dry sand - Green sand that has been dried or baked in suitable oven after the making mold and cores is called dry sand. It possesses more strength, rigidity and thermal stability. It is mainly suitable for larger castings. Mold prepared in this sand are known as dry sand moulds. **Facing sand -** Facing sand is just prepared and forms the face of the mould. It is directly next to the surface of the pattern and it comes into contact molten metal when the mould is poured. Initial coating around the pattern and hence for mold surface is given by this sand. This sand is subjected severest conditions and must possess, therefore, high strength refractoriness. It is made of silica sand and clay, without the use of used sand. Different forms of carbon are used to prevent the metal burning into the sand. A facing sand mixture for green sand of cast iron may consist of 25% fresh and specially prepared and 5% sea coal. They are sometimes mixed with 6-15 times as much fine moulding sand to make facings. The layer of facing sand in a mold usually ranges from 22-28 mm. From 10 to 15% of the whole amount of molding sand is the facing sand.

Backing sand - Backing sand or **floor sand** is used to back up the facing sand and is used to fill the whole volume of the molding flask. Used molding sand is mainly employed for this purpose. The backing sand is sometimes called black sand because that old, repeatedly used molding sand is black in color due to addition of coal dust and burning on coming in contact with the molten metal.

Parting sand - Parting sand without binder and moisture is used to keep the green sand not to stick to the pattern and also to allow the sand on the parting surface the cope and drag to separate without clinging. It may be oven-dried or calcined. This is clean clay-free silica sand which serves the same purpose as parting dust (**plumbago**).

Core sand - Core sand is used for making cores and it is sometimes also known as oil sand. This is highly rich silica sand mixed with oil binders such as core oil which composed of linseed oil, resin, light mineral oil and other bind materials. Pitch or flours and water may also be used in large cores for the sake of economy.

3.3.3 Properties of Moulding Sand

The basic properties required in molding sand and core sand are described as under.

Refractoriness - Refractoriness is defined as the ability of molding sand to withstand high temperatures without breaking down or fusing thus facilitating to get sound casting. It is a highly important characteristic of molding sands. Refractoriness can only be increased to a limited extent. Molding sand with poor refractoriness may burn on to the casting surface and no smooth casting surface can be obtained. The degree of refractoriness depends on the SiO_2 i.e. quartz content, and the shape and grain size of the particle. The higher the SiO_2 content and the rougher the grain volumetric composition the higher is the refractoriness of the molding sand and core sand. Refractoriness is measured by the sinter point of the sand rather than its melting point.

Permeability - It is also termed as porosity of the molding sand in order to allow the escape of any air, gases or moisture present or generated in the mould when the molten metal is poured into it. All these gaseous generated during pouring and solidification process must escape otherwise the casting becomes defective. Permeability is a function of grain size, grain shape, and moisture and clay contents in the molding sand. The extent of ramming of the sand directly affects the permeability of the mould. Permeability of mold can be further increased by venting using vent rods.

Cohesiveness [Bond Strength] - It is property of molding sand by virtue which the sand grain particles interact and attract each other within the molding sand. Thus, the binding capability of the molding sand gets enhanced to increase the green, dry and hot strength property of molding and core sand.

Green strength - The green sand after water has been mixed into it, must have sufficient strength and toughness to permit the making and handling of the mould. For this, the sand grains must be adhesive, i.e. they must be capable of attaching themselves to another body and. therefore, and sand grains having high adhesiveness will cling to the sides of the molding box. Also, the sand grains must have the property known as cohesiveness i.e. ability of the sand grains to stick to one another. By virtue of this property, the pattern can be taken out from the mould without breaking the mould and also the erosion of mould wall surfaces does not occur during the flow of molten metal. The green strength also depends upon the grain shape and size, amount and type of clay and the moisture content.

Dry strength - As soon as the molten metal is poured into the mould, the moisture in the sand layer adjacent to the hot metal gets evaporated and this dry sand layer must have sufficient strength to its shape in order to avoid erosion of mould wall during the flow of molten metal. The dry strength also prevents the enlargement of mould cavity cause by the metallostatic pressure of the liquid metal.

Plasticity and Flowability - It is the ability of the sand to get compacted and behave like a fluid. It will flow uniformly to all portions of pattern when rammed and distribute the ramming pressure evenly all around in all directions and retain the desired shape once the ramming pressure is removed. Generally sand particles resist moving around corners or projections. In general, flowability increases with decrease in green strength, an, decrease in grain size. The flowability also varies with moisture and clay content.

Adhesiveness - It is property of molding sand to get stick or adhere with foreign material such sticking ofmolding sand with inner wall of molding box

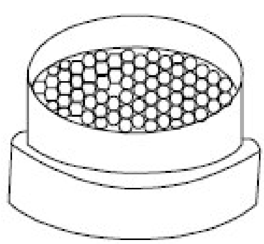
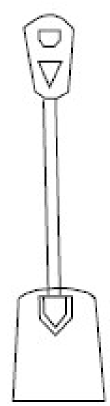
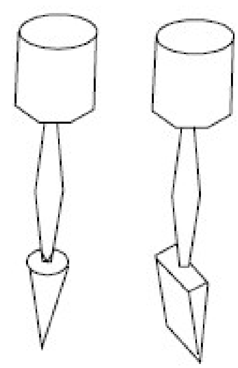
Collapsibility - After the molten metal in the mould gets solidified, the sand mould must be collapsible so that free contraction of the metal occurs and this would naturally avoid the tearing or cracking of the contracting metal. In absence of this property the contraction of the metal is hindered by the mold and thus results in tears and cracks in the casting. This property is highly desired in cores

