2018-19
Sem-II

Manufacturing Processes
MSE315 Laboratory Manual

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(Course Instructor)

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Materials Science and Engineering, IITK

2018-19 Sem-II

LABORATORY TURN DISTRIBUTION

S No.	Title of the experiments
1	**Rolling:** Understanding the elastic and plastic curve and the property changes of Ferrous and non-ferrous metals during cold rolling.
2	**Forging:** Measurements of strain, strain-rate and friction coefficient during Forging.
3	**Moulding:** Molding properties of sodium silicate bonded sand.
4	**Casting:** Shrinkage behavior during permanent mold casting.
5	**Casting:** Fluidity of Aluminum Alloys.
6	**Casting:** To study the various steps of Investment casting process.
7	**Welding:** Microstructural evaluations of MMAW, MAG and TIG welded joints
8	**Powder Metallurgy (P/M):** Study various characteristics of copper powders and evaluate green density as well as strength characteristics (hardness) of cold-compacted and conventional sintered compact.
9	**Severe Plastic Deformation:** Effect of Severe Plastic Deformation on the Microstructure and properties (hardness).
10	**Demonstration** of Physical Vapor Deposition and Plastic Injection Molding.

MSE 315 Manufacturing Processes

2018-2019 (Sem-II) Laboratory Schedule

Days	Time	Lab/Exercise										Demo/ Make-up lab	Lab Exam
		#	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Tuesday	**09:00 - 12:00 (AM)**	**8/1** Group formation	**15/1**	**22/1**	**29/1**	**5/2**	**12/2**	**26/2**	**5/3**	**12/3**	**19/3**	**26/3**	**02/04**
Thursday	**10:00 - 01:00 (AM)**		**10/1**	**17/1**	**24/1**	**31/1**	**7/2**	**14/2**	**28/2**	**7/3**	**14/3**	**28/3**	**4/4**

Group Formation & Manual Distribution	:	**8th January 2019, Tuesday**
First Lab	:	**10th January 2019, Thursday**
Mid Sem Examination	:	**18 February–23th February 2019**
Mid Semester Recess	:	**16th March – 24th March 2019**
Last Lab	:	**4th April 2019, Thursday**
End Sem Examination	:	**April 21nd – 30th April 2019**

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GENERAL INFORMATION

1. **Attendance** in each turn is compulsory. Makeup on other days will not be allowed other than for medical reason. Missing 2 or more experiments will result in Fail grade. Adhere to the lab timing strictly. **Students who are late by more than 5 minutes will not be allowed entry**
2. **Weightage:** Weekly Report (25%); Attendance (10%); Preparedness (10%); Quiz (2 X 10%); End-sem Viva (35%);
3. Dress code: Students must come to the laboratory wearing: (1) trousers, (ii) proper tops and (iii) Leather shoes. Half pants, loosely hanging garments and slippers are **absolutely** not allowed
4. **No mobile phones** or cameras are allowed inside the lab
5. To avoid any injury, the student must take the permission of the laboratory staffs before handling the machines
6. Students are not allowed to touch any hot rolled pieces and injection molded polymers
7. Students must ensure that their work areas are clean
8. At the completion of the experiments, the student should get initials from concerned staff members
9. Laboratory report must be submitted in standard lab-report sheets, available at the shopping center. Reports on ordinary sheets and computer papers will not be accepted
10. Each member of a group must submit lab report individually, even if the experiment was performed in a group. Lab reports must be submitted in the subsequent lab turn
11. The lab report should contain: (i) Title of the experiment, (ii) Three to four lines stating the objectives, (iii) Name of all equipment/tools used along with one line description of its use and (iv) Neatly labeled sketch of the observed microstructures (microstructures can be printed) with few lines of description (v) Results and discussion
12. Every Student Group should obtain a copy of the MSE 315 laboratory manual
13. Student can collect their laboratory reports after correction

MANUFACTURING PROCESSE LABORATORY
MSE 315A LAB. 2018-2019 (SEM-II)
ASSIGNED STAFF FOR EXPERIMENT

Sr. No.	*Task During Exercise*	*Staff Involved & Mobile No.*
1	**Rolling:** Understanding the elastic and plastic curve and the property changes of ferrous and non-Ferrous metals during cold rolling.	***Mr. Rakesh Kumar*** ***7007758308***
2	**Forging:** measurement of strain, strain-rate and friction coefficient during Forging.	***Mr. Nripen Deka*** ***8303306481***
3	**Molding:** Molding properties of sodium silicate bonded sand.	***Mr. Shilankar*** ***8899210147***
4	**Casting:** Shrinkage behavior during permanent mold casting.	***Mr. I P Singh*** ***9452961465***
5	**Casting:** Fluidity of Aluminum Alloys.	
6	**Casting:** To study the various steps of Investment casting process.	***Mr. Anurag Prasad*** ***7379797330***
7	**Welding:** Microstructural evaluations of MMAW, MAG and TIG welded steel.	***Mr. A K Verma*** ***9450729498***
8	**Powder Metallurgy (P/M):** Study various characteristics of copper powders and evaluate green density as well as strength characteristics (hardness) of cold-compacted and conventional sintered compact.	***Mr. Gaurav Mishra*** ***9956547964***
9	**Severe Plastic Deformation:** Effect of Severe Plastic Deformation on preparation of microstructure OM) and its properties (hardness).	**Mr. Sandip Guin *(Tues- TA)*** **Mr. Susanta Nayak (Thurs-TA)**

Note: Demonstration of Physical Vapor Deposition (PVD) & Plastic Injection Molding (PIM).

MANUFACTURING PROCESSES LABORATORY
MSE 315 LAB
2018-2019
TA's Laboratory Schedule

Sr. No.	Name	Experiment No.	Days	Mobile No.	E-mail : Id
1	Mr. Anant Srivastava	1,2,3	Tuesday	96530 43119	anantsr@iitk.ac.in
2	Mr. G Shashidhar	4,5,6	Tuesday	80088 32223	gshashi@iitk.ac.in
3	Mr. K Vishwanath	Attendance, Viva & lab report work	Tuesday	8942873527	vishwak@iitk.ac.in
4	Mr. Rishabh Srivatatva	7,8	Tuesday	70076 66028	rishabhsr@iitk.ac.in
5	Mr. Sandip Guin	9	Tuesday	89725 19318	gsandip@iitk.ac.in
6	Mr. Dhanajay K Yadav	1,2,3	Thursday	97321 91372	dhanan@iitk.ac.in
7	Mr. R. Banerjee	4,5,6	Thursday	7585035436	ritwikbj@iitk.ac.in
8	Mr. Raghvendra R M	Attendance, Viva & lab report work	Thursday	99868 04667	ramraghav@iitk.ac.in
9	Ms. Shipra Bajpai	7,8	Thursday	78001 89396	shipra@iitk.ac.in
10	Mr. Susanta Nayak	9	Thursday	89855 53306	susanta@iitk.ac.in

Note: Maintain & Keep record of Attendance, Viva and Lab report related work by mentioned TA

Experiment-1

Understanding the elastic and plastic curve and the property changes of ferrous and non-ferrous metals during cold

Objectives:

i. Determination of elastic curve during cold rolling (Aluminum, Copper, Brass, Mild steel)
ii. Determination of plastic curve during rolling (Aluminum)
iii. Hardness changes with increasing deformation

INTRODUCTION:

Rolling is the process involving plastic deformation of metals by squeezing action as it passes between a pair of rotating rolls. To control the relative positioning of rolls, a roll positioning system is employed on the mill stand, generally through hydraulic pressure. The most common rolling mill is the 2-high rolling mill, which consists of two rolls usually mounted horizontally in bearings at their ends and vertically above each other rotating in opposite direction. Few pictures of high mills are given in the figure 1.1 The rolls may be driven through couplings at their ends by spindles, which are coupled, to pinions (or gears), which transmit the power from the electric motor. Cross sectional view of arrangement is given in the figure 1.2. The rolling mills could be either reversing or non-reversing type. In the reversing type, which is the most common one, the direction of motion of the rolls can be reversed, and therefore the work can be fed into the mill from both sides by reversing the direction of rotation of rolls. The process may be carried out either at room temperature or at higher temperature. Depending on temperature condition process called cold rolling, warm rolling and hot rolling. Deformation below recrystallization temperature generally 0.3 Tm (in Kelvin) is called cold working and deformation above 0.6 Tm (in Kelvin) is hot working, and in between 0.3 to 0.6 will be in warm working category.

- Deformation below recrystallization temperature requires greater force than hot working.
- Above recrystallization temperature plastic deformation causes the deformation of grains and grain boundaries, a general increase in strength, and a decrease in ductility.
- Properties can be brought back to their original levels by heating the piece in a specific temperature range for a specific time at lower temperature known as recovery.

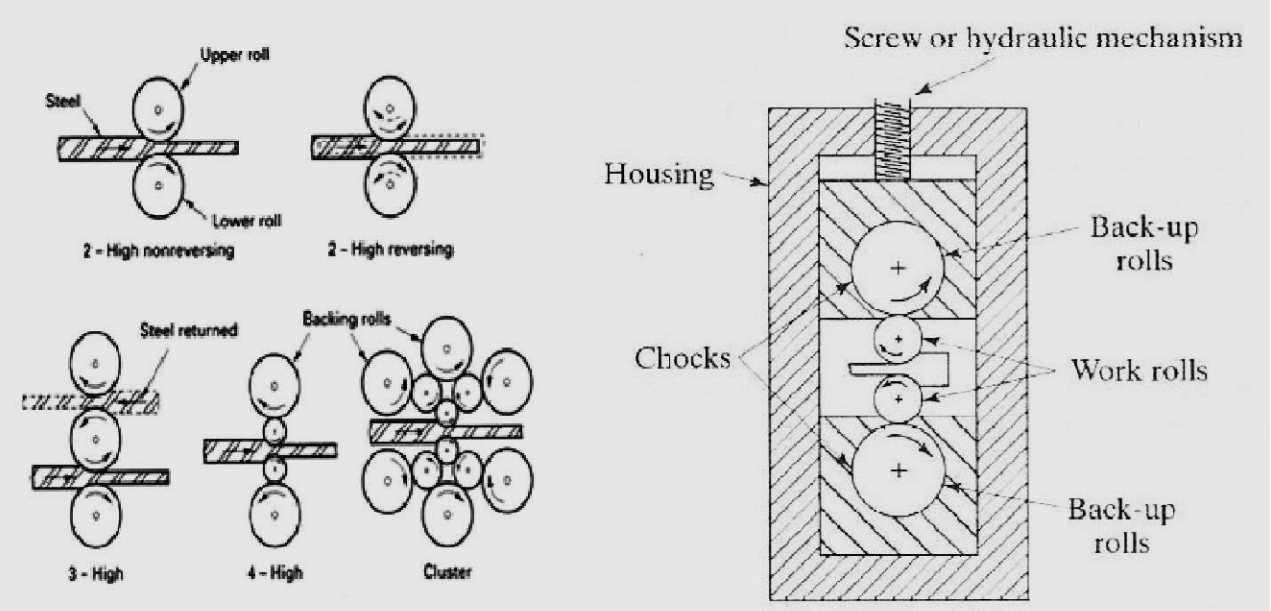


Figure 1.1 Different configuration of rotating mills ***Fig 1.2: Detailed configuration of 4 high mill***

