

MECHANICAL BEHAVIOUR LABORATORY

MSE 313: Laboratory Manual



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**Department of Materials Science & Engineering
Indian Institute of Technology Kanpur
Kanpur – 208016**

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MSE 313: MECHANICAL BEHAVIOUR LABORATORY

Instructor: Nilesh Prakash Gurao (npgurao@iitk.ac.in)

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Batch: Tuesday (Batch-A)

Exp. Date	Exp.1	Exp.2	Exp.3	Exp.4	Exp.5	Exp.6	Exp.7
06/08/2013	A1	A2	A3	A4	A5	A6	A7
13/08/2013	A7	A1	A2	A3	A4	A5	A6
20/08/2013	A6	A7	A1	A2	A3	A4	A5
27/08/2013	A5	A6	A7	A1	A2	A3	A4
03/09/2013	A4	A5	A6	A7	A1	A2	A3
10/09/2013	A3	A4	A5	A6	A7	A1	A2
17/09/2013	A2	A3	A4	A5	A6	A7	A1

Batch: Thursday (Batch-B)

Exp. Date	Exp.1	Exp.2	Exp.3	Exp.4	Exp.5	Exp.6	Exp.7
08/08/2013	B1	B2	B3	B4	B5	B6	B7
15/08/2013	B7	B1	B2	B3	B4	B5	B6
22/08/2013	B6	B7	B1	B2	B3	B4	B5
29/08/2013	B5	B6	B7	B1	B2	B3	B4
05/09/2013	B4	B5	B6	B7	B1	B2	B3
12/09/2013	B3	B4	B5	B6	B7	B1	B2
19/09/2013	B2	B3	B4	B5	B6	B7	B1

- 1) Mid Semester Exam: 16-9-13 to 21-9-13
- 2) Mid Semester Recess: 5-10-13 to 13-10-13
- 3) End Semester Exams: 18-11-13 to 27-11-13

MSE 313: MECHANICAL BEHAVIOUR LABORATORY

LIST OF EXPERIMENT

1. Determination of the tensile properties of different class of materials (Lab-1)
2. Principles of hardness testing comparison of different hardness techniques (Lab-2)
3. Impact testing of materials (Charpy Impact test) (Lab-2)
4. Creep testing of materials (Lab-1)
5. Fatigue testing (Lab-2)
6. Strain aging and yield Point Phenomenon (Lab-1)
7. Effect of work hardening on tensile properties of metal (ACMS)

8-11: Projects

Projects Titles:

- 1) Study of grains orientation by forming slip line in AISI 304 steel
- 2) Tempering effect on AISI 410 stainless steel and hardness measurement
- 3) Microstructure and mechanical properties co-relation in AISI 201 steel by solution heat treatment
- 4) Study of precipitation hardening in AISI 304 steel
- 5) Study of grains orientation by color etchants in AISI 304 steel
- 6) Fabrication of nanostructure austenitic stainless steels.
- 7) Determination of DBTT for different crystal structures (e.g., low C steel, Al)
- 8) Super plastic deformation of materials
- 9) Environmentally Assisted cracking of material, e.g., Hydrogen Embrittlement
- 10) Failure Analysis of real problems using various testing and characterization techniques
- 11) To study the effect of solid-solution strengthening on mechanical properties in metal systems. E.g., brass with increasing amount of Zn
- 12) To study precipitation hardening in metal systems, e.g., Duralumin
- 13) Effect of heat treatment on microstructure and mechanical properties of steel
- 14) Internal stress corrosion and tensile properties correlation in metals .15) Hydrogen embrittlement studies on carbon steels.
- 16) Investigation of the Hall-Petch relationship in polycrystals, e.g., 304 stainless steel
- 17) Effect of heat treatment on the mechanical properties of work-hardening materials
- 18) Fracture strength of brittle materials
- 19) Viscoelastic behavior of polymers
- 20) Plastic anisotropic studies in steels by tensile test at different stain rates.
- 21) Compression test for processing maps
- 22) Welding metallurgy in similar and dissimilar metals.
- 23) Studies on heat effected zone in ferrous metals
- 24) Evolution of constants and coefficients at different stain rates in steels
- 25) Reverse transformation studies in AISI 304 steels

MSE 313: MECHANICAL BEHAVIOUR LABORATORY

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Location: - Materials Testing Lab, Room No.116 (Extension), Ph.no.7959

GENERAL INSTRUCTIONS:

1. Each experiment will be carried out jointly by a group of students.
2. Be prompt and punctual, late entry will not be excused.
3. All students must come to lab with shoes, no exception.
4. Keep your area of work neat and clean environment. Handle things carefully because penalties will be there for misbehavior and/or damaging of the equipment tools.
5. You must come well prepared with the theory/background of the experiment to be done on a particular day.
6. Show the completed lab report and take the signature from your TAs before leaving the lab, otherwise lab report not considerable during at the time of submission.
7. Submit individual laboratory report by hand written or computer printed within next lab.
8. Before entering in to the lab, see the notice board for latest information and instructions, if any.
9. Before leaving the lab, enter your determined values in common report in lab.
10. Take your seat group wise around the study table for miscellaneous works such as reading, writing, and discursion etc.,
11. Lab hours are 2:00PM to 5:00PM; each student should be stay within the lab up to 5 PM.

Experiment 1

Determination of the tensile properties of different class of materials

Objective: To characterize the mechanical behavior of Teflon, a polymer, and understand its special characteristics as compared with metals.

Requirements for the experiment

- a) Tensile specimen correct dimensions
- b) Instron Mechanical Testing Machine
- c) Vernier caliper

Brief Description of the Equipment/Machine

Universal Testing Machine (UTS) used for this experiment is a 10 ton capacity Instron testing machine. This is a screw driven machine. The upper cross head is fixed and is fitted with the transducer type 'load cell'. The lower cross head can be made to move with a range of speeds. The test data is recorded using a 'Strip chart recorder'. The recorder speed can be chosen as required in any specific condition. There are a variety of specimen grips and the appropriate one for the application on hand can be chosen accordingly. The testing machine can be used for Tensile/compressive test, torsion test, bend /flexural test, and also for high temperature tensile tests.

Test Material Data

The polymeric material given is 'Polytetrafluoethylene' abbreviated PTFE and the trade name or commercial name is "Teflon". It is crystalline up to 325 °C. It does not soften appreciably on heating but retains its strength up to 300 °C, and its flexibility down to -200 °C. The advantages of PTFE are that it is completely chemically inert and has a low coefficient of friction, hence its applications in resistant coatings, non-stick films, pistons, etc. Some of the important properties: Specific gravity =2.15; tensile strength = 17.25 MN/m²; Elastic modulus = 414MN/m²; Hardness = 52 HRD and Izod impact 160 J/m

Mechanical Behavior of Polymeric Materials

Polymeric solids (commonly referred to as plastics) show a whole range of stress-strain time responses, depending on conditions, from very creep behavior to stiff elastic behavior, a rubbery range in between. Engineers differentiate between yield stress and ultimate tensile strength in metals, but in polymers these terms are sometimes confused.

The common definitions of yield strength S_y and tensile strength S_u of ductile metals are illustrated in Fig. 1 with reference to a load- extension curve for annealed low-carbon steel. There is essentially no change in cross-sectional area between O and Y, so nominal stress and true stress is the same at yield. The maximum load point U, at which an unstable neck initiates, gives the ultimate tensile strength (or tensile strength) S_u . The flat portion of the curve at Y is really a series of ripples in the load trace, with the associated propagation of Luder bands. Most metals display nominal stress-strain curves like the one in Fig. 2. The flat region at Y in Fig. 1 is not in evident and the yield

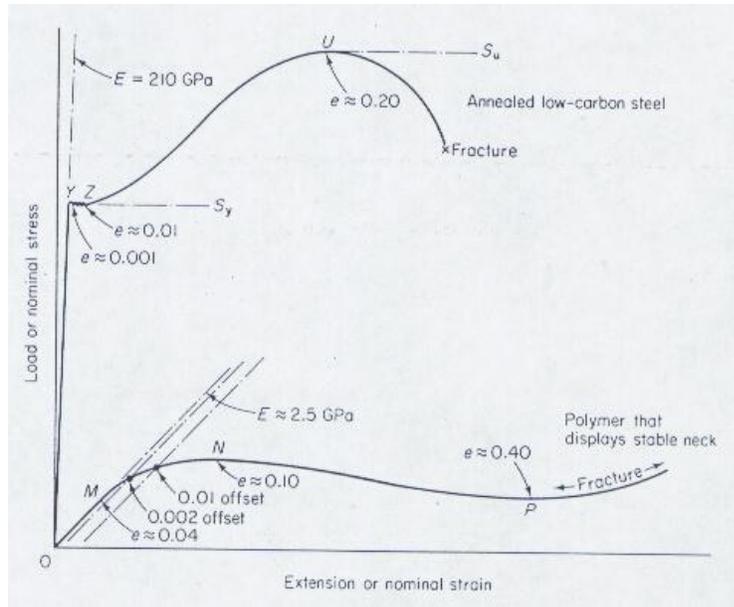


Fig. 1 engineering stress-strain curves for a polymer that displays stable neck propagation ('cold drawing') as compared with annealed plain low-carbon steel that exhibits a pronounced yield point.