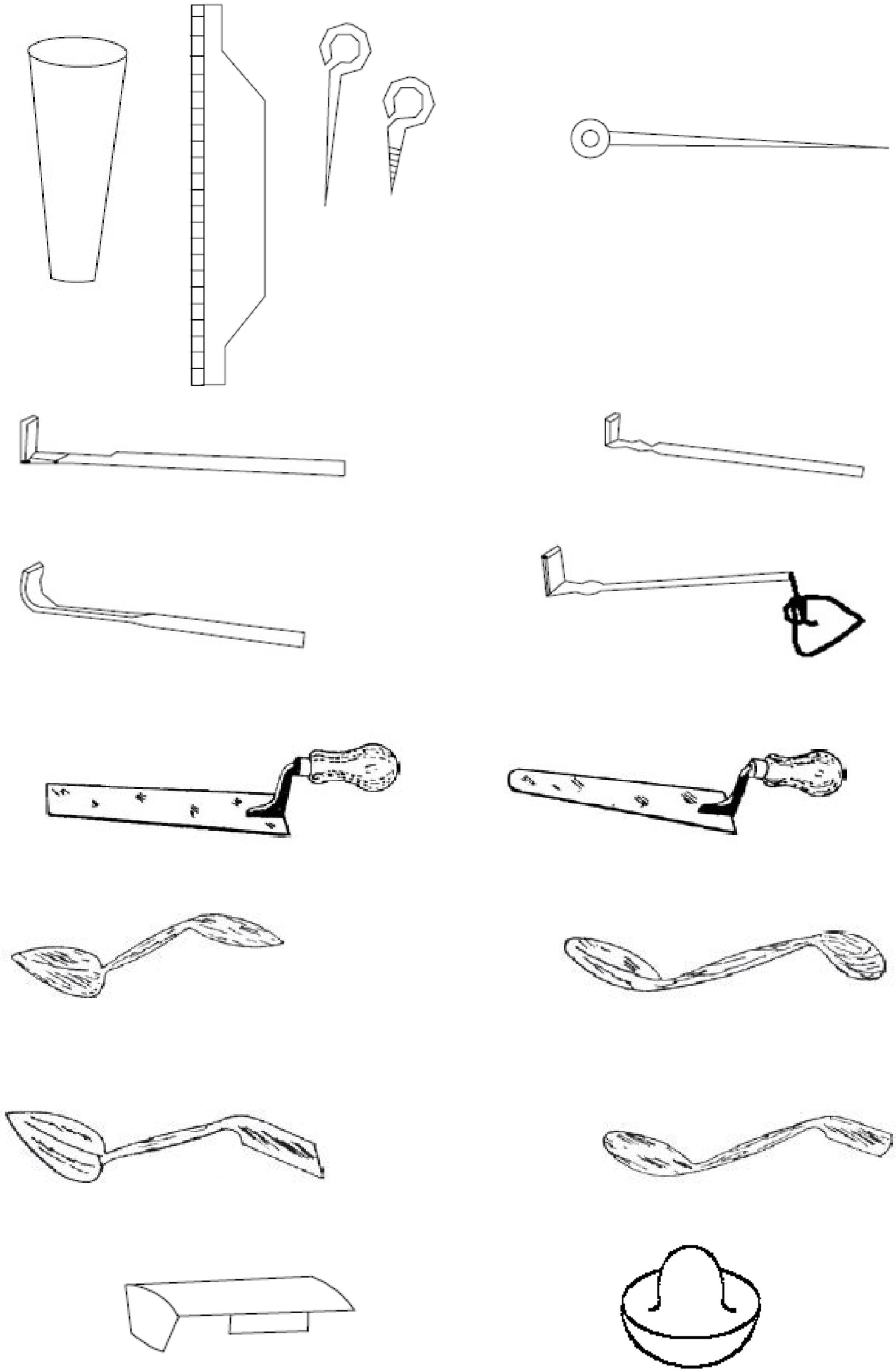
Miscellaneous properties - In addition to above requirements, the molding sand should not stick to the casting and should not chemically react with the metal. Molding sand should be cheap and easily available. It should be reusable for economic reasons. Its coefficients of expansion should be sufficiently low.

3.4 Foundry Hand Tools

The common hand tools used in foundry shop are fairly numerous. The following is a partial list with the diagrams. Identification and description of the tools will be given in class.

- ***Hand riddle, Shovel/Spade, Rammers, Sprue pin (Riser Peg), Strike off bar (Straight edge), Mallet, Draw spike, Vent rod, Lifters (Cleaners), Heart and Square, Trowels, Slicks, Smoothers, Swab, Spirit level, Gate cutter, Gaggers, Spray-gun, Bellows, Flasks (common flasks or containers which are used in foundry shop are mould boxes, crucibles and ladles).***



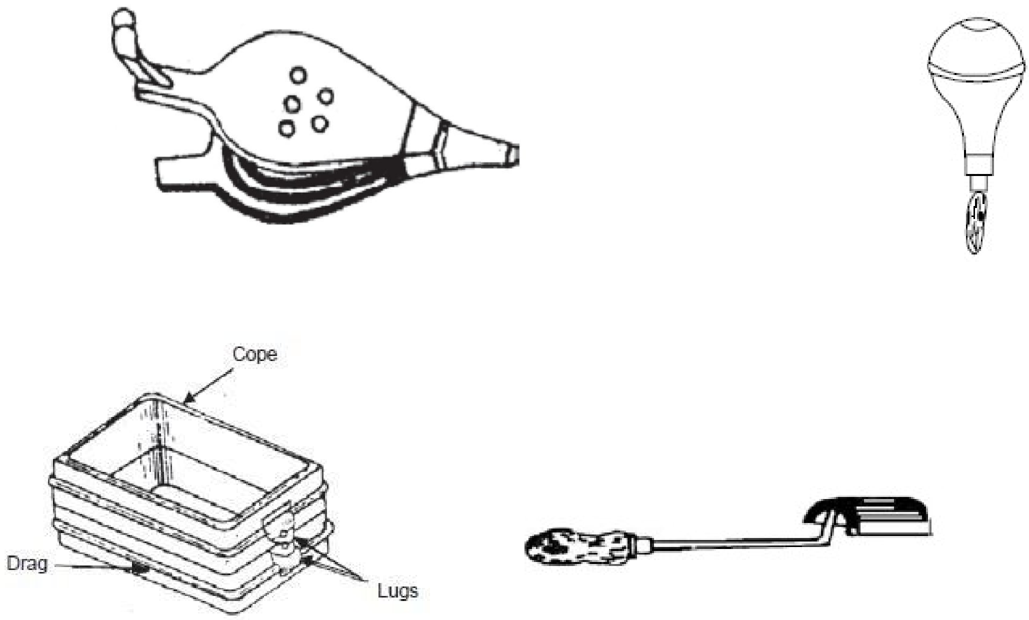


Figure 3.1: Foundry hand tools

3.5 Steps Involved In Making a Sand Mould

Moulding or mould-making is the process of making is the process of making a mould (i.e. mould cavity) out of sand or any other moulding material by means of a pattern. A **pattern is** as a model or replica of the desired casting which when moulded in sand forms an impression called mould or mould cavity. When the mould is filled with molten metal, it forms a casting after solidification of the poured metal. Sometimes, a casting is to be made hollow or with cavities in it. Such types of castings require the use of **cores**. **Pattern-making** is the art of producing patterns as carried out by a specialized carpenter known as the **pattern maker**. Cores also require **core-making** skills.