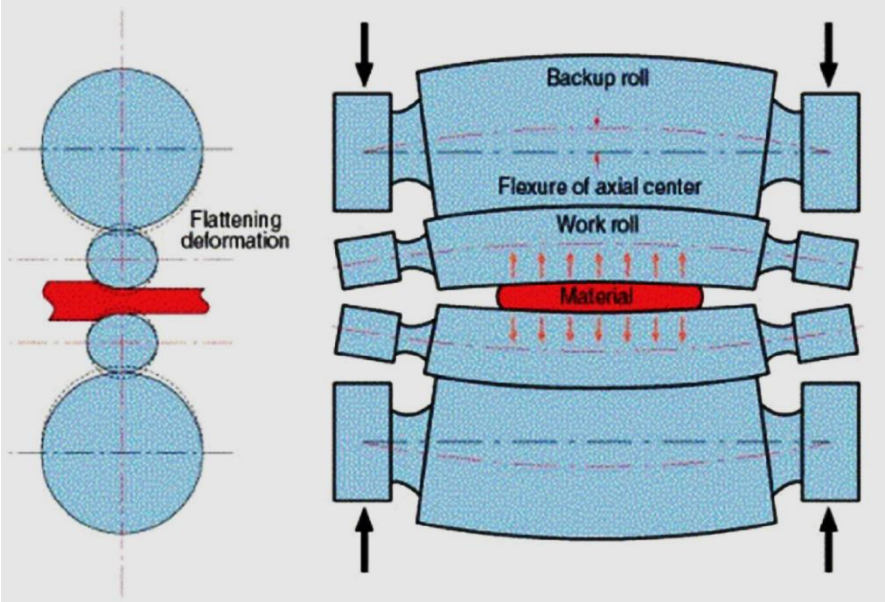


Figure 1.3: Origin of spring back and elastic curve during Rolling

Control of sheet gage (thickness) during rolling is of utmost importance as it determines the amount of deformation taking place and resulting microstructure and properties of the material. Moreover, accurate sheet gage thickness is also required for quality control. The problem in controlling sheet gage thickness can be understood from Figure 1.3. Here we can see that when metal piece is inserted between the work-rolls, it exerts load on to them causing a very small, but significant change in the roll distance. The roll distance is changed temporarily as the roll deformation is elastic in nature and given by 'elastic curve'. Simultaneously, the final thickness of the sheet after rolling is also governed by the initial thickness, which in turn, determines the rolling load, given by 'plastic curve'. An elastic and plastic curve are given in Figure 1.4

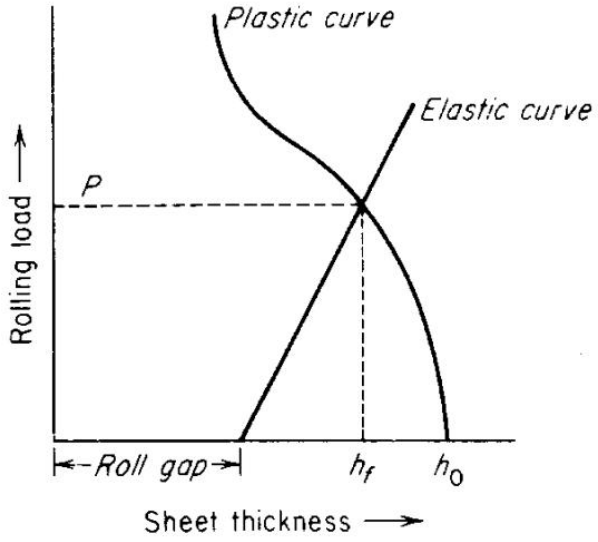


Figure 1.4: Characteristic elastic and plastic curves for a rolling mill [Dieter]

PROCEDURE:

A. <u>Determination of elastic curve in cold rolling:</u>

(1) Given metals: Aluminum, copper, brass and mild steel

(2) Set rolling mill to a constant roll gap.

(3) Roll different pieces of a metal with varying initial thickness without using any lubricant.

(4) Measure and tabulate the rolling load in each case. Also measure the final thickness in each case (h_a). Tabulate the results.

(5) Plot a graph between the final thickness after rolling (X - axis) vs rolling load (Y - axis).

B. <u>Determination of plastic curve in cold rolling:</u>

(1) Given metals: Aluminum

(2) Take 25 -25 mm long various pieces of the given metal strip of the same thickness (~ 6 mm).

(3) Roll the strips to 10, 20, 30, 40, 50, 60 and 70% thickness reduction is single pass without using any lubricant, and measure the rolling load in each case. Also measure the final thickness in each case (h_a). Tabulate the results.

(4) Plot a graph between the final thickness after rolling (X - axis) vs rolling load (Y - axis).

C. Repeat the steps 2-4, using oil as lubricant.

OBSERVATION:

Note: Take at least 5 readings in each case of the following cases.

(1) Data set No.(A) for elastic curve Rolling condition: No lubricant used

S. No.	Roll gap, mm	Metal	Initial thickness of strip, mm	Final thickness of strip, mm	Rolling load, Ton

(2) Data set No.(B) for plastic curve Rolling condition: No lubricant used

S. No.	Metal	Roll gap, mm	Initial thickness of strip, mm	Final thickness of strip, mm	Rolling load, Ton

(3) Data set No.(C) for plastic curve Rolling condition: Lubricant used

S. No.	Metal	Roll gap, mm	Initial thickness of strip, mm	Final thickness of strip, mm	Rolling load, Ton

CALCULATION:

(i) The final thickness of the metal strip (X-axis) vs rolling load (Y-axis) for both the non-lubricated and lubricated cases i.e. elastic curve, , on the same graph [use the data set (A)].

(ii) The final thickness of the metal strip (X-axis) vs rolling load (Y-axis) for both the non-lubricated and lubricated cases i.e. plastic curve, on the same graph [use the data set (B) and (C)].

(iii) Superimpose the curves obtained from the both data on the same graph.

(iv) Report the hardness changes.

QUESTIONS (Not required for the Report):

(1) Differentiate the hot and cold rolling and what are the effects on metals during both rolling processes?

(2) Explain the phenomena of spring back in rolling?

Color Plate-1: Rolling Mill at Engineering Metallurgy Lab

Experiment-2

Measurement of strain, strain-rate and friction coefficient during Forging

Objectives:

i. Characterize effect of forging on barreling and hardness
ii. Conduct ring test and evaluate the deformation in the ring and estimate the friction coefficient

Introduction:

Forging is a manufacturing process involving the shaping of metal using localized compressive forces. The blows are delivered with a hammer (often a power hammer) or a die. Forging is often classified according to the temperature at which it is performed: cold forging (a type of cold working), warm forging, or hot forging (a type of hot working). For the latter two, the metal is heated, usually in a die. Forged parts can range in weight from less than a kilogram to hundreds of metric tons. Forging has been done by smiths for millennia; the traditional products were kitchenware, hardware, hand tools, edged weapons, and jewellery. (Source: Wikipedia)

Advantages and Disadvantages: Forging can produce a piece that is stronger than an equivalent cast or machined part. As the metal is shaped during the forging process, its internal grain deforms to follow the general shape of the part. Thus, the grain is continuous throughout the part, giving rise to a piece with improved strength characteristics.

Some metals may be forged cold, but iron and steel are almost always hot forged. Hot forging prevents the work hardening that would result from cold forging, which would increase the difficulty of performing secondary machining operations on the piece. Also, while work hardening may be desirable in some circumstances, other methods of hardening the piece, such as heat treating, are generally more economical and more controllable. Alloys that are amenable to precipitation hardening, such as most aluminium alloys and titanium, can be hot forged, followed by hardening.

Production forging involves significant capital expenditure for machinery, tooling, facilities and personnel. In the case of hot forging, a high-temperature furnace (sometimes referred to as the forge) is required to heat ingots or billets. Owing to the massiveness of large forging hammers and presses and the parts they can produce, as well as the dangers inherent in working with hot metal, a special building is frequently required to house the operation. In the case of drop forging operations, provisions must be made to absorb the shock and vibration generated by the hammer. Most forging operations use metal-forming dies, which must be precisely machined and carefully heat-treated to correctly shape the workpiece, as well as to withstand the tremendous forces involved. (Source: Wikipedia)

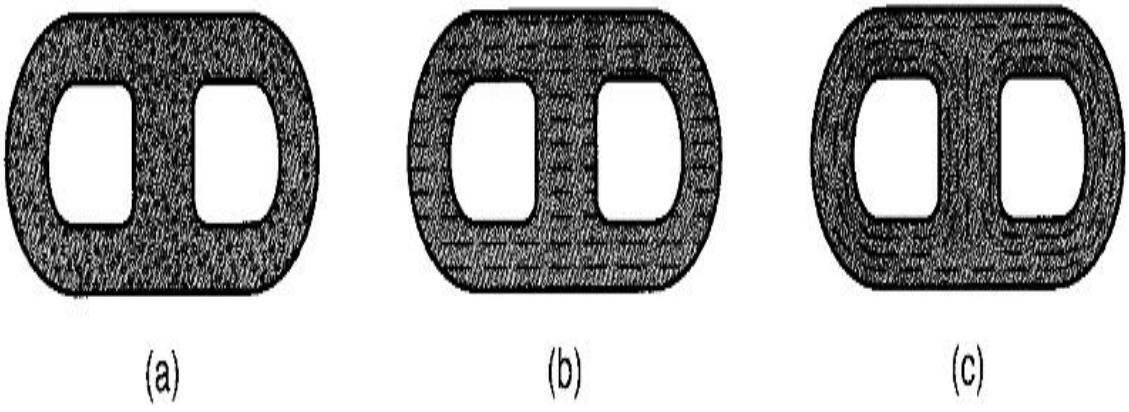


Figure 2.1: Flow Lines (a) Casting (b) Machining (c) Forging

Figure 2.2: A typical Forging press (open die forging)

Procedure:

1. Given metals: Mild steel cylinder and aluminum ring
2. Heat mild steel cylinder to high temperature and soak in for some time.
3. Put it in the forging press and Forge the mild steel cylinder to a flat disc shape.
4. Cut a flat piece from this forged steel disc for further analysis
5. Study the change in hardness, and grain flow structure
6. Measure the hardness of all pieces.
7. Compare the micro structural changes.
8. Take aluminum ring and note the dimensions (inner dia, outer dia, height)
9. Put it in furnace for some time
10. Take out the ring from the furnace and forge it
11. Take the dimensions again (inner dia, outer dia, height)
12. Use these values to estimate the coefficient of friction at the contact surface between the ring and the forging plate.

REPORT:

1. Objective of the experiment.
2. Describe the various steps of forging
3. Note the temperature of forging. Calculate the strain and strain-rate during deformation
4. Brief the reasons of hardness changes during treatment.
5. Estimate the friction coefficient for the aluminum ring theoretically as well as experimentally

Experimental Determination of Friction factor and Friction Coefficient

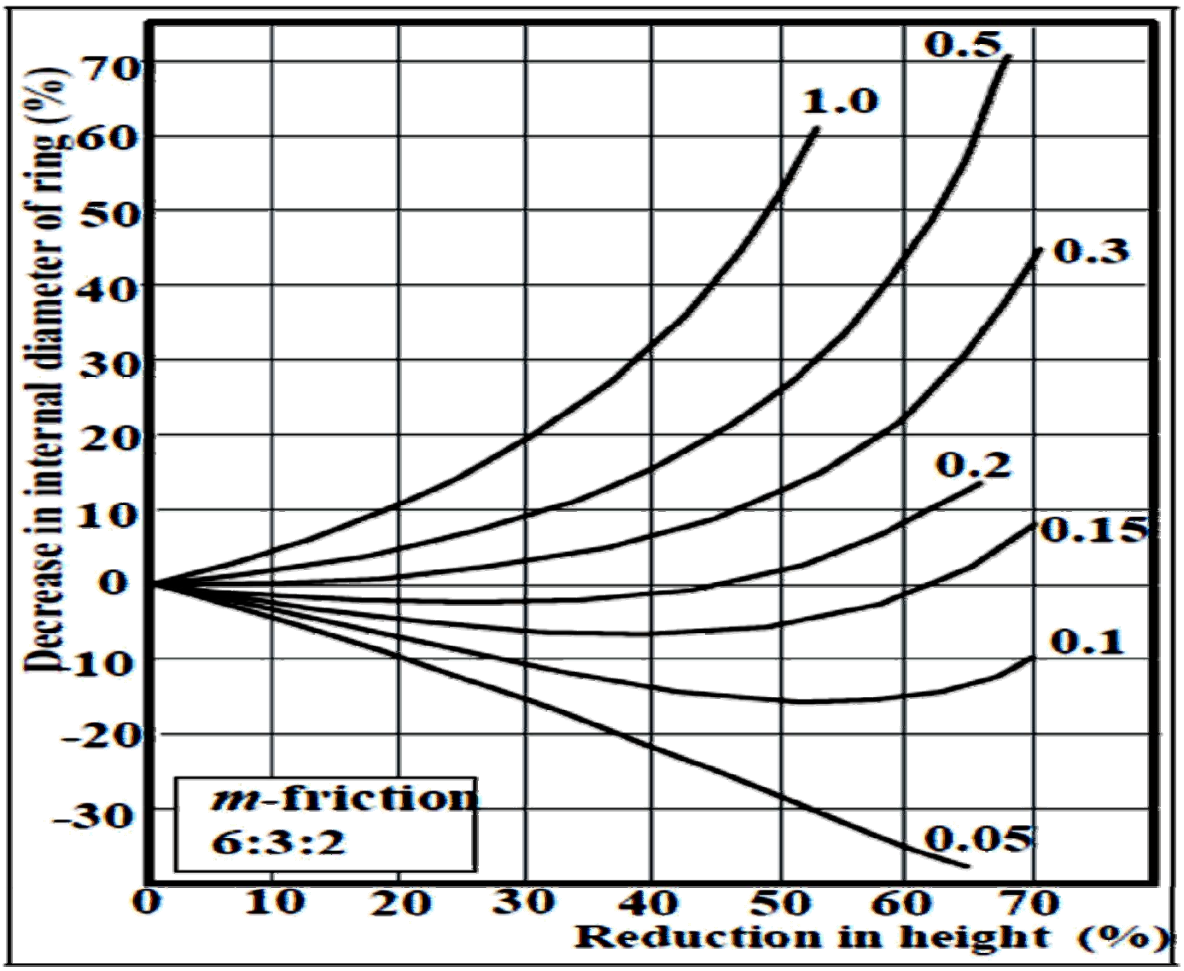
Lubrication Condition	Load	Outer Diameter (D_o)	Inner Dia (Initial) Di	Inner Dia (Final) Df	Initial Height (Hi)	Final Height (Hf)	%Reduction in Inner Diameter (ΔH/Hi) x100	% Reduction in height (ΔH/Hi) X 100	Friction Factor (m)	Friction Coefficient (μ)