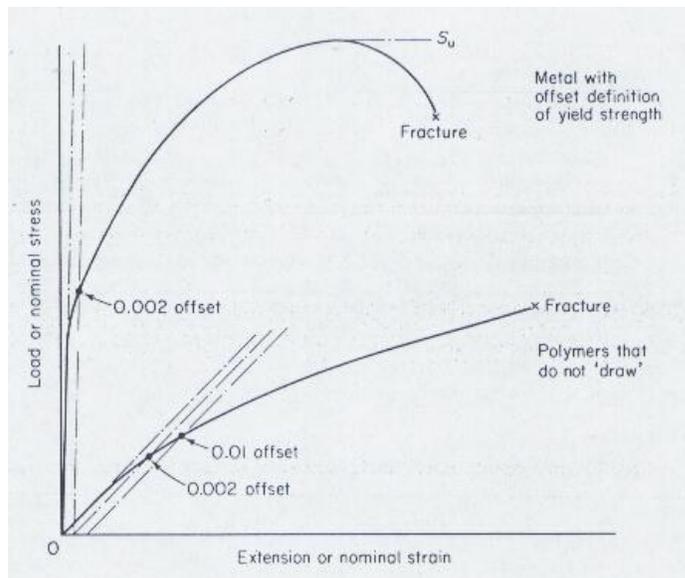


Fig. 2 engineering stress-strain curves for a polymer that does not display localized necking (does not 'cold drawing') as compared with a ductile metal that does not exhibit a pronounced yield point.

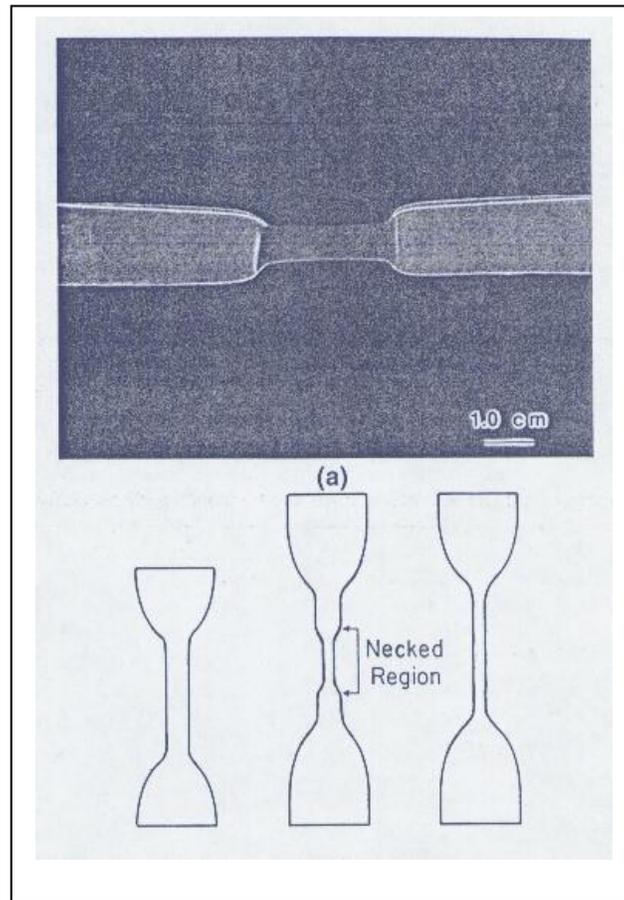


Fig. 3 Neck propagation in a sheet of linear polyethylene.

Point is defined by an offset (proof) method. The associated yield strain is of the order of 0.2%. The reduction in area can be as high as 40% for these metals.

A typical load extension plot for polymers such as polyethylene, nylon, PVC, which draw at room temperature is shown in the lower half of Fig.1. there is departure from linearity at M (where the strain may be about 1%) and the load curve rises to a local maximum at N (where the strain the strain may be 10%), at which point the stable neck initiates. The load then falls as the neck is reduced in cross-sectional area, until stability is reached and the neck propagates along the test piece at the essentially constant load P. Subsequently, after neck has propagated along the length of the test bar, the load increases again and fracture essentially ensues under a rising load. This is a situation akin to failure in brittle materials.

After the local load maximum at N, measurements and definitions of strain in terms of length, such as the nominal or engineering strain given by $(L-L_0)/L_0$ or the draw ratio L/L_0 are quite meaningless because the reduction is non-uniform. Clearly any value is possible depending on the reference gage

length (the percentage elongation in the tensile tests of the metals is likewise meaning less without reference to the starting gauge length. It is most sensible beyond N in Fig. 1 to measure the strain in terms of percentage reduction in area $(A_0 - A) / A_0$ or true strain $\epsilon = \ln(A/A_0) = 2 \ln(d_0/d)$. Then during most of the stable neck propagation, changes in true stress and true strain are minor until the neck propagation to the shoulders. The point at which permanent deformation sets in is somewhere between M and N. The curvature over a large range of strains between M and N and the local maximum in load at N have led some workers to call N the ultimate tensile strength for polymers. Referring to Fig.1 shows that this is erroneous if we mean that ultimate tensile strength is followed by an unstable neck and fracture as is the case with ductile metals. Others identify N as the local yield point, and the similarity of events between N and P and those between Y and Z makes such an approach justified. However, the strains at N are much larger than at Y, and from a design point of view M may be more meaningful as a limiting strain: even then, deformations are greater than traditional metal yield strains.

The load-extension curves for non-drawing polymers looks like the one shown in Fig.2 . Here there is continuously rising load-extension curves and there is no zero slope load maximum. Hence, the usage N as yield value becomes objectionable in this case. Therefore, the offset definition of yield allows a consistent method of determination whatever the shape of the load-extension diagram.

Important Experimental Parameters

- a) *Original Gauge Length* (L_0): Gauge length before application of force.
- b) *Final Gauge Length* (L): Gauge length after rupture, the two pieces having been carefully fitted back together so that their axes lie in a straight line.
- c) *Engineering Stress* (s) and *Engineering Strain* (e) : $s = P/A_0$, $e = (L - L_0)/L_0$,
- d) *True Stress* (σ) and *True Strain* (ϵ) : $\sigma = s(1+e)$, $\epsilon = \ln(1+e)$
- e) *Yield Stress*: For most ductile metals, yield strength is usually obtained from 0.2% offset yield strength/proof stress method by drawing a parallel line with elastic region from 0.002 strains in X-axis.
- f) *Percentage of Total Elongation at Fracture* = $(L - L_0) / L_0$
- g) *Percentage Reduction of Area* = $(A_0 - A) / A_0$
Maximum change in cross-sectional area which has occurred during the test ($A_0 - A$) expressed as a percentage of the original cross-sectional area (A_0), where A is the final cross-sectional area.

Experimental procedure:

- a) Measure the dimensions of the sample. With a pen mark then mark the gauge length reference points. The gauge length should be marked within the parallel section portion of the sample.
- b) Measure original width and thickness of the sample at least four times along the reduced section (gauge length) of the specimen. Find cross-sectional area and average area.
- c) Let the Instron testing machine be switched on and stabilized for at least 30 mins.
- d) Fix the specimen into the testing machine with appropriate grips.
- e) Select the cross-head speed. Select appropriate scales for the “strip chart recorder”.
- f) Start applying the load.
- g) As sample get fractured, note down the total extension from the chart. Immediately after fracture there will be a large elastic recovery.
- h) Measure final gauge length after fracture by carefully.
- i) Measure cross sectional dimensions of the specimen after fracture.

Experimental data collection and presentation

- a) Convert collected data, load in Newton and extension in mm to engineering strain and engineering stress and then to true stress and true strain in excel.
- b) Report % of elongation at fracture, % of reduction in area at fracture
- c) Calculate the yield stress (2% proof stress). Compute the value of Young’s modulus and compare it with the standard value.
- d) Calculate and report the elastic recovery part of the strain.
- e) Calculate the Poisson’s ratio.

Nomenclature

A	Instantaneous area (m^2)
A_0	Original area of cross-section at gauge length (m^2)
A_f	Area in the neck region after failure (m^2)
E	Young’s modulus of elasticity (Kg/m^2 , Pa)
e	Engineering strain
e_0	Yield strain
e_f	Strain at failure
ϵ	True strain
ϵ_0	Strain hardening prior to test
K	Strength coefficient (Kg/m^2 , Pa)

L	Instantaneous gauge length (m)
L ₀	Original gauge length, the portion of sample with minimum diameter (m)
L _f	Gauge length of the failed sample (m)
n	Strain hardening coefficient
P	Instantaneous load (Kg)
P _{max}	Maximum load before failure of specimen (Kg)
s	Engineering stress (Kg/m ² , Pa)
s ₀	Yield stress (Kg/m ² , Pa)
s _u	Ultimate tensile strength (Kg/m ² , Pa)
σ	True stress (Kg/m ² , Pa)
t	time (s)
U _R	Resilience (J/m ³)
U _T	Toughness (J/m ³)

Formulas:

Engineering stress and engineering strain

$$s = P/A_0$$

$$e = (L-L_0)/L_0 = (A_0 - A)/A \quad [\text{Note: Constancy of volume} \Rightarrow A_0L_0 = AL]$$

True stress and true strain

$$\sigma = \frac{P}{A} = \frac{P}{A_0} \frac{A_0}{A} = s \frac{A_0}{A} = s \frac{L}{L_0} = s \left(\frac{L-L_0}{L_0} + 1 \right) = s(e+1)$$

$$\varepsilon = \int_{L_0}^L \frac{dL}{L} = \ln \frac{L}{L_0} = \ln \left(\frac{L-L_0}{L_0} + 1 \right) = \ln(e+1)$$

Definitions and properties within elastic limit

Hooke's law: Within elastic limit, the deformation is proportional to load, i.e., strain is proportional to stress.