1) Initially a suitable size of molding box for creating suitable wall thickness is selected for a two piece pattern. Sufficient care should also be taken in such that sense that the molding box must adjust mold cavity, riser and the gating system (sprue, runner and gates etc.).
2) Next, place the drag portion of the pattern with the parting surface down on the bottom (ram-up) board as shown in Figure 3.2 (a).
3) The facing sand is then sprinkled carefully all around the pattern so that the pattern does not stick with molding sand during withdrawal of the pattern.
4) The drag is then filled with loose prepared molding sand and ramming of the molding sand is done uniformly in the molding box around the pattern. Fill the molding sand once again and then perform ramming. Repeat the process three or four times
5) The excess amount of sand is then removed using strike off bar to bring molding sand at the same level of the molding flask height to completes the drag.
6) The drag is then rolled over and the parting sand is sprinkled over on the top of the drag [Figure 3.2(b)].

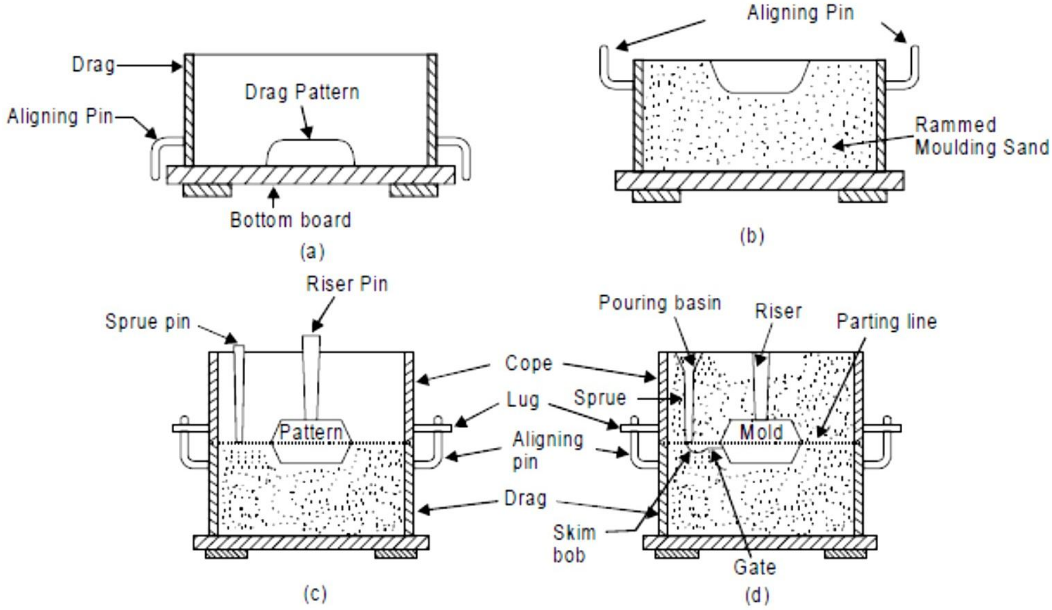


Figure 3.2: Mould making

7) Now the cope pattern is placed on the drag pattern and alignment is done using dowel pins.
8) Then cope (flask) is placed over the rammed drag and the parting sand is sprinkled all around the cope pattern.
9) Sprue and riser pins are placed in vertically position at suitable locations using support of molding sand. It will help to form suitable sized cavities for pouring molten metal etc. [Figure 3.2 (c)].
10) The gaggers in the cope are set at suitable locations if necessary. They should not be located too close to the pattern or mold cavity otherwise they may chill the casting and fill the cope with molding sand and ram uniformly.
11) Strike off the excess sand from the top of the cope.
12) Remove sprue and riser pins and create vent holes in the cope with a vent wire. The basic purpose of vent creating vent holes in cope is to permit the escape of gases generated during pouring and solidification of the casting.
13) Sprinkle parting sand over the top of the cope surface and roll over the cope on the bottom board.
14) Rap and remove both the cope and drag patterns and repair the mold suitably if needed and dressing is applied
15) The gate is then cut connecting the lower base of sprue basin with runner and then the mold cavity.
16) Apply mold coating with a swab and bake the mold in case of a dry sand mold.
17) Set the cores in the mold, if needed and close the mold by inverting cope over drag.
18) The cope is then clamped with drag and the mold is ready for pouring, [Figure 3.2 (d)].