Theoretical Determination of Friction factor

$$m = \frac{-1}{2\frac{Ro}{T}\left(1+\frac{Ri}{Ro}-2\frac{Rn}{Ro}\right)} \times \ln\left[\left(\frac{Ri}{Ro}\right)^2 \times \frac{\left(\frac{Rn}{Ro}\right)^2+\sqrt{3+\left(\frac{Rn}{Ro}\right)^4}}{\left(\frac{Rn}{Ro}\right)^2+\sqrt{3\left(\frac{Ri}{Ro}\right)^4+\left(\frac{Rn}{Ro}\right)^2}}\right]$$

$$Rn = Ro\sqrt{\frac{(Ri/Ro)+(\Delta Ri/\Delta Ro)}{(Ro/Ri)+(\Delta Ri/\Delta Ro)}}$$

Ri = Inner radius of Specimen after deformation
Ro = External Radius of the specimen after deformation
T = Height of the specimen
Ri = Change in internal radius of the specimen after deformation
ΔRo = Change in external radius of the specimen after deformation
Rn = Mean Radius of the specimen



$\mu = m/\sqrt{3}$, m = Friction Factor, μ=Friction Coefficient

Theoretical Determination of Friction Factor

Lubrication Condition	Load	Outer radius (R_o)	Inner Radius (Ri)	Height (H)	ΔRi	ΔRo	Rn	Friction Factor (m)	Friction Coefficient (μ)

Experiment- 3

Molding: Molding properties of sodium silicate bonded sand

Parts:

A. Measure compressive and shear strengths
B. Measure permeability
C. Measure green mould hardness
D. Determine moisture % in the moulding sand

INTRODUCTION:

Green and dry molding sands containing clay as the binder are commonly used in the foundry practice. Binders other than clay such as sodium silicate, molasses, linseed oil etc. are also frequently used as binders. Mold and core making processes based upon the sodium silicate represent a high proportion of the total chemically hardened sands used in the foundry industry. Advantages of using sodium silicate are that (i) it is cheap and easily available, (ii) it is inorganic and does not evolve gases upon heating when the hot liquid metal is poured, and (iii) it does not collapse and burns out after casting and hence gives thermally stable sand. However, in order to generate a proper bond, it is necessary to treat the sand mixture with CO_2 gas (hence the process is also known as the CO_2 process). The chemical reactions between sodium silicate and CO_2 are:

$$Na_2O.2SiO_2 + CO_2 = Na_2CO_2 + 2SiO_2$$

$$Na_2O.2SiO_2 + 2CO_2 + H_2O = 2NaHCO_3 + 2SiO_2$$

In the reactions SiO2 separates as the silica, which causes an increase in the viscosity of the binder and hence an increase in the strength of the bond. In addition to these chemical reactions, some loss of water from the silicate occurs when the CO2 is passed, which also causes an increase in the viscosity of the bond and increase in its strength. Thus, if a proper bonding has to be achieved, the gassing time and the pressure are to be controlled properly.

Part (A): COMPRESSIVE AND SHEAR STRENGTH MEASUREMENT

OBJECTIVE: To determine the compressive strength, shear strength of molding sand.

EQUIPMENT USED: Universal strength machine, high dry strength attachment (oven), sand rammer, compressive & shear pads.

PROCEDURE:

1. Make 6-standard sand samples of dia 50mm X 50mm height by sand rammer.
2. Make 3 samples first and then heat in the oven maintained at 150 °C for drying for 40 minutes.
3. After drying samples, take them out from the oven and cool them in air for 15 minutes.
4. For compression strength both dry and un-dried samples are placed on lower compression pads.
5. Press the mode key on indicator till ‘Co 0.00’ appears on control box. If required set “0” by rotating the trim-pot on control box.
6. Press ‘START’ key so that loading will start; & the maximum reading in kg/cm2 can be measured with peak hold facility and automatic unloading will be started.

7. Note down the readings.
8. Press 'RST' key to come out the cycle.
9. Now the machine is ready for next test.
10. Take 3 readings and average will give the result.
11. Repeat above steps for shear strength testing

REPORT QUESTION:

1. Tabulate results of compressive and shear strength of variously treated samples

Part (B): PERMEABILITY TEST

OBJECTIVE: To determine the permeability of moulding sand.

EQUIPMENT USED: Permeability meter, Orifice of diameter 1.5 mm, specimen tube, sand rammer.

PROCEDURE:

1. Make a sand sample by ramming it three times.
2. Lift the air tank drum slowly, keeping the valve at (D) position to avoid any water entering in the air tube.
3. Now put the valve on (O) position to hold the drum
4. Place the specimen tube over the rubber sealing boss.
5. Put the valve on (P) position.
6. Find the Permeability number from the Pressure Gauge.
7. Compare it with chart fixed on the instrument.

REPORT QUESTION:

1. Tabulate results of permeability of variously treated samples.

Part (C): GREEN MOULD HARDNESS TEST

OBJECTIVE: To determine the green mould hardness of the sand mould

EQUIPMENT USED: Mould hardness tester.

PROCEDURE:

1. Apply the mould hardness tester vertically, placing the tip on the mould surface whose hardness is to be measured.
2. Gently press on the surface until the surface of the bottom ring contacts the mould surface throughout the periphery.
3. Depth of penetration of the tip into the mould indicates the green hardness which is indicated on the dial directly.

REPORT QUESTION:

1. Tabulate results of green mould hardness of variously treated mould samples.

Part (D): MOISTURE TEST

OBJECTIVE: To determine the moisture % in the molding sand.

EQUIPMENT USED: Moisture tester, weighing M/C.

PROCEDURE:

1. Take few gm of molding sand in a cup and place it in the moisture testing device.
2. Now take one spoon of calcium carbide and put it in the cap of moisture testing device.
3. Now place the cap back on moisture testing device, tighten the screw and shake it properly, this ensures the immediate mixing of sand sample and CaC_2.
4. Watch the dial on the device.
6. Keep the instrument in vertical position.Observe the reading when pointer stops further movements.
7. This will give direct reading of moisture % in the sand.

REPORT QUESTION:

1. Tabulate results of moisture % in the sand.

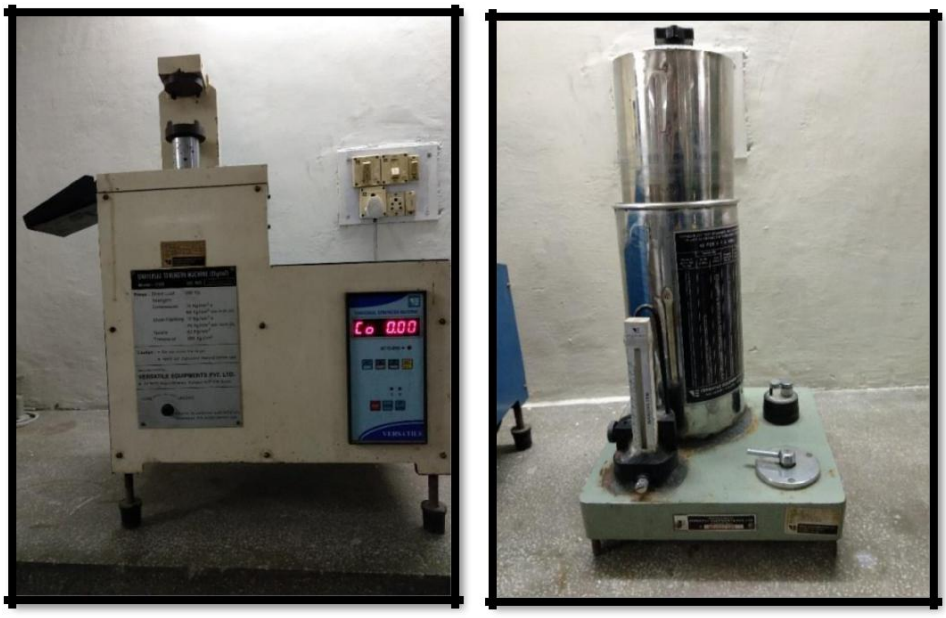


Figure 3.1 (left) Universal strength tester used for measuring compressive strength and shear strength; (right) Permeability testing equipment

Sand Testing Observation Table

A) **Moisture Test of Sample** - Moisture Percent by weight

B) Permeability Number

C)

Sr. No.	Permeability before Co_2 Pass	Permeability after Co_2 Pass	Permeability of heated Samples

D) Compressive Strength of Sample (Kg/cm^2)

Sr. No.	Compressive Strength after Co_2 Pass
1	
2	

E) Shear Strength of Sample (Kg/cm^2)

Sr. No.	Shear Strength after Co_2 Pass
1	
2	

F) Hardness Test

Sr. No.	Hardness	Hardness	Hardness
	Upper Surface	Lower Surface	Middle Surface
1			
2			
3			

Experiment- 4

Shrinkage behavior during permanent mold casting

OBJECTIVES:

Study the pipe formation in a cast metal ingot in 4 different conditions

INTRODUCTION:

When a liquid metal is poured in a stationary metal mould, and allowed to solidify, pipe formation inside the solidified ingot occurs. Pipe is the shrinkage cavity formed in the ingot. Pipe is of two types – Primary and Secondary. Primary pipe is located in the upper central portion of the ingot. The Secondary Pipe is located inside the ingot. The ingot mould is usually tapered from the top to the bottom of the mold, primarily to facilitate stripping of the ingot after solidification. The taper shape gives rise to the two principal types of moulds – big – end up and big – end down. The rate at which heat is extracted from an ingot solidifying in a mould, and hence to rate of solidification, is affected by many factors, some of which are the thickness, shape, and temperature of the mould, the superheat of the liquid metal, and the cross-section of the ingot. The nature of pipe formed in ingots greatly depends on the type of mould used. In the present experiment, the effect of big – end up and big – end down type moulds on the pipe formation will be studied.

PROCEDURE:

1. Melt the given metal/alloy.
2. Pour the liquid metal/alloy in ingot shape mould made from steel. Use two casting conditions – Big- end up and Big-end down. Allow it to solidify.
3. Measure the volume of the primary pipe formed in the upper portion of the ingot.
4. Cut the solidified ingot in the longitudinal direction.
5. Measure the volume of secondary pipe formed inside the ingot.
6. Calculate the yield of the sound metal in the ingot.

REPORT:

1. Objective of the experiment
2. Materials used
3. Procedure in your words, including the melting of metal/alloy.
4. The volume of primary and secondary pipe.
5. Yield of sound metal in %.
6. Schematic diagram of the moulds

7. Schematic diagram of the cross – section of the ingot showing the pipes
8. Draw a typical ingot structure showing the casting defect for killed steel in the following four cases –
   a) Big – end up, hot topped
   b) Big – end down, hot topped
   c) Big – end up, without hot topped
   d) Big – end down, without hot topped.