Young's modulus of elasticity, E: The ratio of stress to strain below elastic limit.

Offset yield strength s_0 : Stress corresponding to the intersection of the stress strain curve and a line parallel to the elastic part of the curve offset by strain 0.002.

$$s_0 = P_{(\text{strain offset} = 0.002)} / A_0$$

Resilience: The maximum energy absorbed per unit volume within elastic limit

$$U_R = 0.5 * s_0 e_0$$

Definitions and properties in plastic range

Strain hardening: The relationship between stress and strain is nonlinear during plastic deformation. Like E in elastic range, strength coefficient, K, strain hardening exponent, n and amount of strain hardening prior to test, ϵ_0 are used to characterize material in plastic range.

$$\sigma = K (\epsilon + \epsilon_0)^n, \Rightarrow \log \sigma = \log K + n \log (\epsilon + \epsilon_0)$$

Ultimate tensile strength: The maximum engineering stress before rupture of specimen.

$$s_u = P_{\max} / A_0$$

Toughness: Ability to absorb energy per unit volume in the plastic range.

$$U_T = 0.5 * (s_0 + s_u) * e_f$$

Experimental Procedure

1. Measure L_0 , A_0 .
2. Switch on Lloyd tensile testing machine and follow the instruction on its panel.
3. First set the machine in manual mode and accept all other options as default values.
4. Carefully use double arrow button in upward and downward direction to adjust the position and fix the sample in grip. Precautions should be taken to avoid any hitting between grip and sample for load cell safety.
5. Double click icon "GO" on the computer.
6. Set testing machine under remote control mode through its panel.
7. On computer, select menu "New test setup" through arrow keys and press enter.
8. Leave all the options default except for the following
Test type = TENSION

Y axis = 10,000 Newtons

X axis = 30 mm

Speed = 5 – 10 mm/minute

Limit = 30 mm

9. Press Esc.
10. Select menu "Perform test".
11. Accept all the default options.
12. Empty graph will be displayed.
13. Follow the instructions in the menu given at the bottom.
14. First initialize load and strain to zero.
15. Start your experiment and observe the sample till it fails.
16. Note the graph displayed on the screen.
17. Select "Cursor". Move it from left to right and note down all the coordinates.
18. Save your test results.
19. Press "Esc"
20. On main menu, select "Leave machine control program"
21. Switch off testing machine.
22. Remove sample from the grip
23. Measure L_f and A_f of the failed sample and place it in the scrap container.

Results

Please use following tables format. Clearly show all the unit conversion factors for determining s , e , σ , ϵ using column 2 and column 3 values in table 2 separately outside table for one set of values. Please show calculations in table 3. Plot true and engineering stress strain curves in single graph. Also, plot log-log graph for determining K , n and ϵ_0 . For determining ϵ_0 , change its value starting from 0 such that you obtain straight line. For plotting, you may use computer.

Table 1

L_0	A_0	$d(L-L_0)/dt * 60,000$ (Strain rate in mm/min)	L_f	A_f

Table 2

Serial #	$(L-L_0) * 10^3$	Load (Newtons)	e	s	ϵ	σ
1						
2						
3						
4						
5						
6						
7						
8						
9						

Table 3

E	
S_0	
e_0	
S_u	
e_f	
K	

n	
ϵ_0	
U_R	
U_T	

Conclusions

Analyze results and write unique observations.

Questions

1. Which properties you think are sensitive to strain rate ?
2. Which properties are engineered for a) Spring, b) Metal working, c) machine component subjected to constant load ?
3. What is the root cause behind strain hardening ?
4. Although Young's modulus of elasticity for glass is more than steel, steel is preferred for designing engineering components. Why ?
5. Schematically compare hot working and cold working for relationship between stress and strain.

Note: In report, no marks are allocated for information copied from this manual. You may directly use the symbols without defining them. All the units must be in SI.

Questions

- a) Compare the value of Young's modulus and Poisson's ratio with that for Al and Cu.
- b) What is "die-less drawing" process?

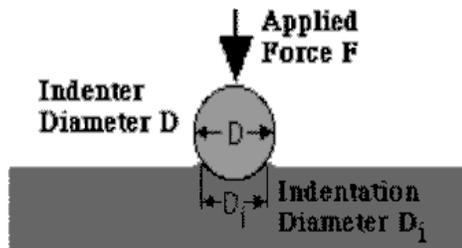
Experiment 2

Principles of hardness testing comparison of different hardness techniques

Object of the Experiment: To measure and compare the Brinell, Rockwell and Rockwell superficial hardness of mild steel, aluminum and brass.

Brinell hardness test

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell hardness number is calculated by dividing the load applied by the surface area of the indentation.



$$\text{BHN} = \frac{F}{\frac{\pi}{2} D \cdot (D - \sqrt{D^2 - D_i^2})}$$

The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

Rockwell hardness test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F_0 (Fig. 1A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Fig. 1B). When equilibrium has again been reached, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig. 1C). The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

$$HR = E - e$$

F_0 = preliminary minor load in kgf,
 F = total load in kgf

F_1 = additional major load in kgf
 HR = Rockwell hardness number

e = permanent increase in depth of penetration due to major load F_1 measured in units of 0.002 mm

E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

D = diameter of steel ball

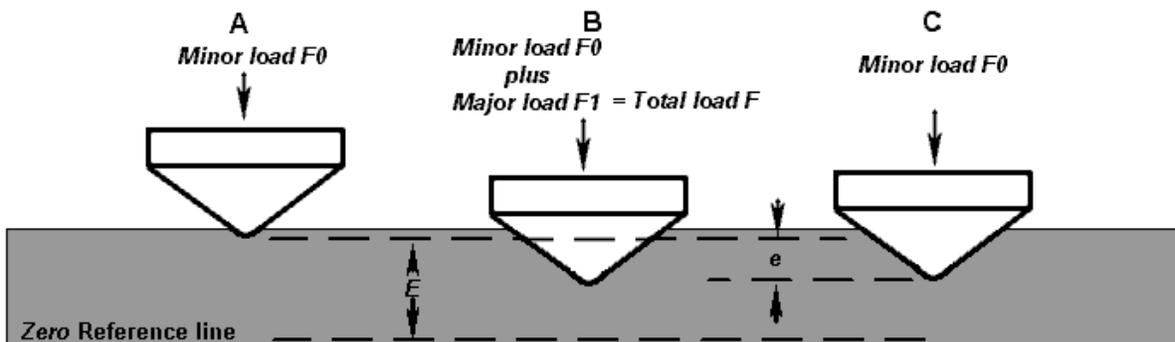


Fig. 1. Rockwell Principle

Rockwell Hardness Scales

Scale	Indenter	Minor Load F_0 kgf	Major Load F_1 kgf	Total Load F kgf	Value of E
A	Diamond cone	10	50	60	100
B	1/16" steel ball	10	90	100	130
C	Diamond cone	10	140	150	100
D	Diamond cone	10	90	100	100
E	1/8" steel ball	10	90	100	130
F	1/16" steel ball	10	50	60	130
G	1/16" steel ball	10	140	150	130
H	1/8" steel ball	10	50	60	130
K	1/8" steel ball	10	140	150	130
L	1/4" steel ball	10	50	60	130
M	1/4" steel ball	10	90	100	130
P	1/4" steel ball	10	140	150	130
R	1/2" steel ball	10	50	60	130
S	1/2" steel ball	10	90	100	130
V	1/2" steel ball	10	140	150	130

Typical Application of Rockwell Hardness Scales

HRA: Cemented carbides, thin steel and shallow case hardened steel

HRB: Copper alloys, soft steels, aluminum alloys, malleable irons, etc

HRC: Steel, hard cast irons, case hardened steel and other materials harder than 100 HRB

HRD: Thin steel and medium case hardened steel and pearlitic malleable iron

HRE: Cast iron, aluminum and magnesium alloys, bearing metals

HRF: Annealed copper alloys, thin soft sheet metals

HRG: Phosphor bronze, beryllium copper, malleable irons

HRH: Aluminum, zinc, lead

HRK, HRL, HRM, HRP, HRR, HRS and HRV: Soft bearing metals, plastics and other very soft materials

Advantages of the Rockwell hardness method include the direct Rockwell hardness number readout and rapid testing time. Disadvantages include many arbitrary non-related scales and possible effects from the specimen support anvil.