Example of making another mould which involves a core is illustrated in Figure 3.3

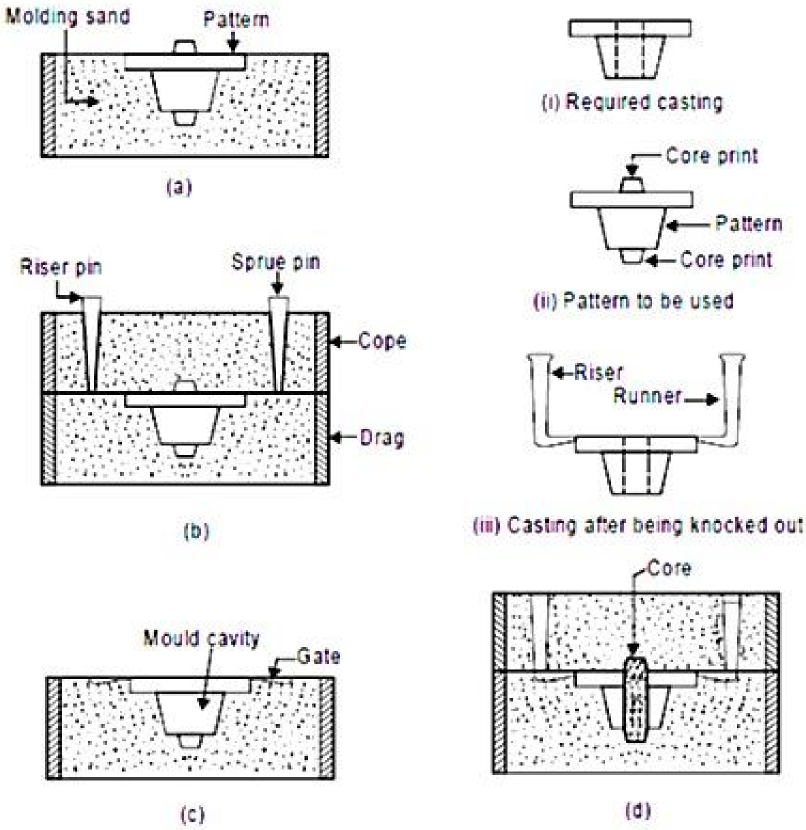


Figure 3.3: Example of making a mould with core

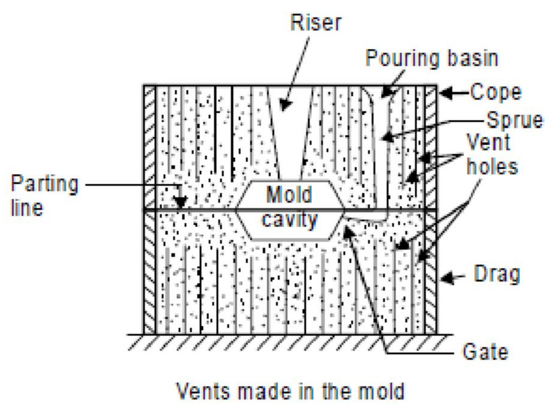


Figure 3.4: Venting

3.5.1. Venting of Moulds

Vents are very small pin types holes made in the cope portion of the mold using pointed edge of the vent wire all around the mold surface as shown in Figure 3.4. These holes should reach just near the pattern and hence mold cavity on withdrawal of pattern. The basic purpose of vent holes is to permit the escape of gases generated in the mold cavity when the molten metal is poured. Mold gases generate because of evaporation of free water or steam formation, evolution of combined water (steam formation), decomposition of organic materials such as binders and additives (generation of hydrocarbons, CO and CO_2), expansion of air present in the pore spaces of rammed sand. If mold gases are not permitted to escape, they may get trapped in the metal and produce defective castings. They may raise back pressure and resist the inflow of molten metal. They may burst the mold. It is better to make many small vent holes rather than a few large ones to reduce the casting defects.

3.5.2 Gating System In Moulds

Figure 3.5 shows the different elements of the gating system. Terms and implications shall be discussed in class.

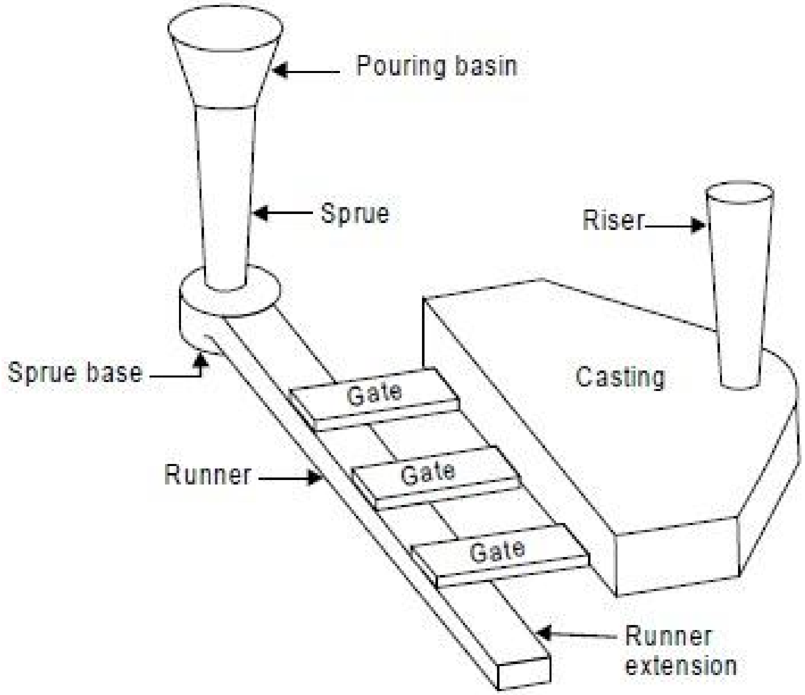


Figure 3.5: Gating System

3.6 Theory of Casting and Solidification

Metal castings form integral components of devices that perform useful functions for human beings. The cast component has a shape, size, chemical composition and metallurgical microstructure, which are determined by engineering decisions. The engineering professionals that carry out this process work together, sharing information so that the casting will perform as intended in a timely and cost effective manner. It should be noted that the casting may only be a small part of the useful device (usually in more sophisticated devices like an automobile where there may be hundreds of components), or it may be the entire device (simple device like a frying pan). The metal casting process is the simplest, most direct route to a near net shape product, and often the least expensive. This process in its fundamental form requires a mould cavity of the desired shape and molten metal to pour into the mould cavity. Human beings have been producing castings for thousands of years, most often pouring molten metal into moulds made of sand. This is schematically shown in Figures 3.6 and 3.7 which define the basic components of a mould cavity (*cope, drag, parting line, riser, sprue, pouring basin*, etc.), as well as that part of the molten metal handling system known as a ladle. The production of molten metal and moulds to make castings has traditionally been an art form, an expression of human creativity carried out both for aesthetic and practical reasons. The objective of metal casting has been to produce useful implements for human consumption as well as beautiful works of art. It is clear on examination of ancient art castings as well as modern industrial castings that their production requires significant skill as well as technological know-how.