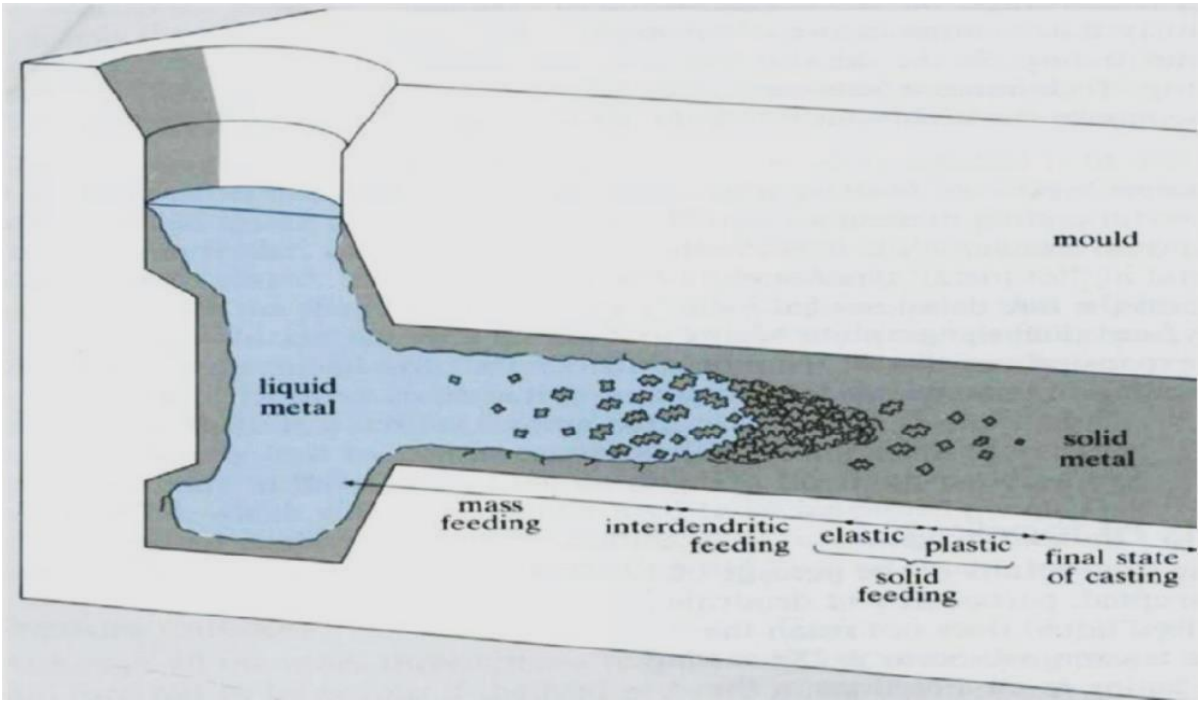


Figure 4.1: Solidification of liquid metal showing various zones.

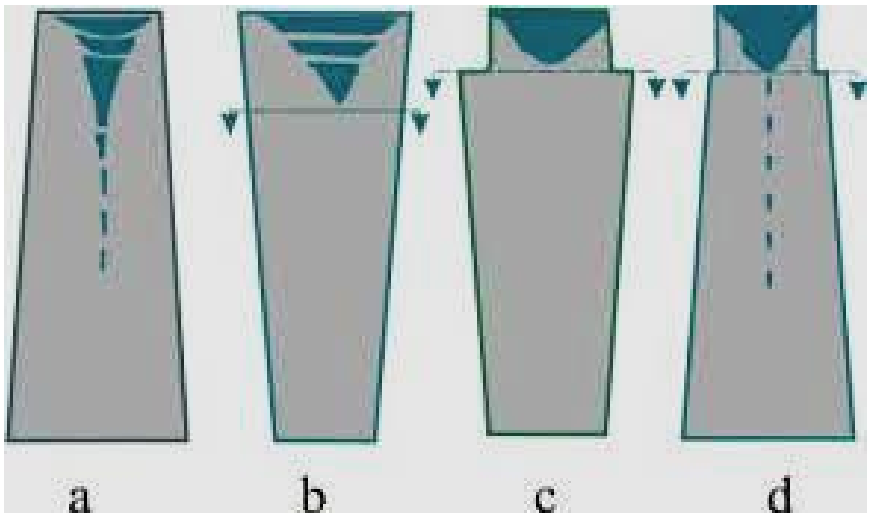


Figure 4.2: Shrinkage defects in casting

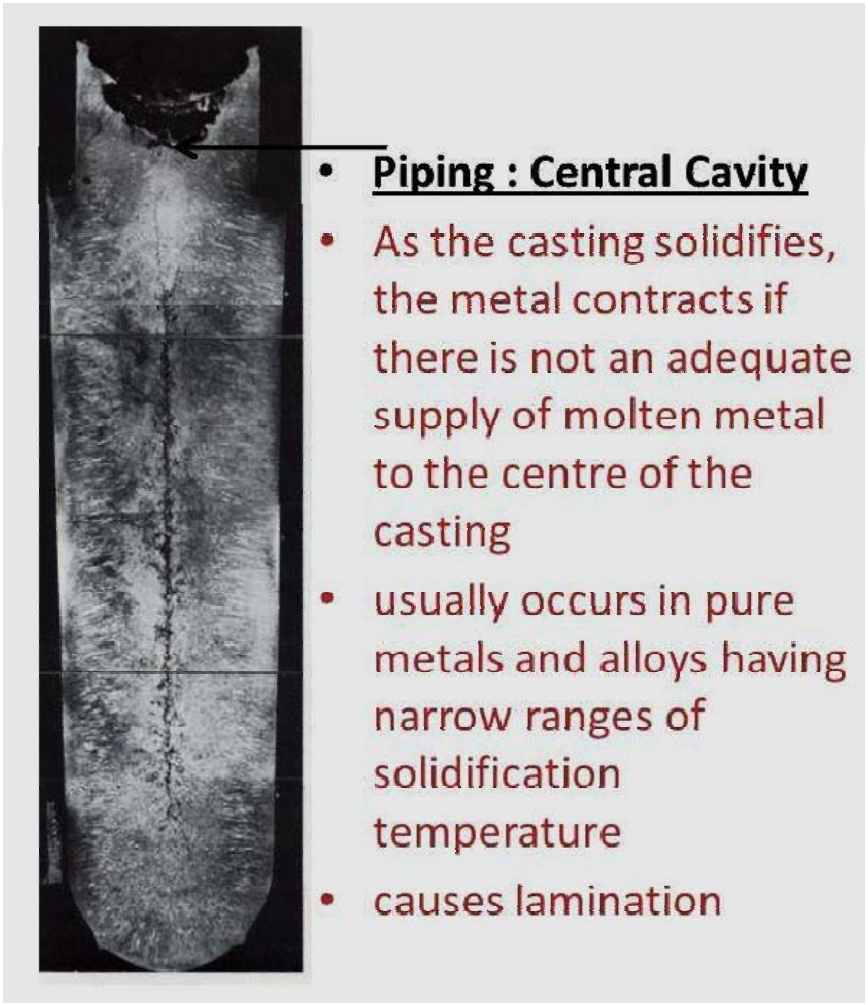


Plate-2: Casting Defect

Experiment- 5

Fluidity of Aluminum Alloys

OBJECTIVE:

To assess the finger casting fluidity of short arid long freezing range aluminum alloys.

INTRODUCTION:

Fluidity is a term which is commonly used to designate two different properties of liquid metals and alloys. The physicists define fluidity as a reciprocal of the coefficient of the viscosity and give the term of fluidity an absolute meaning. The metallurgists consider fluidity in a broader aspect, defining it as the ability of metal and alloys to flow freely, and thus to feed a mould and reproduce the desired contour before such freezing occurs as would offer an abstraction to its further flow. The term "Fluidity" is used a general sense to describe the ability of metal both to flow and fill the mould.

Both metal and mould characteristics are involved in determining fluidity. The following metallurgical factors exhibit greater or less influence on fluidity:

a) Metal composition and freezing process
b) Superheat
c) Metal viscosity
d) Surface tension
e) Surface oxide films
f) Adsorbed gas films
g) Suspended inclusions and
h) Inclusions precipitating during freezing

Of these factors, first two are important. With regard to superheat, it stands to reason that is heated to a higher temperature will have a longer period in the mould in which it is liquid, and hence it will flow farther than metal not so highly heated. It has been amply demonstrated that changes in metal composition can markedly affect fluidity. Best fluidity is obtained for pure components, eutectics or phases that freeze congruently, whereas poorest fluidity is for the long freezing range (LFR) alloys. Fluidity testing can be broadly divided into two groups:

a) Test with constant section channels and

b) With variable section.

The commonly used test methods in shop floor are spiral fluidity and finger casting fluidity. Spiral fluidity is used for both ferrous and non-ferrous base alloys. In the spiral fluidity test, melt is poured into the mould of spiral shape with a fixed cross-section. The fluidity index is the length of the solidified metal in the spiral passage. The greater the length of the solidified metal, the greater is its fluidity. Figure 3.1 shows the spiral fluidity test mould. Advantages of the spiral mould are that standard mounding boxes can be used and the mould is small enough to be handled with ease. The practical limitation is that this test requires a laboratory standard of control to obtain reproducible results, and cannot be readily used in the shop floor. In the finger casting fluidity test, instead of pouring the melt into a spiral of fixed cross section, melt feeds into five fingers of varied cross section. The fluidity reported from this experiment is the sum of the lengths in the five fingers. This procedure conflates the cavity parameters with the fluidity of the metal. Figure 3.2 shows the finger fluidity test mould.

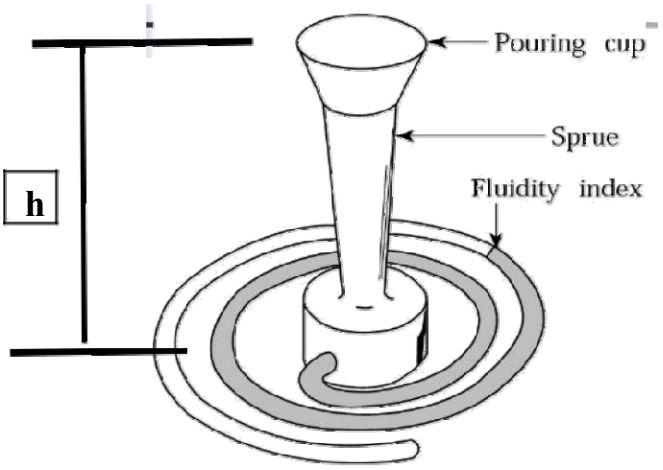


Figure 5.1 Spiral fluidity test

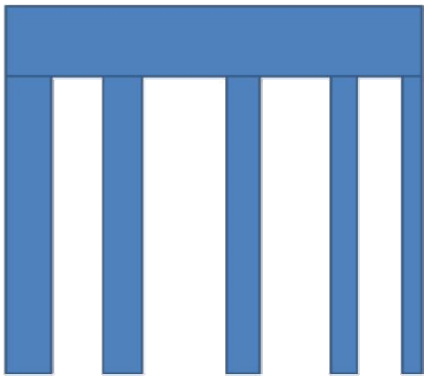


Figure 5.2 Finger Casting fluidity test

OBJECTIVE:
To assess the fluidity by Spiral fluidity test and finger casting fluidity of short arid long freezing range aluminum alloys.

PROCEDURE:

1. Prepare sand moulds using given finger casting fluidity test patterns.
2. Melts given are of Al alloys. They are of short freezing and long freezing range.
3. Measure the temperature before pouring into moulds (in both cases pouring temperature should be same).
4. Obtain the fluidity castings by theoretically and by experimentally and assess the fluidity of the alloys.

$$L_f \simeq \frac{\rho_s a v}{2h(T_M - T_0)}(H + c'\,\Delta T)$$

ρs =Density of Al = 2.7 g/cc, v = Velocity of stream = √ (2gh)

a = radius of channel cross section, h= Heat transfer coefficient (0.04 cal/(cm^2 c.s)

ΔT = Super heat

REPORTS:

1. Objective of the experiment.
2. The methods of melting, preparation of moulds, temperature measurement etc.
3. Fluidity assessment of two different alloys and consequences in routine casting method.