Rockwell Superficial Hardness Test

The Rockwell Superficial hardness test method consists of indenting the test material with a diamond cone (N scale) or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F_0 (Fig. 2A) usually 3 kgf. When equilibrium has been reached, an indicating device that follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position. While the preliminary minor load is still applied an additional major load, is applied with resulting increase in penetration (Fig. 2B). When equilibrium has again been reached, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig. 2C). The permanent increase in depth of penetration, e , resulting from the application and removal of the additional major load is used to calculate the Rockwell Superficial hardness number.

$$HR = E - e$$

F_0 = preliminary minor load in kgf

F_1 = additional major load in kgf

F = total load in kgf

HR = Rockwell hardness number

e = permanent increase in depth of penetration due to major load F_1 , measured in units of 0.001 mm

E = a constant of 100 units for diamond and ball indenters

D = diameter of steel ball

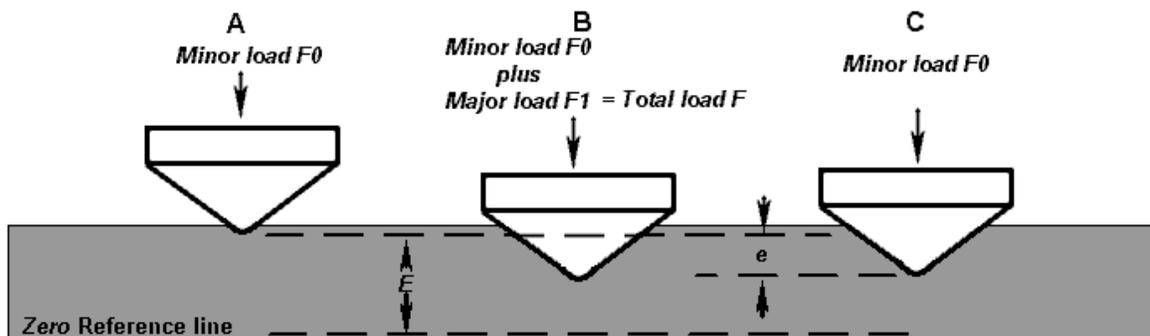


Fig. 2. Rockwell Superficial Principle

Rockwell Superficial Hardness Scales

Scale	Indenter Type	Minor Load <i>F₀</i> kgf	Major Load <i>F₁</i> kgf	Total Load <i>F</i> kgf	Value of E
HR 15 N	N Diamond cone	3	12	15	100
HR 30 N	N Diamond cone	3	27	30	100
HR 45 N	N Diamond cone	3	42	45	100
HR 15 T	1/16" steel ball	3	12	15	100
HR 30 T	1/16" steel ball	3	27	30	100
HR 45 T	1/16" steel ball	3	42	45	100
HR 15 W	1/8" steel ball	3	12	15	100
HR 30 W	1/8" steel ball	3	27	30	100
HR 45 W	1/8" steel ball	3	42	45	100
HR 15 X	1/4" steel ball	3	12	15	100
HR 30 X	1/4" steel ball	3	27	30	100
HR 45 X	1/4" steel ball	3	42	45	100
HR 15 Y	1/2" steel ball	3	12	15	100
HR 30 Y	1/2" steel ball	3	27	30	100
HR 45 Y	1/2" steel ball	3	42	45	100

Experimental Procedure

- a) Polish the surface of the specimens that have been provided to you..
- a) Fit the specimen in the sample holder
- c) After fitting the sample, perform the Brinell, Rockwell and Rockwell superficial hardness of mild steel, aluminum and brass.

- d) Measure the dimensions (diameter in case of Brinell) of the indentations produced by Brinell and Rockwell techniques. Take mean of the three readings in each of the three cases.

Experimental data collection and presentation

- a) Calculate the Brinell hardness from the formula mentioned above.
- b) Write sample readings in a tabulated form.
- c) Compare the Brinell, Rockwell and Rockwell superficial hardness of mild steel, aluminum and brass surface.
- d) Report the data

Questions

- a) Compare the Brinell, Rockwell and Rockwell superficial hardness of mild steel, aluminium and brass surface.
- b) What do you understand by geometrically similar indentations?
- c) What precautions would you take while performing Rockwell hardness test?
- d) Which hardness test would you recommend for mild steel casting?

Experiment 3

Impact testing of materials (Charpy Impact Test)

Objective: To interpret ductile brittle behavior of mild steel from the absorbed energy during impact at various temperatures.

Requirements for the experiment

- d) V-notched specimen
- e) Swing pendulum Impact Testing Machine
- f) Liquid nitrogen
- g) Optical pyrometer
- h) Temperature controller heater
- i) Water
- j) Stopwatch

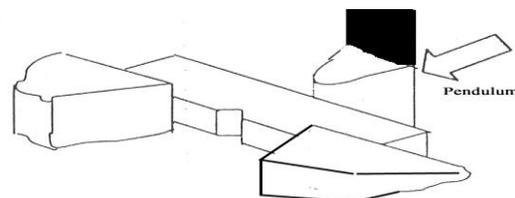
Brief Description of the Equipment/Machine

Impact testing machine used for this experiment contains a heavy swing pendulum. This pendulum has the maximum capability of impacting energy of 264 ft pound force= $264 \times 0.3048\text{m} \times 9.8\text{ms}^{-2} \times 0.45362\text{ Kg} = 343.977\text{ J}$. A scale is provided in the machine, which range from 0 – 264 foot pound (ft Lb). An indenter will move on this scale when pendulum is allowed from its horizontal static position to impact the V-notched specimen. There is a stand at the bottom of the machine where V-notched specimen is supported as a beam in horizontal position.

Theory

Impact test is undoubtedly the most commonly used test that is done to characterize the ductile to brittle transition behavior in materials. The impact test is done by placing a square shaped V-notched specimen in the machine (Fig.1). **Generally, the Charpy specimen has a square cross-section of dimensions 10mm × 10mm and contains a 45° V notch of 2 mm deep with root radius of 0.25 mm.** A heavy pendulum released from a known height strikes the sample on its downward swing and fractures it. After the test bar is broken, the pendulum rebounds to a height that decreases as the energy absorbed in fracture increases. By knowing the mass of the pendulum and the difference between its initial and final heights, the energy absorbed by the fracture can be measured. In impact testing machine will be used here has the indenter facility to indicate energy in foot pound (ft Lb) force absorbed by the fracture. If the temperature of the testing is lowered, the V-notch impact test can be used for determining the ductile to brittle behavior in a material. A typical curve in figure 2 shows different transition temperature on steel by different definition. Transition temperature of phosphorus and carbon are shown in figure 3 (a) and (b) respectively by four different definition of determination of transition temperature.

Fig.1 Schematic diagram of impact testing



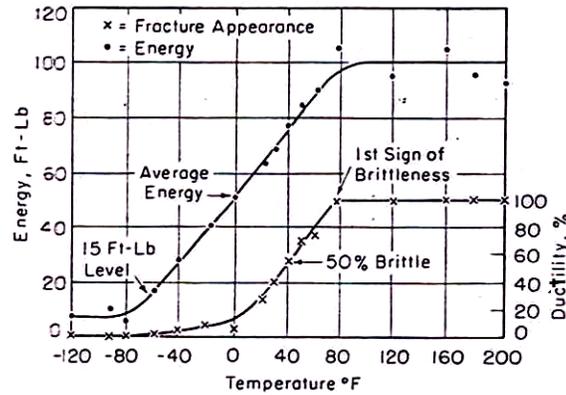


Fig.2 Typical curve showing different transition temperature on steel

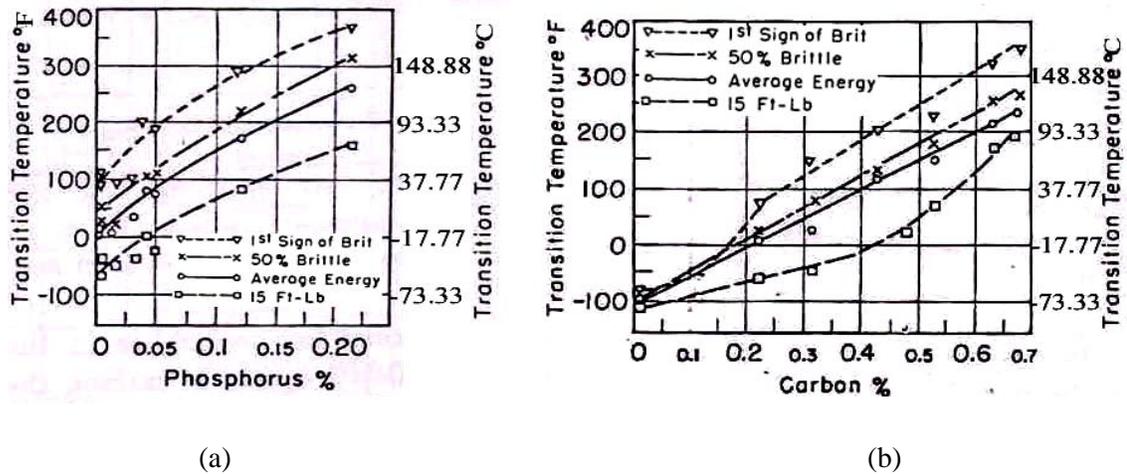


Fig. 3 Effect of (a) phosphorus, (b) carbon on transition temperature using different definition

In Charpy specimen, the plastic constrain to the notch produces a triaxial state of state of stress. The relative values of the three principal stresses depend strongly on the dimension of the bar and the geometry of the notch. The maximum plastic stress concentration, K_{\square} (energy absorbed in fracturing the material) is given by

$$K_{\square} = \left(1 + \frac{\pi}{2} - \frac{\omega}{2} \right)$$

Fracture surface examination shows fibrous (shear fracture), granular (cleavage fracture) or a mixture of both which can be distinguished in magnification glass or even without magnification.