The ancient artisan used traditions and learned skills passed down through the ages, as well as experience to produce acceptable castings. The modern producer of industrial castings makes use of these same skills, but supplements them with an understanding of the fundamental principles of fluid flow, heat transfer, thermodynamics and metallurgical microstructural development. These latter engineering skills are used to help design a system which will allow the metal caster to produce a sound (pore free) casting, free from defects (sand inclusions, slag, cracks, etc.), with the correct dimensions and combination of mechanical properties to satisfy the designer's requirements for the intended application. Producing a "good" casting requires a design effort to:

i. Create a gating system (pouring basin, sprue, and runner) to bring molten metal into the mould cavity free from entrapped slag, sand or gases.

i. Provide a riser which feeds liquid metal into the casting cavity as the liquid is cooling and solidifying (all liquid metals will shrink as they cool and most liquid metals will shrink as they solidify). The riser may have to provide up to 5 - 7% by volume for the casting as it solidifies.

ii. Metals will shrink as they solidify). The riser may have to provide up to 5 - 7% by volume for the casting as it solidifies.

iii. Control heat flow, Q in the Figure 3.6, out of the casting so that the last liquid to solidify is in the riser.

iv. Control the rate of heat flow so as to control the nature of the solidified product.

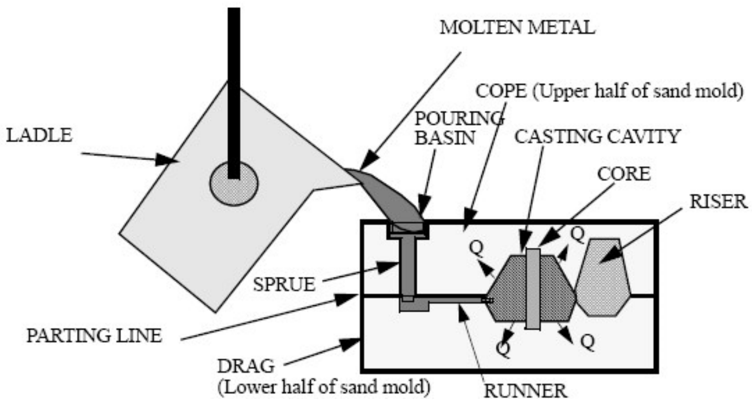


Figure 3.6: Components of a Mould Cavity (schematic)

The amount of heat that must be removed from a casting to cause it to solidify is directly proportional to the amount of **superheating** and amount of metal or the **casting volume**. On the other hand, the ease of heat removal from a casting is directly related to the amount of exposed surface area through which the heat can be extracted and the insulating value of the mould. Chvorinov reflected this observation in the following relationship:

$$t_s = B\left(\frac{V}{A}\right)^n \qquad [3.1]$$

Where t_s = total solidification time (i.e., time interval from pouring to completion of solidification), V = volume of casting, A = surface area of casting, and B = mould constant; which is a function of: (i) the metal being cast (ii) the mould material (iii) the mould thickness, and (iv) the amount of superheat.

The ratio (V/A) for a casting, is known as its **modulus**.

3.6.1 Riser Design

Riser design in sand mold castings requires, as a minimum, that the riser solidify after the casting. The **Chvorinov's rule** is used to ensure that the casting will solidify before the riser. This is done by calculating the minimum size of the riser whose total solidification time exceeds that of the casting. i.e.:

$$t_{s(Riser)} > t_{s(Casting)} \quad or \ B_R \left(\frac{V}{A}\right)^n_{Riser} > B_C \left(\frac{V}{A}\right)^n_{Casting}$$

$$B(Modulus\ of\ riser)^n \quad > B(Modulus\ of\ casting)^n$$

But the mould constant B is the same for riser and casting since both riser and casting are of the same metal and in the same mould. That is, $B_R = B_C$. Assuming n = 2, and a 25% difference in solidification time (i.e. the riser takes 25% longer time to solidify than the casting);

$$t_{s(Riser)} = 1.25 t_{s(Casting)} \qquad [3.2]$$

Substituting for t from Equation 3.2 we have:

$$\left(\frac{V}{A}\right)^2_{Riser} = 1.25 \left(\frac{V}{A}\right)^2_{Casting} \qquad [3.3]$$

Calculation of the riser size then requires the selection of riser geometry (generally a cylinder is used since it has a large volume to surface area ratio) and a specification of a height-todiameter ratio, so that the riser side of the equation will have only one unknown. For a cylinder of diameter D and height H,

$$Volume\ (V) = \pi D^2 \frac{H}{4} \ \ and \ \ Surface\ Area\ (A) = \pi DH + 2\pi \frac{D^2}{4}$$

Hence, specifying the riser height as a function of the diameter enables the V/A ratio to be written as a simple expression with one unknown, namely D.

3.6.2 Casting Yield

The casting yield is defined as the ratio:

$$Casting\ Yield\ (CY) = \frac{Weight\ of\ Castings\ Produced}{Weight\ of\ Metal\ Poured} \times 100\% \qquad [3.4]$$

It is obvious that the goal for a metal casting plant would be to make casting yield as high as possible. Maximization of the yield will involve reducing the number and size of the risers as an important contributor. Of course, reducing the size of the gating system will also have a significant effect on casting yield.

Example 3.1:

Using Chvorinov's rule with n = 2 and assuming 25% difference in solidification time between riser and casting, calculate the dimensions of an effective riser for a casting that is a 20 cm x 40 cm x 60 cm rectangular block. Assume that the riser and the casting are not connected except through a gate and a runner, and that the riser is a cylinder of height/diameter ratio = 1.5.