QUESTIONS

1. What are the other methods for measuring fluidity? What are their advantages and drawbacks? Which of them is the more commonly used?
2. How does the composition affect the fluidity?
3. Is it possible to relate chemical composition and fluidity in steels and cast irons? If so, give the relations.
4. For a given casting, the fluidity is less. There no choice given in selecting the alloy. Apart from superheating the liquid what are the other possibilities? Discuss.

Fluidity Testing Observation Table

Sr. No.	Fluidity (cm)	Fluidity (cm)	%Error
	Experimental	Theoretical	
1			
2			
3			

Experiment- 6

Investment casting process

OBJECTIVES:

Make a part using investment casting process to understand various steps involved

INTRODUCTION:

Investment casting is one of the oldest manufacturing processes, dating back thousands of years, in which molten metal is poured into an expendable ceramic mold. The mold is formed by using a wax pattern - a disposable piece having the shape of the desired part. The pattern is surrounded, or "invested", into ceramic slurry that hardens during heating into the mold. Investment casting is often referred to as "lost-wax casting" because the wax pattern is melted out of the mold after it has been formed. Lox-wax processes are one-to-one (one pattern creates one part), which increases production time and costs relative to other casting processes. However, since the mold is destroyed during the process, parts with complex geometries and intricate details can be created, which is unique feature of the process.

Investment casting can make use of most metals, most commonly using aluminum alloys, bronze alloys, magnesium alloys, cast iron, stainless steels, and tool steels. This process is beneficial for casting metals with high melting temperatures that cannot be molded in plaster or metal. Parts that are typically made by investment casting include those with complex geometry such as turbine blades, firearm components. High temperature materials are also common, which includes parts for the automotive, aircraft, and military industries.

Investment casting requires the use of a metal die, wax, ceramic slurry, furnace, molten metal, and any machines needed for sandblasting, cutting, or grinding. The process steps include the following:

- ***Pattern*** - The wax patterns are typically molded into a metal die and are formed as one piece. Cores may be used to form any internal features on the pattern. Several of these patterns are attached to a central wax gating system (sprue, runners, and risers), to form a tree-like assembly. The gating system forms the channels through which the molten metal will flow to the mold cavity.

- ***Mold creation*** - This pattern tree or single pattern is dipped into slurry of fine ceramic particles, coated with more coarse particles, and then dried to form a ceramic shell around the patterns and gating system. This process is repeated until the shell is thick enough to withstand the molten metal it will encounter. The shell is then placed into an oven and the wax is melted out leaving a hollow ceramic shell that acts as a one-piece mold, hence the name "lost wax" casting.

- ***Drying & Pouring*** - The mold is preheated in a furnace to approximately 250^0C and the molten metal is poured into the gating system of the mold, filling the mold cavity. Pouring is typically achieved manually under the force of gravity, but other methods such as vacuum or pressure are sometimes used.

- **Time for Solidification** - After the mold has been filled, the molten metal is allowed to cool and solidify into the shape of the final casting. Cooling time depends on the thickness of the part, thickness of the mold, and the material used.

- ***Casting removal & Finishing*** - After the molten metal has cooled, the mold can bebroken and the casting removed. Often times, finishing operations such as grinding or filing are used to smooth the part at the gates.

- ***Heat treatment*** is also sometimes used to harden the final part.

PROCEDURE:

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

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

The metal casting pattern is then dipped in refractory slurry or POP (plaster of parries) based slurry. A ceramic/POP layer is obtained over the surface of the pattern. The pattern is then repeatedly dipped into the slurry to increase the thickness of the ceramic/POP coat. In some cases, the pattern may be placed in a flask and the ceramic/POP slurry poured over it. Once the refractory coat over the pattern is thick enough, it is allowed to dry in air in order to harden. The next step in this manufacturing process is the key to investment casting. The hardened ceramic/POP mold is turned upside down and heated to a temperature of about 150^0C. This causes the wax to flow out of the mold, leaving the cavity for the metal casting.

The ceramic/POP mold is then heated to around 250^0C. This will further strengthen the mold, eliminate any leftover wax or contaminants and drive out water from the mold material. Parallelly the group will make a similar pattern with the thermocole and prepare the molasses mold for melt metal poring.

Pouring the casting while the mold is hot allowing the liquid metal to flow easily through the mold cavity, filling detailed and thin sections. Pouring the metal casting in a hot mold also gives better dimensional accuracy, since the mold and casting will shrink together as they cool. After pouring of the molten metal into the both molds, the casting is allowed to set as the solidification process takes place. The final step in this manufacturing process involves breaking the ceramic/POP mold from the investment casting and opening of sand mold.

Figure 6.1: Various wax shapes to be used for investment casting

Advantages of Manufacturing by Investment Casting

- Investment casting is a manufacturing process that allows the casting of extremely complex parts, with good surface finish.
- Very thin sections can be produced by this process. Metal castings with sections as narrow as 0.5 mm have been manufactured using investment casting.
- Investment casting also allows for high dimensional accuracy. Tolerances as low as 0.08 mm have been claimed in ideal case.
- Practically any metal can be investment cast. Parts manufactured by this process are generally small, but parts weighing up to 25 -30 Kgs have been found suitable for this technique.
- Parts of the investment process may be automated.

Limitation of Manufacturing by Investment Casting

- Investment casting is a complicated process.
- Investment casting is relatively expensive.
- Investment casting is not suitable for heavy objects.

REPORT THE FOLLOWING:

1) Complete Flow chart of process completed during experiment.
2) Composition of slurry and molasses sand.
3) Utility of Investment Casting compare to other sand casting.
4) Advance replacement of Investment Casting.
5) Any defect formed on the cast product.
6) Any modification of the process you would like to do.

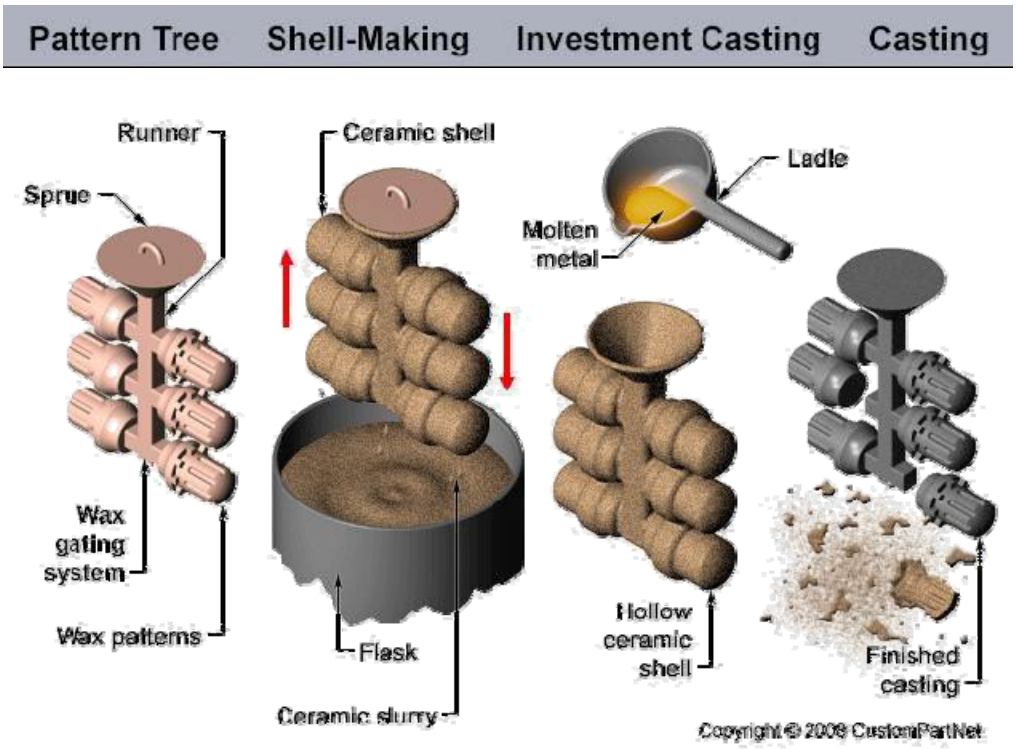


Figure 6.2: Various steps during Investment casting

Color Plate-3: Al. Induction Furnace at Engineering Metallurgy Lab

Experiment- 7

Welding: Microstructural evaluations of MMAW, MAG and TIG welded steel

OBJECTIVES:

i. Study the effect of heat affected zone (HAZ) on the microstructure and properties of steel weldment. (Plot hardness vs distance for various processes)
ii. Study of the size of HAZ for various welding processes

INTRODUCTION:

Fusion welding methods are the most effective ways for joining metals and alloys. These methods play a very important role in the manufacturing industries. They are employed in manufacturing of products such as ships, railways, earth moving equipment, automobiles, space vehicles, buildings, bridges, farm equipment mining equipment, furnaces, boilers, home appliances and many other products of common use. These processes include oxy-fuel gas welding, arc welding, thermite welding, electro-slag welding, electron beam welding, laser welding etc. Arc welding is the most common fusion welding methods for joining ferrous as well as non-ferrous metals and their alloys. Shielded metal arc welding, gas tungsten arc welding, gas metal arc welding, flux core arc welding, submerged arc welding, plasma arc welding and electron gas welding are the fusion welding processes belonging to the family of the arc welding processes. Fusion welding processes, however, are among some of the most complex metallurgical processes since large variety of metallurgical phenomena occur in a brief time interval when the weld bead is being made. The engineer, when specifying the welding operation, is concerned with gas-metal reactions, slag-metals reactions, solidification and heat-flow considerations, solid-state reactions and transformations, and of course reliability and cost. Thus, the engineer is not just concerned with the area of coalescence produced by the fusion welding, but with the entire welded joint which includes the region around the coalesced zone as well as the zone itself.

The manual metal arc welding (MMAW) is the most basic form of arc welding. It uses high current and low voltage electricity to form an electrical arc. It has a consumable electrode, which conducts the arc onto the work metal, melts in the process and forms filler metal. The arc must be manually started; i.e, by striking the workpiece with the electrode like lighting a match. All metals react with oxygen in the air, and react much quicker when temperatures are elevated. MMAW overcomes this by including a coating on the electrode that vaporizes along with the metal and forms a cloud of slag that keeps the oxygen out. This slag solidifies on the weld and is chipped away to see the weld. The metal active gas welding (MAG) is a sophisticated form of welding. It works on the same principle as MMAW with the different ways of dealing with shielding and electrodes. It uses a continuous wire as an electrode. The wire is continuously fed, at the rate at which it is used up into filler metal. It uses CO_2 to shield the working area and prevent oxidation of welded metal part. This means that one can weld more reactive metals, such as aluminum. There is no slag to be chipped away in MAG welding.

A designer must anticipate two problems inherent in the fusion welding process: (1) the effect of localized heating and cooling on the microstructure and properties of the base metal and (2) The effect of the residual stresses that are locked in the weldment as a result of the uneven cooling of the weld deposit. The heat affected zone (HAZ) is the region of the base metal, adjacent to the weld bead, where the temperature has caused the microstructure of the base metal to change. In carbon and alloy steels HAZ is particularly important because of the phase changes that occur in them when they are subjected to heating and cooling from high temperature. The depth of penetration in fusion welding is affected by the welding velocity, welding current, and the degree of preheat. It influences the preparation of the joint and the number of phases required to complete the weld. For ferrous materials peak temperature and cooling rate are important factors from the point of view of predicting whether rates are important for predicting whether the martensitic transformation will occur or not.

PROCEDURE:

1. Take pieces of 5 mm thick, 25 mm wide and 80 mm long steel plates and remove dust/rust/oil from the surfaces them using a sand paper or cloth. Weld the two pieces of steel plates by MMAW process, MAG Process as described below.

2. Heat input to the job is related to the welding current. Welding current is changed by varying the open circuit voltage of the welding machine and the slope of the volt-ampere curve. Set the desired welding current.
3. Lay a weld bead at the center of the plate at an average speed of about 10 mm/min by striking the arc and moving the electrode manually till about 20 mm long bead is formed.
4. When the welded plate is cooled to a temperature < 500°C, remove the plate from the table and cool it to room temperature in running water.
5. Remove the slag if deposit from the welded plate by wire brushing. A clean bead will be visible.