Experimental procedure :

- j) Slowly swing the pendulum. When pendulum velocity increases, take it to the horizontal position by applying upward force carefully so that the pendulum will stick over there.
- k) Draw the indenter to the position of 264 ft Lb.

- l) For determining the impact energy at lower temperature, keep the specimen in liquid nitrogen for 15 minutes. The specimen to be dipped in liquid nitrogen will be instructed by your T.A.
- m) Keep your stopwatch ready. Remove the specimen with the help of tongs and immediately keep it at the bottom of the machine horizontally. Start your stopwatch just after bringing out the specimen from liquid nitrogen. The notch of the specimen should remain behind to the impact load of the swing pendulum (fig.1). Immediately measure the temperature of the specimen by optical pyrometer after keeping the specimen at the horizontal stand. The temperature noting for different specimens after removing from liquid nitrogen should follow the interval of 1 mins, 2 mins, 3 mins, 4 mins, 5 mins respectively according to instruction given by T.A. After noting temperature, release the pendulum immediately.
- n) Now indenter will move towards zero end of the scale. Count the number of division from zero to the position of the indenter after impact. This will give the energy of the specimen absorbed by impact of the pendulum.
- o) For determining energy at room temperature, simply put specimen horizontally, record room temperature from optical pyrometer or room temperature from thermometer, release the pendulum record the energy.
- p) For determining energy at higher temperature, starting from 35⁰C, 50⁰C, 65⁰C, 80⁰C, 90⁰C, 100⁰C, keep the specimen on the hot plate of temperature controller heater and set the temperature to required value and cross check it by thermometer after some times. Then remove the specimen, keep it immediately on the Charpy stand and release the pendulum.

Experimental data collection and presentation

- a) A plot can be obtained of temperature versus impact energy as shown in figure one for various specimens.
- b) Finally, the transition temperature can be determined by either of the four different definition. You are advised to obtain by 15 ft Lb definition.

Data Reporting :

- a) Report the time allowed to the specimen before releasing pendulum and also report the temperature of the specimen before releasing pendulum.
- b) Report energy of specimen absorbed due to impact

Conclusions

- a) Energy absorbed of the specimen in impact testing determined.
- b) Mention if transition temperature is determined (It would be possible after completion of all testing by all group)

Questions

- c) Comment on the fracture surface of the specimen
- d) How do the following factors affect the brittle to ductile transition transition temperatures
 - i) Grain size
 - ii) carbon content
 - iii) Phosphorus content
- c) How do you measure DBTT ?

Experiment 4

Creep testing of materials

Objective: To study the constant load creep behavior of lead at room temperature.

Requirements: Lead sample, Screw gauge, Vernier calliper

Principle

Crystalline materials may undergo plastic deformation by (i) slip, (ii) twinning, (iii) diffusion assisted atomic migration and (iv) grain boundary sliding. Among these methods, mechanisms of plastic deformation by diffusion assisted atomic migration and grain boundary sliding occur at high temperature [$T/T_{MP} > 0.4$] where T_{MP} is the melting point of the material. The other two mechanisms, i.e. the slip and the twinning may occur at low as well as room temperatures. The two high-temperature deformation mechanisms are time-dependent. Therefore, if a material is loaded at high temperature, even if below its yield strength, it will deform and accumulate strain with respect of time. The high-temperature time-dependent deformation of a material occurring at constant stress is called *creep*. Creep occurs in materials due to an increased high-temperature mobility of atoms (by diffusion) as well as that of dislocations (by mechanism of climb). The creep test measures the dimensional changes that occur due to the applied load at an elevated temperature. Creep behavior of a material is the most important consideration for choosing it for high temperature application.

Creep Curve:

Creep properties of a material are generally determined by means of a test in which a constant uniaxial load or stress is applied to the specimen, which is maintained at high temperature, and the resulting strain is recorded as a function of time. Typical shape of a creep curve is shown in Fig.1. When the load is applied, an instantaneous strain develops in the material and gives rise to the strain ϵ_0 at time $t = 0$. The material initially deforms at a very rapid rate ($d\epsilon/dt$), but as time proceeds the rate of deformation progressively decreases and becomes constant. This regime of deformation is referred to as the first-stage of creep or the *primary creep*. In the second-stage of creep, generally referred to as the *secondary creep* or the *steady-state creep*, the strain rate remains constant for a long time. Although considerable deformation can occur under the steady-state creep conditions, the strain rate eventually begins to accelerate with time and the material enters the *third-stage* or the *tertiary creep*. Deformation then proceeds at an ever-faster rate until the material can no longer support the applied stress and fracture occurs. The material thus shows the minimum creep rate, $d\epsilon/dt$, in the steady-state regime. This minimum creep rate is considered as the engineering design parameter in selecting a material for high-temperature applications.

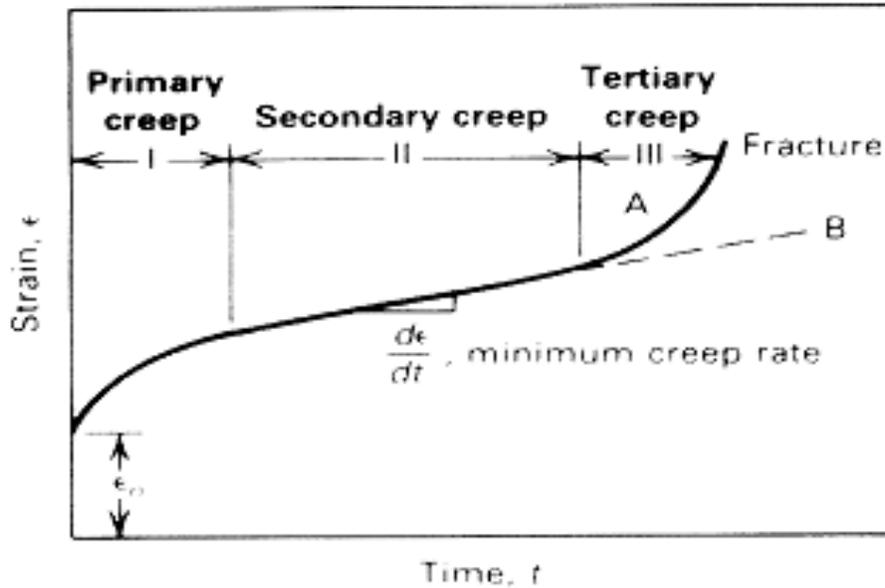


Fig. 1 Schematic illustration of Creep-curve shapes

Variations in the shape of the creep curve are caused by (a) extrinsic parameters such as changes in test temperature and the stress applied [Fig. 2] and (b) intrinsic material parameters such as (i) strain hardening/softening processes (recovery /recrystallization/ precipitate coarsening etc. and (ii) internal damage processes (cavitation and cracking).

As shown in Fig. 2, higher temperatures and stresses reduce the extent of the primary creep and practically eliminate the second stage, with the result that the creep rate accelerates almost from the beginning of the loading. In contrast with the decrease in temperature and/or the stress, the first two stages become clearly defined.

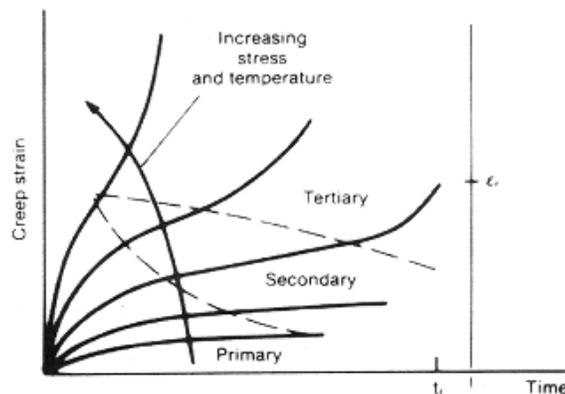


Fig 2 Creep curves obtained at different temperatures and/or stress

Equipment:

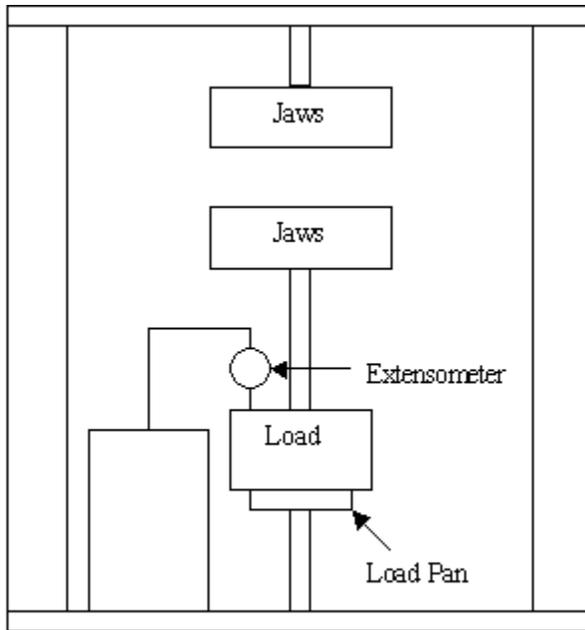


Fig. 3 Schematic of the Creep testing Machine

Important Parameter and Equation:

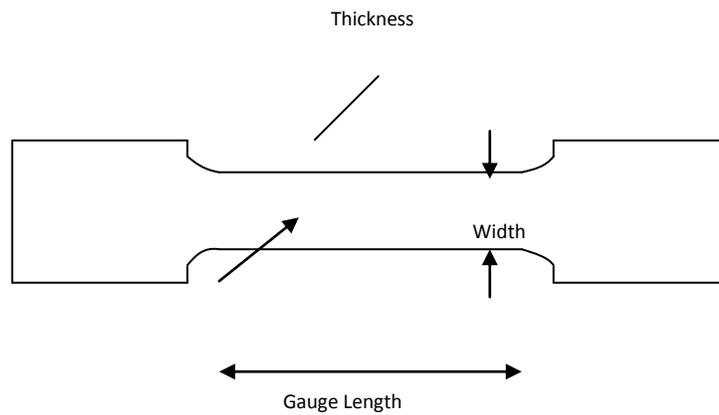


Fig. 4 Lead Sample

Engineering Stress σ (N/mm²)= Load (in Kg)*9.81(m/sec²)/(thickness (m)*width (m))

Strain (ϵ)= Elongation (mm)/Gauge Length (mm)

One full rotation of the big dial of extensometer= single step movement in small dial = 1mm

Experimental Procedure:

1. Mark the sample for the reduced gauge length (uniform width)
2. Measure the dimensions (gauge length and width by vernier caliper and thickness by screw gauge) of the given lead sample
3. Fix the ends of the sample up to mark in the jaws of the machine
4. Support the load pan from bottom till the first reading
5. Put the specified load on the load on load pan
6. Adjust the extensometer position on the load such that needle on small and big dial is at '0' position
7. Slowly remove the bottom support from the load pan and start take readings till sample breaks, of the big dial after every 10 second. Add 100 when small dial needle moves a single step
8. Convert dial readings into extension (mm)

Report:

1. Write sample readings and calculate stress
2. Plot strain vs time
3. Calculate the creep rate as a function of time and identify the various stages of creep
4. Report the minimum creep rate at each stage

Questions:

1. Can you do the creep test on steels using the same set up? Explain your answer.
2. What is the importance of minimum creep rate?
3. What are the precautions to be taken during creep testing?
4. What is effect of Grain size on the creep behavior of materials?

Experiment 5

Fatigue Testing

Object of the experiment

To study the effect of fluctuating stress normally encountered in the cyclic loading of materials in service.

Requirements for the experiment

- b) Specimen with the correct design
- c) Vernier calipers
- d) Dead weight as load
- e) Wrench for tightening the bolt of specimen holder

5. Brief description of the equipment/machine

The schematic diagram of the fatigue testing machine is shown in Fig.1. It consists of a 3-phase motor with 2800 rpm speed. The machine is designed to carry out testing of two specimens simultaneously. The samples for fatigue test can be of three types as shown in Fig.2 depending upon the loading scheme provided by the machine. The specimens can be either cyclically loaded in the axial manner [Fig.2 (a)] or in a rotating manner [Fig.2 (b) and (c)]

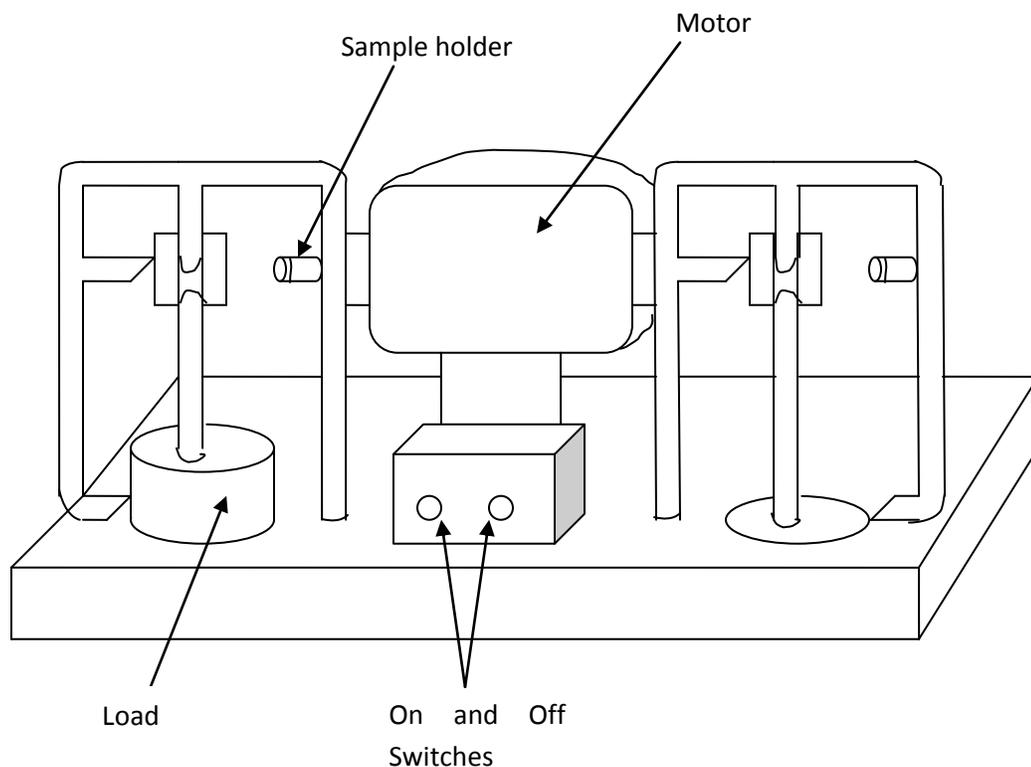


Fig.1 Schematic diagram of Fatigue testing machine

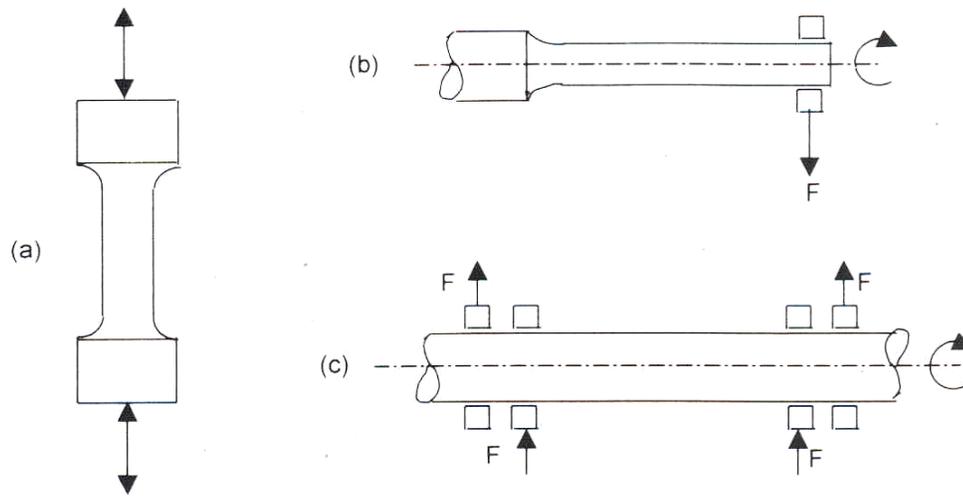


Fig.2 Loading schemes for laboratory scale fatigue testing: (a) Axial loading of the specimen, (b) single-end rotating cantilever testing machine and (c) Four-point rotating cantilever testing machine

Important Parameters and Equations

A fluctuating stress cycle can be considered to be made up of two components, a mean or steady stress σ_m , and an alternating or variable stress σ_a . We must first consider the range of stress σ_r . As can be seen from Fig. 3a & 3b, the range of stress is the algebraic difference between the maximum and minimum stress in a cycle. Thus,

$$\sigma_r = \sigma_{\max} - \sigma_{\min}$$

The alternating stress is one half of the range of stress.

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{\max} - \sigma_{\min}}{2}$$

The mean stress is the algebraic mean of the maximum and minimum stress in the cycle.

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2}$$

Two other parameters are also used for representing fatigue data:

$$\text{Stress Ratio (R)} = \frac{\sigma_{\min}}{\sigma_{\max}}$$

$$\text{Amplitude ratio (A)} = \frac{\sigma_a}{\sigma_m} = \frac{1 - R}{1 + R}$$

For a fully reversed stress cycle, as shown in Fig.3 (a), the Stress Ratio, R is -1 and if the stresses are partially reversed, R becomes a negative number less than 1 . If the stress is cycled between a maximum stress and no load, the stress ratio becomes zero. If the stress is cycled between two tensile stresses, the stress ratio becomes a positive number less than 1 .