Solution:

$$\left(\frac{V}{A}\right)^2_{Riser} = 1.25 \left(\frac{V}{A}\right)^2_{Casting} \ \ldots\ldots\ldots\ldots\ldots\ldots (a)$$

$$V_{Casting} = 20 \times 40 \times 60 = 48{,}000\ cm^3$$

$$A_{Casting} = 2(20 \times 40) + 2(20 \times 60) + 2(40 \times 60) = 8{,}800\ cm^3$$

$$\Rightarrow \left(\frac{V}{A}\right)^2_{Riser} = 1.25 \left(\frac{48{,}000}{8{,}800}\right)^2_{Casting} = 37.19\ \ cm^2 \ldots\ldots (b)$$

$$But\ we\ are\ given\ that\ (H/D)_{Riser} = 1.5$$

$$\Rightarrow H_{Riser} = 1.5D_{Riser}$$

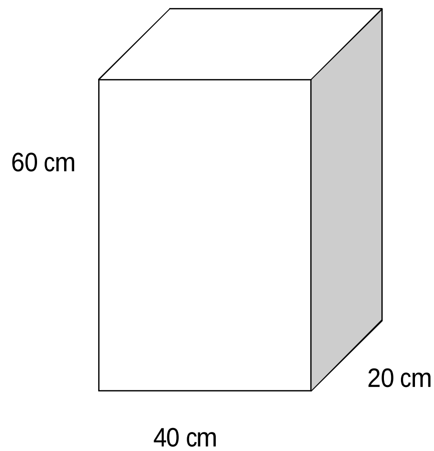
$$But\ V_{Riser} = \pi D^2 \frac{H}{4} == \pi D^2 \frac{(1.5D)}{4} = \frac{1.5\pi D^3}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(c)$$

Also,

$$A_{Riser} = \pi DH + 2\pi \frac{D^2}{4} = \pi D(1.5D) + 2\pi \frac{D^2}{4} = 1.5\pi D^2 + 0.5\pi D^2 = 2\pi D^2 \ldots\ldots..(d)$$

Substituting (c) and (d) in (b), we have:

$$\left(\frac{1.5\pi D^3/4}{2\pi D^2}\right)^2 = 37.19\ \ cm^2$$



$$\frac{1.5\pi D^3}{4(2\pi D^2)} = \sqrt{37.19}\,cm^2 = 6.098360435\ cm$$

$$D = \frac{6.098360435}{0.1875}\ cm \cong 32.52\ cm$$

$$Since\ \ \frac{H}{D} = 1.5$$

$$\Rightarrow H = 1.5 \times 32.52 = 48.78\ cm$$

Hence, the dimensions of an effective riser for the casting are:

- D = 32.52 cm
- H = 48.78 cm

3.6.3 Casting Structure

Most of the strength characteristics of castings are acquired during the solidification process. The grain size of the casting has a predominant effect on the mechanical properties. The yield strength of the material is related to the grain size by the popular **Hall – Petch equation**:

$$\sigma_y = \sigma_o + kd^{-\frac{1}{2}} = \sigma_o + \frac{k}{\sqrt{d}} \qquad [3.5]$$

Where σ_y is the yield strength, σ_on is frictional stress in the lattice, d is the grain diameter or inter-dendritic spacing and k is a material constant! The relation above shows that fine grain structure (small grain size) enhances strength. Therefore, to increase the strength of a casting, the conditions operating during solidification must be controlled to produce numerous and tiny grains. Such conditions include the *cooling rate*, the use of *inoculants*, application of *mechanical vibration*, or use of *electromagnetic stirring* during solidification. Apart from grain size, the mechanical properties are also affected by the form and distribution of microconstituents which are sensitive to casting conditions. Properties may be further influenced by segregation and micro-porosity.

In wrought metals [i.e. mechanically worked or plastically deformed products], mechanical deformation in manufacture not only confers shape but produces grain refinement, closure of voids and redistribution of segregates. It may even, in the presence of severely defective conditions, lead to failure during manufacture. These features have often been regarded as providing an element of insurance which is absent in casting.

Example 3.2:

The lower yield point for a cast iron that has an average grain diameter of $5 \times 10^{-2} mm$ is 135MPa. At a grain diameter of $8 \times 10^{-3} mm$, the yield point increases to 260MPa. Using the Hall – Petch equation, determine k

Solution:

From the information given, two simultaneous equations in two variable, σ_o and k, can be generated as follows:

$\sigma_y = \sigma_o + kd^{-\frac{1}{2}} = \sigma_o + \frac{k}{\sqrt{d}}$ [Hall - Petch]

$$135 = \sigma_o + k(5 \times 10^{-2})^{-\frac{1}{2}} = \sigma_o + \frac{k}{\sqrt{0.05}} = \sigma_o + \frac{k}{0.2236068} = \sigma_o + 4.472136k \ldots (i)$$

$$260 = \sigma_o + k(8 \times 10^{-3})^{-\frac{1}{2}} = \sigma_o + \frac{k}{\sqrt{0.008}} = \sigma_o + \frac{k}{0.0894427} = \sigma_o + 11.18034k \ldots (ii)$$

Solving simultaneously; (ii)-(i), we have:

$$[260 - 135] = [\sigma_o - \sigma_o] + k[11.18034 - 4.472136] \ldots \ldots \ldots \ldots (iii)a$$

$$125 = 0 + 6.7082039k \ldots \ldots \ldots \ldots (iii)b$$

$$6.7082039k = 125 \ldots \ldots \ldots \ldots (iii)c$$

$$\therefore k = \frac{125}{6.7082039} = \mathbf{18.63 MPa}$$

3.6.4 Patterns and Shrinkage Rule

The pattern is a model or replica of the exterior of the intended casting. It is made of a suitable material, commonly softwood or metal and is used to make the mould cavity. The success of a casting process depends a lot on the quality and the design of the pattern. A *draft* or *taper* is required in the vertical surface so that the pattern can be withdrawn from the mould without breaking the mould.

Allowance for shrinkage and thermal contraction must be provided on the pattern. Metals shrink during solidification and further contraction of the casting takes place as it cools from the *solidus* to room temperature. The size of the pattern must therefore be larger than that required in the casting and in order to avoid making due allowance by calculations in the production of the pattern, the ***pattern maker*** is provided with a special ***shrinkage rule*** which is slightly longer than a standard rule. For example, the linear shrinkage of cast iron is about 10 mm per meter; therefore the shrinkage rule used to make the pattern for cast iron casting is 10 mm longer per metre than a standard rule. Approximate shrinkages for some of the common casting alloys are presented in Table 3.1.