6. Cut all the welded plates vertically so that the bead cross-section can be examined and polish the sectioned surface for its visual and micro structural examination.

10. Measure the size of the pool and the depth of penetration.

11. Measure the hardness of the welded joint as a function from the distance from weld axis.

12. Etch the polished surface and observe the microstructures of various weld zones. Estimate the width of the heat affected zone (HAZ) in each case.

REPORT:

1. Objective of the experiment.
2. Appearance, pool size and depth of penetration as a function of different processes.
3. Hardness vs. distance plots for various processes.
4. Size of the heat affected zone (HAZ) as a function of welding processes.
5. Microstructures and associated differences with respect to different welding processes.
6. Hardness profile of weld joint as a function of distance from the weld axis.

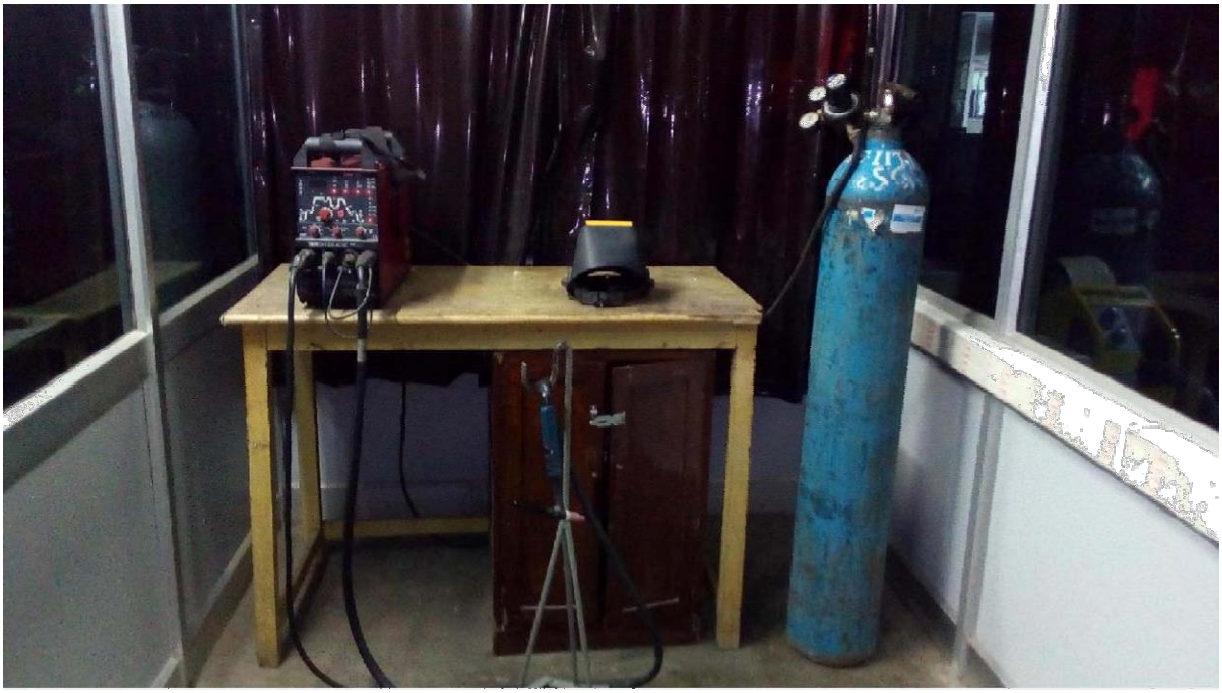


Plate-4: Various Welding facilities at Engineering Metallurgy Lab

Experiment- 8

Powder Metallurgy (P/M): Study various characteristics of copper powders and evaluate green density as well as strength characteristics (hardness) of cold-compacted and conventional sintered compact.

OBJECTIVES:

1. Study particle characteristics of the given metal powders.
2. Study the die compaction behavior of the given metal powder and to determine tap
3. Density, green density and green strength of the compacts.

INTRODUCTION:

Powder metallurgical (P/M) processing of the metals and alloys plays an important role in manufacturing various engineering components for several applications. The conventional P/M technology for making components starts with metal powders as the raw material, which is pressed in dies of suitable shape to produce green compacts. These green compacts are subsequently, sintered at high temperature under protective atmosphere with following objective: (i) to develop proper bonds between higher to mechanically pressed powder particles comprising the green compacts and (ii) to reduce the porosity level in the sintered compact so that it has still higher relative density. However, parts produced by the conventional P/M approach always contain some residual porosity. Non-conventional P/M technologies have been developed with the objective of completely eliminating the porosity from the manufactured part.

Metal powders are produced by various methods, such as (a) atomization, (b) solid-state reduction of metal oxides or other compounds, (c) chemical precipitation from organic or inorganic solutions, (d) electrolysis, (e) mechanical alloying etc. Each of these generic processes may have several specific variants for metal powder preparation. The shape, size and their distribution of as- synthesized metal powders depend on the specific method of production, variables associated with the process and their control. The tapping of a powder stock in the die and its behavior during compaction and sintering is substantially influenced by its size and shape characteristics. It can be mentioned here that the spherical powder particles with uniform size distribution is usually preferred from the point of view of good flowability during compaction as well as for good sinterability.

Metal powders have different shapes such as spherical, rebounded, dendritic, acicular, rod-like flaky, irregular etc. An analysis of size and its distribution of a given batch of powder, coarser than 44 μm, are generally carried out by sieves. There are specialized methods for determining the size and its distribution for powders, finer than 44 μm, i.e. the powder of sub-sieve size.

The density of loose powder is known as the apparent density. It is measured by allowing the loose powder to flow through the Hall flow meter. Very often, the loose powder is mechanically vibrated and/or tapped so that the particles in the loose mass further settle and occupy a smaller volume. The density of the powder mass obtained after its mechanical

vibration or tapping, is known as the tap density. The apparent density and tap density are useful indices for understanding the behavior of the powder during its compaction.

It has already been discussed in class lectures that for most of the conventional powder metallurgy applications for manufacturing various engineering components, the metal powder has to be compacted in dies of the appropriate shape. Compressibility of a given metal powder depends on various physical properties of the metal or alloy and also on the (a) size and shape of the powder and (b) friction characteristics and the die/powder interface. Thus, the compressibility of a metal powder is an index of its densification behavior under the application of an external pressure. The compressibility of a powder compact is often measured in terms of the green density, achieved at a given applied pressure. Typical illustration of the cold compaction process to obtain a green powder compact is shown in Fig. 6.2. Alternatively, it is defined in terms of a densification parameter, which is given as,

$$\text{Densification parameter} = \frac{\text{Green Density - Apparent Density}}{\text{Theoretical Density - Apparent Density}}$$

From the above definition of the densification parameter, it is clear that it represents the fractional densification achieved with respect to the theoretically maximum attainable densification. Green strength of a compact is expressed as Transverse Rupture Strength. The schematic illustration of the three-point flexural set up is shown in Fig. 6.3. In the transverse rupture strength test, specimens are broken in a special testing fixture. The specimen in the testing fixture is supported by two hardened steel rods. Another rod presses the specimen at the center till it breaks. The green strength of the powder compact is calculated from the following relationship.

$$S = 3PL / 2t^2W$$

Where,

S	=	Transverse rupture strength, kg/m^2
P	=	Breaking load, Kg.
L	=	Distance between the supporting rods, mm
t	=	Thickness of the green specimen, mm
W	=	Width of the green specimen, mm

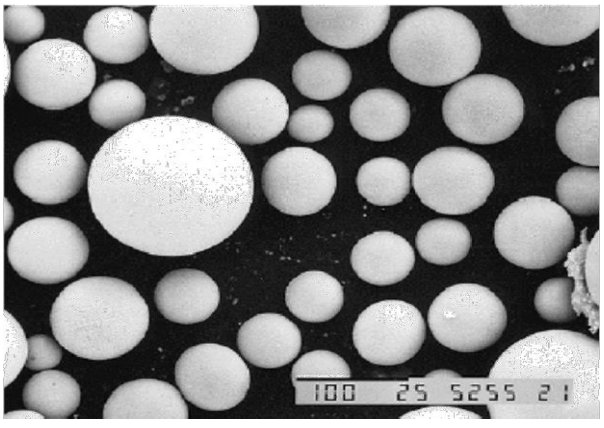


Figure 8.1: Scanning electron microscope image revealing typical size and shape of Nickel-based superalloy powder particles synthesized by the rotating electrode process.

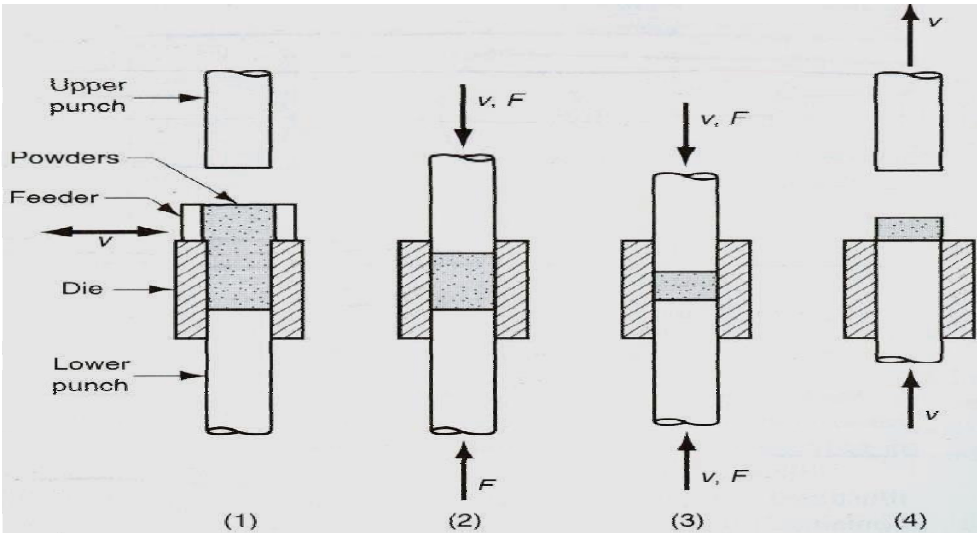


Figure 8.2: Conventional method of compaction: (1) Filling die cavity with powder by automatic feeding system, (2) initial and (3) final positions of upper/lower punches and (4) ejection of sample.

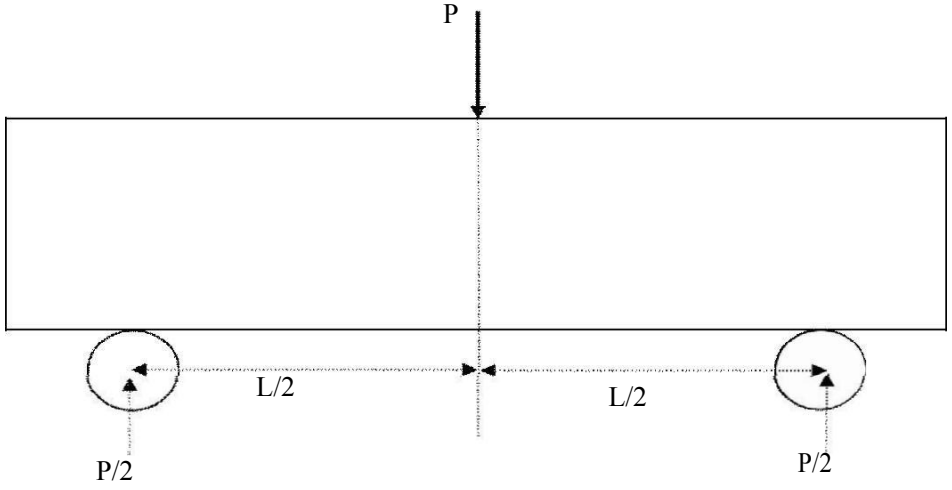


Figure 8 .3: Schematic illustration of three-point flexural strength measurement of rectangular cross section bar

PROCEDURES:

A. Powder Size and Characteristic

1. Weigh about 100 g of metal powder given to you.
2. Sieve the weight powder in the set of sieves for about 20 minutes
3. Weight the powder on each sieve and tabulate the weights as weight percentages of the whole mass.
4. Observe different batches of powders under the stereo-microscope.
5. Neatly sketch the powder particle morphology of powders given to you for the observation of their shapes.