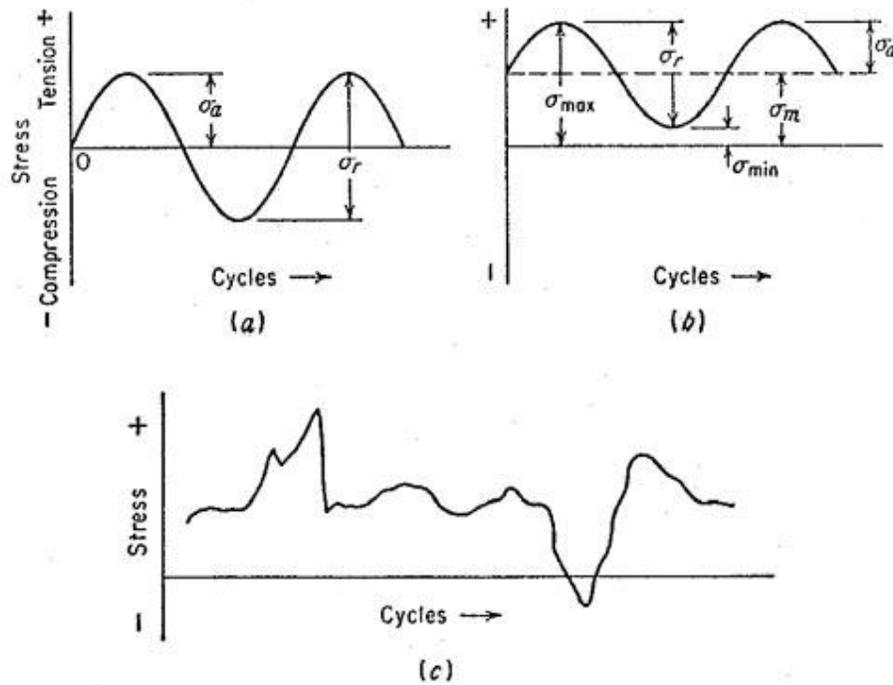


Fig 3. Typical fatigue stress cycles. (a) Reversed stress; (b) repeated stress; (c) irregular or random stress cycle

The results of fatigue crack initiation tests are usually plotted as maximum stress, minimum stress or the stress amplitude on (y-axis) against the number of cycles to failure, N (on the x-axis). The number of cycles to failure is generally plotted on the logarithmic scale, while stress is plotted either on the linear or logarithmic scale.

The regime in which the peak load is above the yield strength of the material is referred to as the low cycle fatigue. Components usually endure $<10^4$ cycles during low cycle fatigue. In contrast, when the peak cyclic stress is below the yield strength of the material, the component undergoes more than 10^4 cyclic reversals and the regime is referred to as the high cycle fatigue. Fig.4 depicts some of the general characteristics of fatigue.

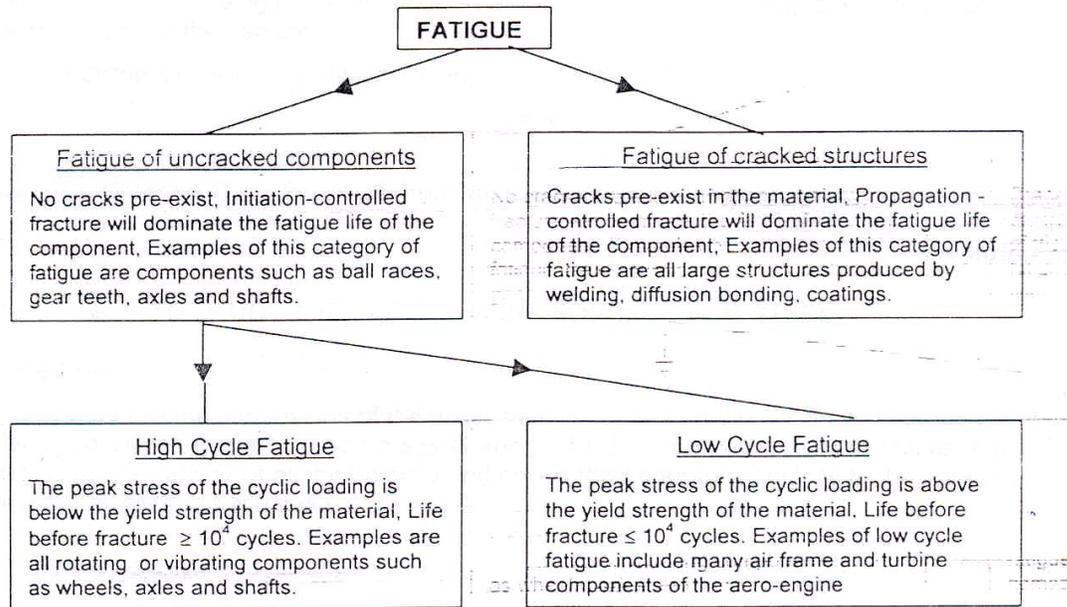


Fig5. Some of the important characteristics of fatigue

The peak stress in case of cantilever bar testing is obtained by the following formula. For the four-point cantilever bending the peak stress, σ_a is given by

$$\sigma_a = \frac{32Mb}{\pi d^3}$$

Where Mb is the bending moment $=PI/2$, d is the diameter of the sample, P is the applied load L is the length of the sample.

For the single-end cantilever testing

$$\sigma_a = \frac{32Px}{\pi d^3}$$

Where x = distance along the length from the fixed end and maximum value of x is l

Experimental Procedure

- Polish the sample surface as smooth as possible and observe for any surface defects and deep scratch/machining marks. Reject the sample if you find any defects.
- Measure dimensions of the given specimen of mild steel.
- Fit the specimen in the sample holder such that it passes through the opening provided in the rod on which the loads are seated.
- After fitting the sample, keep the desired load on the seat provided for the loads.
- Switch on the instrument to conduct the fatigue test and record the time for the failure, when it occurs.
- Note the appearance of the fractured surface in each case.

Experimental Data Collection and Presentation

- e) Calculate the peak stress from the formula mentioned above.
- f) From the time taken for fatigue failure, calculate the number of cycles to failure [$N = \text{RPM} \times \text{time for failure}(\text{min})$].
- g) Report the value of σ_a and N .
- h) Report the appearance of the fractured surface.
- i) Make S-N plots using results of all the batches and obtain the endurance limit.

9. Significance of the experiment/conclusions

The fatigue tests of mild steel will give the value of stress below which it can endure infinite number of cycles which is important from the engineering design point of view.

Experiment 6

Stain aging and yield point phenomenon

Objective To study the strain aging behavior of steel (associated with the yield-point phenomena) using load-elongation curve obtained from tensile test.

Requirements for the experiment

- k) Tensile specimen
- l) Universal Testing Machine (UTM)
- m) Computer aided software to be coupled with UTM

Brief description of the equipment/machine

Universal testing machine used for this experiment is Hounsfield extensometer, model H 20 K-W of 20 K-N capacity. The specimen is held at ends by means of grips with grip holder of the cross head. One end of the specimen is kept fixed while the other end is attached to a mobile cross-head. The cross head moves by means of an electric motor. The equipment has a provision for simultaneously measuring the applied load verses elongation.

Specimen geometry :

Tensile specimen had been machined of the dimension shown in **Fig.1** according to ASTM A-370 where gauge length to diameter ratio is 4 : 1.

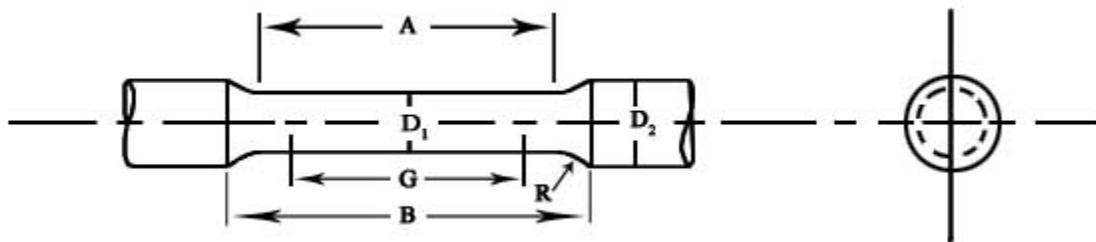


Fig.1 Tensile specimen

Gauge length (G) = 16mm, Length of reduced section (A) = 20 mm, Distance between shoulders (B) = 28 mm, Diameter of reduced section (D1) = 4 mm, Grip diameter (D2) = 8 mm, Radius of curvature (R) = 4 mm.