Table 3.1: Shrinkages for some casting alloys

Alloy	**Shrinkage (mm/meter)**
Cast iron	10
Steel	20
Brass	15
Aluminium	13
Magnesium base alloy	13

If the casting is to be machined due allowance (machining allowance) for the extra metal necessary must be made when designing the pattern.

3.7 Defects In Sand Casting

Defects in sand castings are caused by poor or wrong foundry practice, especially in connection with mould-making, melting and pouring techniques. Factors such as good mould design, careful mould preparation, control of alloy composition, satisfactory melting and pouring techniques, careful deslagging and degassing all have a considerable effect on the quality of the finished casting.

The general types of defects encountered in sand castings are: porosity, non-metallic inclusions, and cracks. However, defects can be classified into two main groups, viz.

- Those observable by direct visual examination [can be seen with unaided eyes]
- Those identified by a non-destructive testing technique (NDT or NDE) such as radiography or ultrasonic examination.

Some examples of defects, particularly those identifiable by direct visual examination include: **blowholes, scabs, displaced cores, misplaced cores, shrinkage cavity, cold shut, incompletely filled mould** [description shall be given in class].

UNIT FOUR

JOINING TECHNOLOGY

4.1 Introduction

Joining technology is one out of a large number of viable alternatives for manufacturing a component. There are a large number of joining techniques available and the problem is sometimes how to select the best method of joining for a particular situation. The relative importance of such factors as strength of the joint, ease of the technique, cost, corrosionresistance, appearance (aesthetics), whether or not a leak-tight permanent joint or a non-leaktight joint is required will depend very much on specific applications. Joining technology can be broadly divided into:

- ***Mechanical joints*** [interlocking, nuts and bolts, screws, hinges, rivets, use of nails, etc.];
- ***Metallurgical joints*** [welding, brazing, soldering], and
- ***Polymeric joints*** [adhesive bonding using glues, gums].

In ENG 201, we shall concentrate on ***fusion arc welding*** as illustrated in Figure 8.

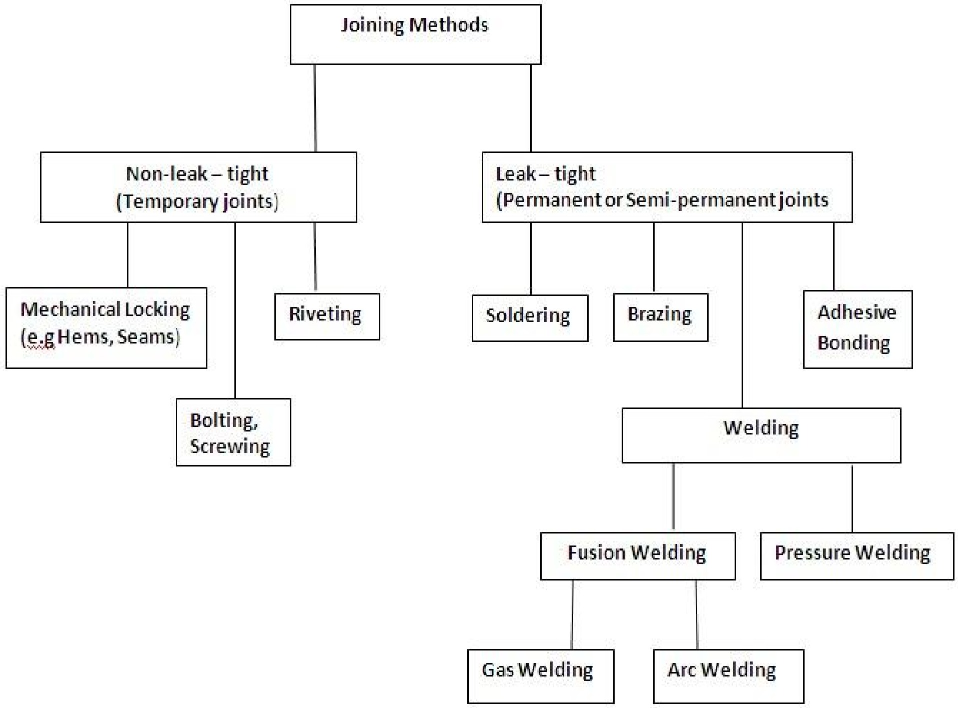


Figure 4.1: Joining Methods

4.2 Welding Theory

A weld is a union or joint between pieces of metal at faces rendered plastic or liquid by heat or pressure or both. Welding is the art and techniques involved in the making of such a joint.

Arc Welding - An electric arc is formed when an electric current passes between the electrode and the work piece. The electrode and the plate are connected to the power supply unit. The arc is started by momentarily touching the electrode on to the plate and withdrawing it to about 3 – 4 mm from the plate. Arcs can be generated using AC or DC. In DC arcs, two modes exist, namely: Direct Current Straight Polarity (DCSP) and Direct Current Reverse Polarity (DCRP).

Weld Dilution - Compositional changes are noticed after welding especially when the filler metal and the one being joined are of different compositions. In general, dilution is defined as:

$$D = \frac{Weight\ of\ parent\ metals\ melted}{Total\ weight\ of\ fused\ metal} \times 100\% \qquad [4.1]$$

The formula for calculating dilution D during welding is given as:

$$D = \left(\frac{C_w - C_f}{C_p - C_f}\right) \times 100 \qquad [4.2]$$

Where C_w = % carbon in the weld, C_f = % carbon in the filler (and electrode), C_p = % carbon in the parent metal.

Example 4.1:

Calculate the percentage dilution of the weld pool in an arc welding operation if the parent metal contains 0.32 wt% carbon, the electrode 0.28 wt% C and the weld pool 0.32 wt% C.

Solution: $D = \left(\frac{C_w - C_f}{C_p - C_f}\right) \times 100 = \frac{0.30 - 0.28}{(0.32 - 0.28)} \times 100\% = \mathbf{50}\%$

Tungsten Inert Gas (TIG) Welding - In the TIG welding, an arc is established between the end of the tungsten electrode and the parent metal at the joint line. The electrode does not melt (hence it is non-consumable and the welder keeps the arc gap constant). The current is controlled by the power supply unit. Filler metal usually available in one metre lengths of wire is added to the leading edge of the pool as required. The molten pool is shielded by an inert gas which replaces the air in the arc area. Argon is the most commonly used shielding gas.