B. Powder Density

1. Taking about 150 – 200 g of the given powders and gradually pass them separately in the graduated measuring cylinder of the Tap Density Meter.
2. Gradually make the upper powder level horizontal and measure the volume. Calculate the tap density of both the batches of given metal powders.
3. Introduce vibrations in the powder by taping (5 at a time) and observe the decrease in powder volume. Calculate the density of the powder. Repeat this procedure till the density approaches a stable value.

C. Green Density

1. Weigh pre-determined mass of the powder for preparing the rectangular green compact.
2. Compact these powders at three different loads. Calculate the applied pressure at the three different loads.
3. Eject the green compact from the die carefully and weigh each green compact.
4. Measure the dimensions of green compacts and calculate the densities of the compacts followed by volume.

D. Green Strength

1. Measure the width and thickness of the green compact in mm.
2. Carefully place the rectangular green compact over the fixture. Take care that the specimen projects equally on both the sides of the fixtures.
3. Switch on the loading device (it automatically stops once the specimen breaks). Read the breaking load.
4. Calculate the green strength of the entire three specimens.

COMPACTION EFFECTS ON SINTERING:

The higher compaction pressures contribute to an increase in density and neck contact size in green compact, while reducing the rate of neck growth during sintering. Further, the higher compaction pressures lead to larger net neck sizes. Also, the shrinkage decreases with an increasing compaction pressure. It is the sintered neck size which dominates the properties such as strength and ductility, thus, higher compaction pressures are generally beneficial. Increasing the compaction pressure gives better dimensional control, less sintering shrinkage, and better final properties.

OBJECTIVES:

a) To study the sintering behavior of a powder compact prepared from copper powder.
b) To measure the density and properties of the sintered powder compact.

PROCEDURE:

1. Blend copper powder and 0.5 wt. % zinc stearate lubricant.
2. Prepare cylindrical compacts from the blended powder mixture at three different pressures using the given die and punch. Also, apply the lubricant on the walls of die and punch. Select the pressure in such a way that there is no problem in handling the compacts.
3. Weigh the compacts and measure their dimensions, i.e. diameter and thickness, and calculate the green density of the pellets.
4. Place the green compacts over a Nimonic tray and insert the assembly in the hot zone of the tubular furnace, kept at the selected temperature of 850$_{o}$C for 30 minutes. Close the furnace ends and introduce a protective gas inside the furnace.
5. Allow a sintering time of 30 minutes for all the compacts. Switch-off the furnace and take out the Nimonic tray gradually from the hot zone. Cool it in the cold zone for sufficient period of time.
6. Measure the dimensions of the sintered compacts and weigh them again. Calculate the density of the sintered compacts.
7. Measure the hardness values of each sintered compacts.

REPORT:

1. Objective of the experiment.
2. Particle size distribution of the given powder in terms of the particle size (in sieve size as well as in microns) distribution histogram.
3. Cumulative particle size distribution of the given powder.
4. Morphologies of the given powders indicating the presence of features such as, powder shape, size, distribution etc.
5. Apparent density of powders.
6. Tap density of the powders as a function of tapping vibrations and the effect of powder shape and morphology on the apparent density and the tap density of the powder.
7. Observations i.e. dimensions before and after sintering in a tabular form.
8. The basic features of the powder compaction press
9. Plot the green density values with compaction pressure
10. Plot the green strength of powder compacts with compaction pressure.

Sr. No.	Compaction Pressure, MPa	Green Compacts			Sintered Compacts		
		Wt, g	Dia, mm	Thickness, mm	Wt, g	Dia. mm	Thickness, mm
1							
2							
3							

Calculation: Calculate green compact density, sintered compact density, sintered compact porosity and the densification parameter. Use the following formula for calculating the densification parameter.

$$\text{Densification parameter} = \frac{(\text{Sintered Density - Green Density})}{(\text{Theoretical Density - Green Density})}$$

QUESTIONS:

1. What are the limitations of your sieve shaker? What improvements can be made?

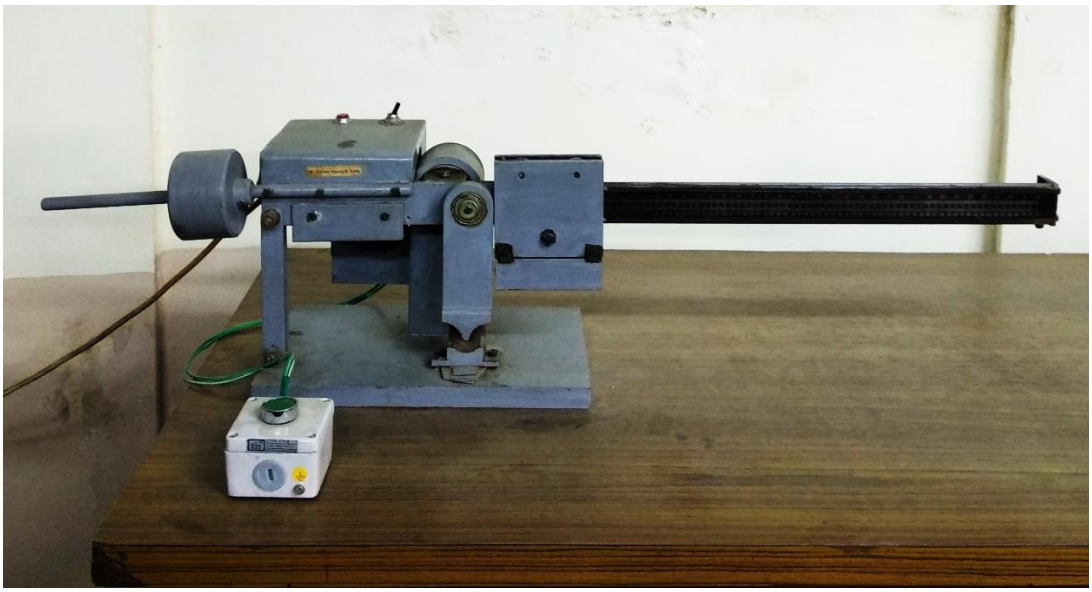
2. What will be the effect of various particle shapes and morphologies on the results obtained from the sieve analysis? Why is it difficult to sieve metal powder particles finer than 325 mesh size?

3. How would be the accuracy of the tap density data affected by the volume of the metal powder taken for the sampling?

4. What was the production methods of the given metal powder used in your experiments? If you were given a powder produced by a different method how do you expect your results to be different from what you have got.

5. How is particle size expected to affect green strength and density variations with pressure? How does the compaction pressure affect the density of the powder compact prepared from a (i) soft and (ii) hard powder of the same material?

Color Plate-5: Powder compaction (Left) and sintering facility (Right) at Engineering Metallurgy Lab



Color Plate–6 Green Strength Tester

Experiment- 9

Severe Plastic Deformation (SPD)- Effect of Severe Plastic Deformation on preparation of microstructure (OM) and its properties (hardness)

OBJECTIVES:

Calculate strain and strain-rate for various chips and compare with strain and strain-rate imposed during rolling

INTRODUCTION:

Severe Plastic Deformation is a process of prepare bulk nano-structured material by deformation induced grain size reduction. This is achieved by severe plastic deformation leading to formation of defects (mostly dislocations), which causes grain size reduction. Severe Plastic Deformation is a metal working process used to produce large strains without producing any significant changes in the overall dimension of the material. Machining is one such process by which severe plastic deformation can be achieved. In fact, the machined region undergoes severe shear deformation. Machining can be used to achieve the desired geometry of the work piece by using sharp cutting tools. During machining, gradual removal of excess material takes place in the form of machined chips. The form of machined chips depends mainly upon:

- Work piece materials.
- Cutting tool material
- Geometry of cutting tool
- Feed Rate
- Depth of cut
- Cutting Speed

Sevier Plastic Deformation is a result of chip formation in simple plane strain machining. In this process a sharp wedge shaped tool removes a preset depth of material a0 by moving in a direction perpendicular to its cutting edge. Deformation occurs by shear concentrated in a narrow zone; often idealized as a shear plane. The geometry of the deformation zone and shear strain in this shear plan model are determined by the shear angle Ø and the rake angle α. The effective strain 'ε' for the chip is given by

$$\varepsilon = \Upsilon/\sqrt{3} = \frac{\cos\alpha}{\sqrt{3}\times\sin\varphi\cos(\varphi - \alpha)}$$

where φ is calculated from measurement of a_0 (un deformed chip thickness) and a_c (deformed chip thickness)

$$\tan\varphi = r - r^2\frac{r\cos\alpha}{1 - r\sin\alpha}$$

where r is ratio of uncut chip thickness to deformed chip thickness , $r = a_0 / a_c$

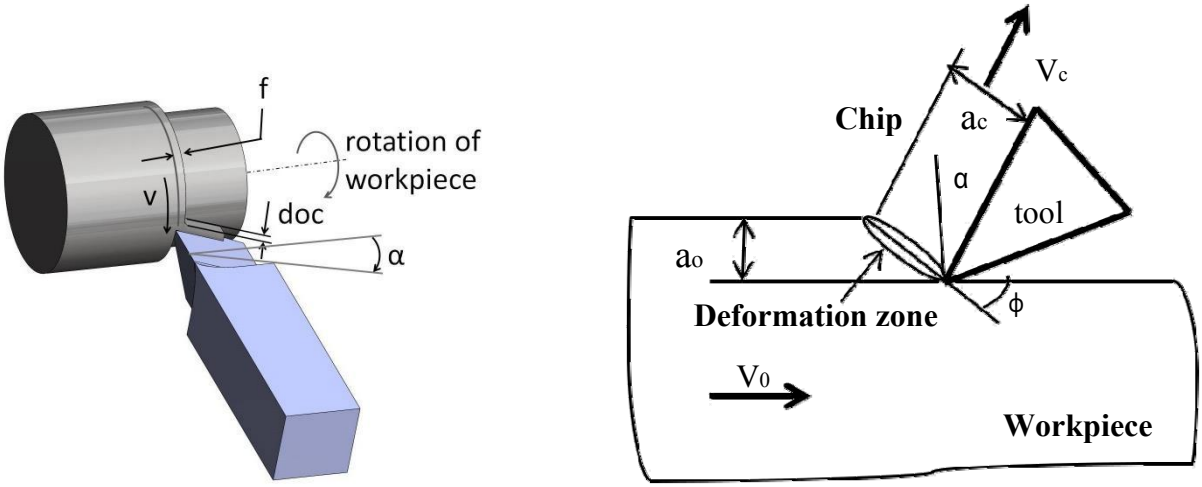


Figure 9.1 : (a) Schematic of lathe machining and various parameters associated with it. (b) Geometry of the orthogonal machining process during single tool machining.

Strain-rate is given by

$$\dot{\varepsilon} = \frac{\Upsilon}{\sqrt{3}} = \left(\frac{C}{\sqrt{3}}\right) * \left(\frac{Vs}{L\Upsilon}\right)$$

where, *Vs* (=V0 X cos α/ cos (φ - α)) is the shear velocity, *L* is the length of shear plane and *C* is a proportionality constant whose value is approximately 4.8.

Deformation temperature is given by

$$\Delta T = \frac{(1-\beta)K\gamma}{\rho C}$$

where, β is the partition parameter, *K* is shear strength and ρC is the heat capacity of the material.

PROCEDURE

Take a mild steel rod and machine it at given machining conditions. The feed rate given to the sample was 0.17 mm. HSS cutting tool can be used for machining. A lot of heat is generated during the process of machining and it can damage the surface of the component being machined. Hence a coolant is usually applied to ensure smooth surface and safe life of cutting tool.

Collect the chips produced and mount in the cold setting compound for desired polishing. After successfully mounting and polishing, measure the hardness of both samples. Take Optical and SEM micrographs of the microstructure after proper polishing.

Report the Following:

1. Flow chart of experiment
2. Measure a_c
3. Calculate strain (Use a_0= 0.5 mm) for both the rake angle
4. Calculate strain-rate for all the machining conditions.
5. Hardness of unmachined material and machined chips. Changes in hardness due to change of rake angle.
6. Compare Optical and SEM micrographs of the chip with the unmachined mild steel.