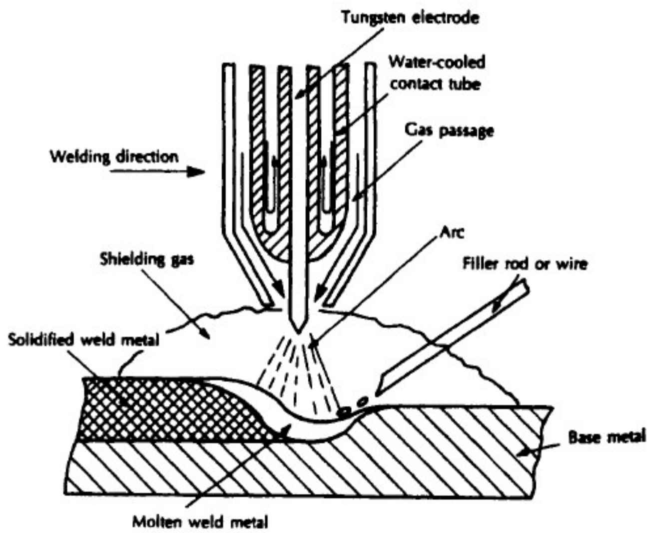


Figure 4.2: Schematic of the tungsten inert gas (TIG) arc welding process

TUTORIAL/ASSIGNMENT QUESTIONS

Instruction: Answer all the questions SERIALLY as they appear. Use the space(s) provided beneath each question for your solutions. For questions that have numerical answers, you MUST enclose your answers in a box thus, $\boxed{\underline{\underline{\textit{Weld Dilution} = 45\%}}}$

FOUNDRY TECHNOLOGY [1 – 6]

Problem 1:

a) Using Chvorinov's rule with n = 2 and assuming 25% difference in solidification time between riser and casting, calculate the dimensions of an effective riser for a casting that is a 2″x 6″x 13″ rectangular plate. The riser sits directly on top of the flat rectangle with its circular surface being part of the surface of the casting. Assume that the riser is a cylinder of height/diameter ratio = 1.8.

b) If the casting is a cast iron whose density is 7.30 g/cm^3, determine the casting yield. Assume that the weight of metal poured is equivalent to the weight of casting plus riser.

Problem 2: Three pieces of castings have the same volume but different shapes. One is a sphere; the second is a cube and the third a cylinder with height that is equal to the diameter of its base.

a) Rank their order of solidification.
b) Assuming that the volume is 300 cm^3, determine the dimensions and areas of the shapes.

Problem 3: The lower yield point for a cast iron that has an average grain diameter of $5 \times 10^{-2} mm$ is 140MPa. At a grain diameter of $8 \times 10^{-3} mm$, the yield point increases to 275MPa. Determine $\boldsymbol{k}$ and $\boldsymbol{\sigma_o}$ for the cast iron based on the Hall-Petch equation. At what grain diameter will the lower yield point of the cast iron be 200 MPa?

Problem 4: One dimension of a steel casting is to measure 20 cm. Using the information in Table 3.1 and the explanation given in class (lecture), determine the required length of this dimension for the pattern.

Problem 5: Sketch the shape of a typical *sprue cutter* (*sprue peg*) and give reasons for the geometrical configuration you have sketched. [Use information given in class/lecture].

Problem 6: Sketch the following foundry hand tools: (a) Heart and Square, (b) Peen Rammer, (c) Riddle, (d) Lifter or Cleaner. [Hint: Details were given in class/lecture].

JOINING TECHNOLOGY [7 – 12]

Problem 7: Draw and label the electrode polarities of the two modes of DC arcs.

Problem 8: Assuming 45% dilution, what will be the approximate carbon content in a buttwelded joint if the parent and filler metals contain 0.40 wt% C and 0.15 wt% C respectively?

Problem 9:

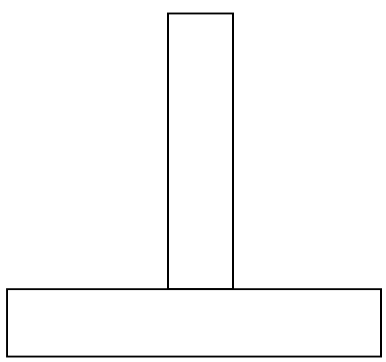
a) With a sketch, show the point of dilution during welding.

b) During an arc welding operation, a parent metal was found to contain 0.30 wt%C, the electrode 0.25 wt% C and the weld pool 0.27 wt% C. calculate the percentage dilution of the weld pool.

Problem 10: Draw the diagram showing the structure of the oxyacetylene flame; label it and show the point of maximum temperature with an X on the point.

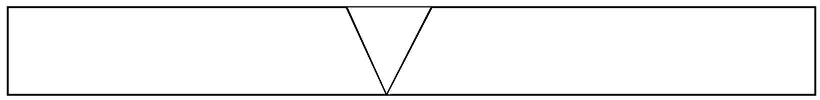
Problem 12: There are many types of welded joints and closer investigation would reveal that that both the welds and the joints can be categorized into groups. There are four basic types of joints: Butt, "T', Corner, and Lap. The diagrams below are some metals to be welded; identify the weld types and indicate the place where the weld will be deposited by marking "X" at the place.

(a)

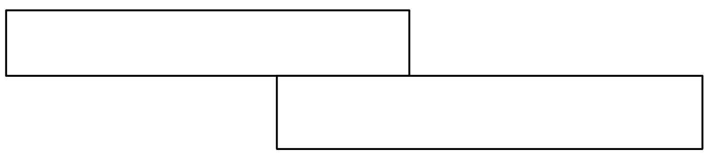


(b)

(c)



(d)



LABORATORY & ASSIGNMENTS WORKBOOK

For

(ENGINEERING WORKSHOP PRACTICE III)

ENG 201