Experiment- 10:
Demonstration

Part (a) Physical Vapor Deposition (PVD) Part
(b) Plastic Injection Molding (PIM) Demo

Part (A): Physical Vapor Deposition (PVD)

OBJECTIVES:

i. To study the deposition of film by PVD process.

INTRODUCTION:

Physical vapor deposition (PVD) describes a variety of vacuum deposition methods which can be used to produce thin films. PVD is a fundamentally a vaporization technique, involving transfer of material on an atomic level. It is an alternative process to electroplating. It describes a variety of vacuum deposition methods used to deposit thin films by the condensation of a vaporized form of the desired film material on to various work piece surfaces PVD processes are carried out under vacuum conditions. The process involved four steps:

1) Evaporation (2) Transportation (3) Reaction (4) Deposition

Evaporation

During this stage, a target, consisting of the material to be deposited is bombarded by a high-energy source such as a beam of electrons or ions. This dislodges atoms from the surface of the target, 'vaporizing' them.

Transportation

This process simply consists of the movement of 'vaporized' atoms from the target to the substrate to be coated and will generally be a straight-line affair.

Reaction

In some cases, coatings, will consist of metal oxides, nitrides, carbides and other such materials. In these cases, the target will consist of the metal. The atoms of metal will then react with the appropriate gas during the transport stage. For the above examples, the reactive gases may be oxygen, nitrogen and methane. In instances where the coating consists of the target material alone, this step would not be part of the process.

Deposition

This is the process of coating build up on the substrate surface. Depending on the actual process, some reactions between target materials and the reactive gases may also take place at the substrate surface simultaneously with the deposition process.

In PVD it consists of mainly evaporation and Sputtering process, we mainly discuss thermal evaporation process.

The thermal evaporation of materials in vacuum is a versatile and popular method to provide a thin film coating on a substrate. In evaporation, a material is heated in vacuum until it boils, the resulting vapour then condenses on the substrate to form a thin film. This film can be from a few atoms thick (less than 1nm) to hundreds or thousands of nm thick. Thermal evaporation is carried out at high vacuum, typically better than 1x10-6 mbar.

For materials with higher melting points which cannot be easily evaporated by resistive heating the e-beam evaporation processes are used. Resistance evaporation systems pass a high electrical current through a filament or a 'boat' source in which the material is placed, the heating effect of which is sufficient to evaporate many materials. Electron beam sources use a dedicated power supply to provide a high-power electron beam to heat the source material, and are capable of evaporating higher melting point or reactive materials.

Figure 10.1: Equipment for Physical Vapor Deposition

What are PVD Coatings Used For?

PVD coatings are deposited for numerous reasons. Some of the main ones are:
1) Improved hardness and wear resistance 2) Reduced friction 3) Improved oxidation resistance

The use of such coatings is aimed at improving efficiency through improved performance and longer component life. They may also allow coated components to operate in environments that the uncoated component would not otherwise have been able to perform.

Advantages of the Physical Vapour Deposition Process

- Materials can be deposited with improved properties compared to the substrate material
- Almost any type of inorganic material can be used as well as some kinds of organic materials
- The process is more environmentally friendly than processes such as electroplating

Disadvantages of the Physical Vapour Deposition Process

- It is a line of sight technique meaning that it is extremely difficult to coat undercuts and similar surface features
- High capital cost
- Some processes operate at high vacuums and temperatures requiring skilled operators
- The rate of coating deposition is usually quite slow

Procedure:

A) Starting Vacuum Pump.

1) Check whether gasket is fitted well in the groove of the bell jar & the bell jar is properly installed in the unit.

2) Check whether all the valves are properly closed before switching on the unit.

3) Now, turn on the main power switch indicated by the glowing LED.

4) Turn on the rotary pump and open the gas ballast and close the gas ballast after 5 minutes also switch on the pirani gauge in range-1

5) Turn on the roughing valve and wait for a pressure of 0.02 mbar. Then switch off the roughing valve and turn on the backing valve

(Note: Roughing and Backing valve should never be open at the same time).

6) When pressure in backing reaches 0.02mbar switch on the water supply to diffusion pump

7) Turn o the diffusion pump and continue for minimum of 30 minutes for DP oil to get heated.

8) Now, set the pirani gauge in range-2, In this setting it measures the pressure of the vacuum chamber.

9) Open High Vacuum Valve very slowly and wait till required pressure (>10-5 mbar) is read on the penning gauge

B) Loading-Sample

1) Open the air admittance valve to bring the roughing chamber to atmosphere.

2) Load the sample and depositing the material.

3) Keep the Source Shutter tightened and close the air admittance valve.

4) Turn on the roughing valve and turn off the backing valve wait till pressure in roughing comes 0.02 mbar.

5) Pour approximately 1.5-2 ltr of liquid nitrogen to fill up the container.
6) Open H.V.V and note pressure reading w.r.t time.
7) Switch on the substrate heater and maintain at required experimental temperature (Turn on the Heater only when base pressure is below 10-5 mbar).

Deposition

8) In general switch off the penning gauge and continue to monitor the backing pressure.
9) Switch on the supply to DTM and electrode.
10) Slowly rotate the voltage Variac and monitor DTM for required deposition rate.
11) Once deposition is achieved, open the shutter Anticlockwise. Note the time voltage, deposition rate and thickness from DTM.
12) After completion of deposition close the shutter.
13) Turn off the voltage Variac slowly.
14) Turn of DTM.

Report Question:

1) What are the main variable to control the deposition.
2) Why we use Nitrogen liquid in a D.P.
3) What is the role of Roughing, Backing and High Vacuum Valve.
4) What is the application of thermal evaporation process in PVD.
5) Can you suggest a simple way to calculate the thickness of the coating? Apply it and obtain a value and comment on its accuracy.

Part (B): Plastic Injection Molding (Demo)

OBJECTIVES:

i. To study the various steps involved in Plastic Injection molding

INTRODUCTION:

Materials such as polystyrene, nylon, polypropylene and polythene can be used in a process called injection molding. These are thermoplastics - this means when they are heated and then pressured in a mold they can be formed into different shapes. In this process, we formed an article by forcing molten plastic material under pressure into a mold where it is cooled, solidified and subsequently released by opening the two halves of the mold. Injection molding is used for the formation of intricate plastic parts with excellent dimensional accuracy. A large number of items associated with our daily life are produced by way of injection molding. Typical product categories include house wares, toys, automotive parts, furniture, rigid packaging items, appliances, medical disposable syringes etc. Look around you and you'll probably see dozens of injection molded parts in your wallet, kitchen, car and office. Through a line diagram main parts of injection molding are as shown in figure 8.1:

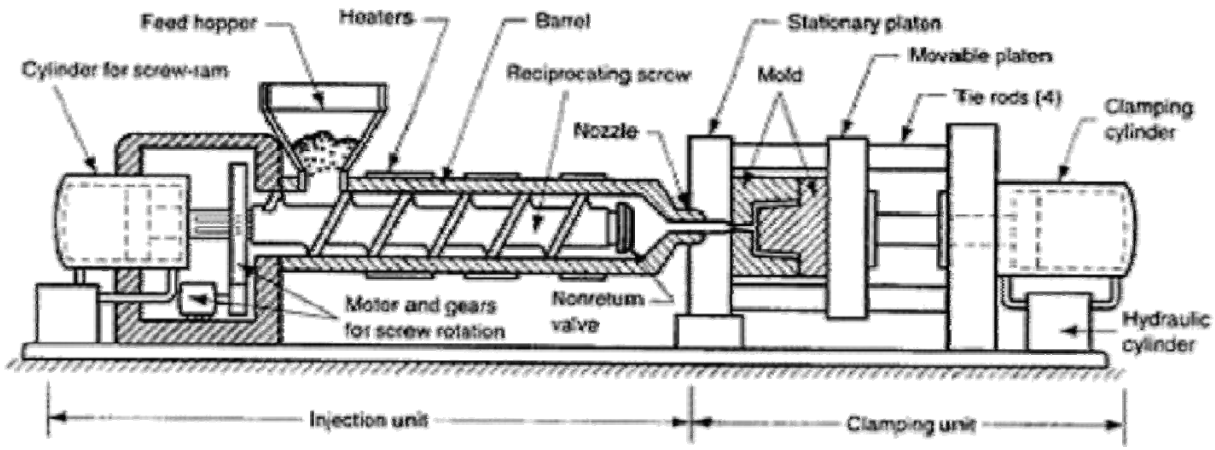


Figure 10.2: Schematic of plastic injection molding

Such a widely-used manufacturing process must have few advantages for getting things made this way, right? Let's have a look at some of the advantages and disadvantages of injection molding.

Advantages of Injection Molding:

- Fast Production, low labor cost and lower rejection rate.
- Accuracy in weight of objects.
- Choice of desired surface finish and colors.
- Choice of ultimate strength of articles.
- Faster start-up and shut down procedures Minimum wastage.
- Stability of processing parameters.
- Versatility in processing different raw materials.
- Option in article sizes by changing the mold.
- Minimum secondary molding operations.

Disadvantages of Injection Molding:

- High Initial tooling cost.
- High running cost.
- Part design restriction o cost of prediction for a molding job is often difficult.

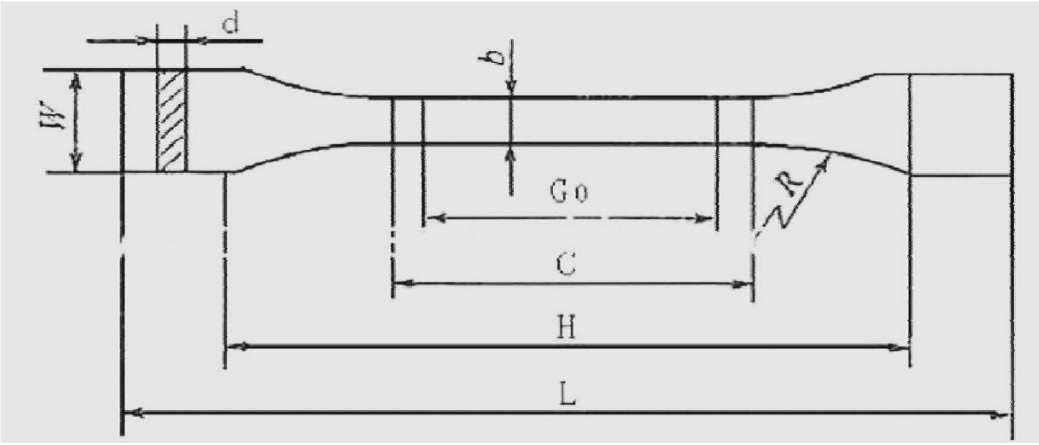


Figure 10.3: Dogbone shaped plastic injection molded part

PROCEDURE:

The process cycle for injection molding is very short, and consists of the following four stages:

1. ***Clamping*** - Prior to the injection of the material into the mold, the two halves of the mould must first be securely closed by the clamping unit. Each half of the mold is attached to the injection molding machine and one half is allowed to slide.

2. ***Injection*** - The raw plastic material, usually in the form of pellets, is fed into the injection molding machine, and advanced towards the mold by the injection unit. During this process, the material is melted by heat and pressure. The molten plastic is then injected into the mold very quickly and the buildup of pressure packs and holds the material.
3. ***Cooling*** - The molten plastic that is inside the mold begins to cool as soon as it makes contact with the interior mold surfaces. As the plastic cools, it will solidify into the shape of the desired part. However, during cooling some shrinkage of the part may occur.

4. ***Ejection*** - After sufficient time has passed, the cooled part may be ejected from the mold byte ejection system, which is attached to the rear half of the mold. When the mold is opened, a mechanism is used to push the part out of the mold. Force must be applied to eject the part because during cooling the part shrinks and adheres to the mold.

After the injection molding cycle, some post processing is typically required. During cooling, the material in the channels of the mold will solidify attached to the part. This excess material, along with any flash that has occurred, must be trimmed from the part, typically by using cutters.

Report the Following:

1) Describe the Injection Molding Process. Why is it called Injection Molding Process?
2) What are the alternatives of Injection Molding process?
3) Characterize the plastic used for Injection Molding
4) Draw the Flow chart of Injection Molding Process

Color Plate-6: Plastic Injection Molding Equipment at Engineering Metallurgy Lab

Rough Page