Theory:

Strain aging is behavior associated with the yield-point-phenomenon in which the strength of the metal is increased and the ductility is decreased on heating at a relatively low temperature after cold-working. **Fig.2** shows the effect of strain aging on the flow curve for a low-carbon steel. The low-carbon steel strained plastically through the yield-point elongation and then unloading and retesting without appreciable delay or any heat treatment does not show any yield point, since the dislocations have been torn away from the atmosphere of carbon and nitrogen atoms. If now the specimen is strained to point Y and unloaded, and then again reloaded after aging for several days at room temperature or several hours at an aging temperature like 300°F, the yield point will reappear and will be now higher than the initial yield point. The reappearance of the yield point is due to the diffusion of carbon and nitrogen atoms to the dislocations during the aging period to form new atmospheres of interstitials anchoring the dislocations. The strain aging behavior leads to non uniform deformation, hence is detrimental. It can be controlled by addition of nitride and carbide forming elements in order to lower the nitrogen and carbon content.

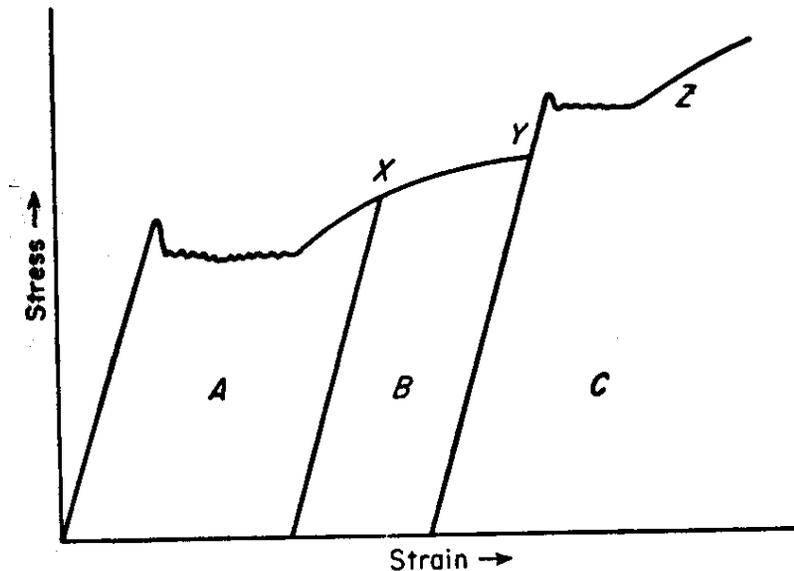


Fig 2. Stress-strain curves for low-carbon steel showing strain aging. Region A, original material strained through yield point. Region B, immediately retested after reaching point X. Region C, reappearance and increase in yield point after aging at 300°F

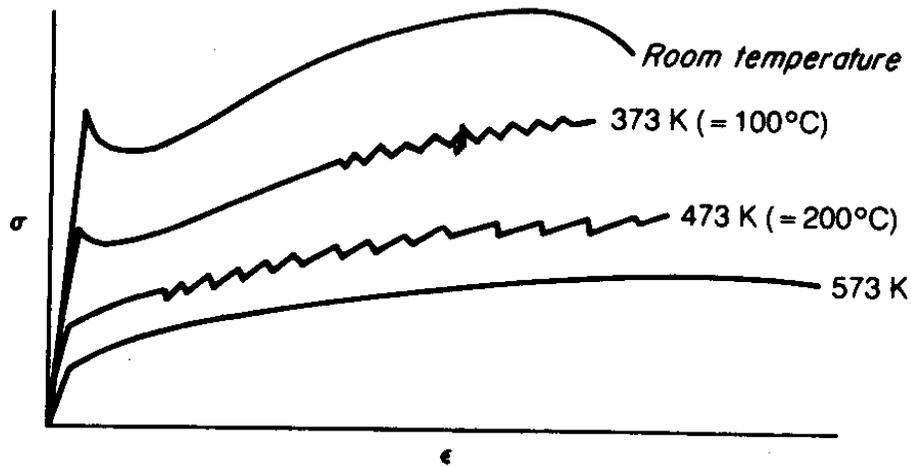


Fig. 3 Portevin-LeChaterlier Effect

Fig. 3 shows the stress-strain behavior of iron with increasing temperature. The dynamic strain aging behavior is called *Portevin-LeChaterlier* Effect. At higher temperature, the solute atoms mobility is high and they are able to lock the dislocations easily. Hence the yield point phenomena increases. However at higher temperatures, this phenomena is not observed as now the solute atoms are not able to pin the dislocations because of their excessively high mobility.

Experimental procedure:

- q) Turn on computer, turn on UTM, open software to collect data
- r) Fix one end of the specimen with fixed end of extensometer by grip holder and fix other end of the specimen by adjusting movable cross-head.
- s) Apply a little force (within 20 N) to make sure of proper fixing of specimen
- t) Make zero force and zero extension by click corresponding button on the machine.
- u) Click Test button then extension button.
- v) Carry out the test to a load value just above the yield point behavior. Stop the experiment and give print command.
- w) Collect data in software by exporting to excel.
- x) Again bring the sample to zero force and zero load. Repeat the steps (f) -(j)
- y) Remove this sample and keep it in water (approx at 100°C) for 30 mins.
- z) Repeat steps (a) -(k)

Experimental data collection and presentation:

- a) Report the experimental plots of load vs elongation for the loaded and reloaded (without delay) condition after combining the two sets of data.
- b) Report the experimental plots of load vs elongation for the loaded and reloaded (with aging treatment) condition after combining the two sets of data.
- c) Report and comment on the presence/absence of yield point elongation for both the conditions, without aging and with aging.

Significance of the experiment/conclusions:

From practical aspect, it is undesirable to have strain aging in deep drawing steel because the reappearance of the yield point can lead to difficulties with surface markings or *stretcher strains* due to the localized heterogeneous deformation.

Questions:

1. Why is the yield point after aging higher than the initial yield point ?
2. Which has a more important role, Carbon or Nitrogen, in the strain aging of iron?
3. Name three elements that can added to low carbon steel to reduce strain aging. How do alloying elements reduce strain aging?

Experiment 7

Effect of work hardening on the tensile properties of metals

Objective: To study the effect of cold rolling on the tensile properties of steel.

Theory

Engineering stress and engineering strain

$$s = P/A_0$$

$$e = (L-L_0)/L_0 = (A_0 - A)/A \quad [\text{Note: Constancy of volume} \Rightarrow A_0L_0 = AL]$$

True stress and true strain

$$\sigma = \frac{P}{A} = \frac{P}{A_0} \frac{A_0}{A} = s \frac{A_0}{A} = s \frac{L}{L_0} = s \left(\frac{L-L_0}{L_0} + 1 \right) = s(e+1)$$

$$\varepsilon = \int_{L_0}^L \frac{dL}{L} = \ln \frac{L}{L_0} = \ln \left(\frac{L-L_0}{L_0} + 1 \right) = \ln(e+1)$$

Effect of Cold Drawing on Tensile Properties of SAE -1016 Steel:

Reduction of area by drawing, %	Y.S (MPa)	T .S (MPa)	Elongation in 50 mm, %	Reduction of area, %
0	276	455	34	70
10	496	517	20	65
20	565	579	17	63
40	593	655	16	60
60	607	703	14	54

Requirements for the experiment

- a) Tensile specimen
- b) Universal Testing Machine (UTM)
- c) Computer aided software to be coupled with UTM
- d) Vernier caliper
- e) Punching stand, puncher and hammer
- f) Cold rolled Steel samples (20%,40%,& 60% reduction approx.)

Important Parameters and Equations

- a) *Original Gauge Length* (L_0): Gauge length before application of force.
- b) *Final Gauge Length* (L_u): Gauge length after rupture, the two pieces having been carefully fitted back together so that their axes lie in a straight line.
- c) *Engineering Stress* (s) and *Engineering Strain* (e) : $s = P/A_0$, $e = (L_u - L_0)/L_0$,
- d) *True Stress* (σ) and *True Strain*(ϵ) : $\sigma = s(1+e)$, $\epsilon = \ln(1+e)$
- e) *Tensile Strength* or *Ultimate Tensile Strength*: Stress corresponding to the maximum force
- f) *Yield Stress*: When the metallic material exhibits a yield phenomenon, a point is reached during the test at which plastic deformation occurs without any increase in the force.

Yield strength : $= F_Y/A_0$, Where F_Y = Load at the yielding point;

A_0 : Initial area of the specimen

For most ductile metals, yield strength is usually obtained from 0.2% offset yield strength/proof stress method by drawing a parallel line with elastic region from 0.002 strain in X-axis.

Lower yield stress is taken to be yield strength when yield point elongation is observed.

- g) *Upper yield stress*: Value of stress at the moment when first decrease in force is observed (see Fig. 2).
- h) *Lower yield stress*: Lowest value of stress during plastic yielding

i) *Yield Point Elongation* : The extension associated with discontinuous yield which occurs at approximately constant load following the onset of plastic flow. It is associated with the propagation of Luder lines or bands” (See Fig. 2)

j) *Percentage of Total Elongation at Fracture* = $(L_u - L_0)/L_0$

k) *Percentage Reduction of Area* = $(S_0 - S_U)/S_0$

Maximum change in cross-sectional area which has occurred during the test ($S_0 - S_U$) expressed as a percentage of the original cross-sectional area (S_0).

Where S_u is the final cross-sectional area.

l) *Strain hardening co-efficient (n)*:

$\sigma_t = K \epsilon_t^n$, Where σ_t = true stress, ϵ_t = true strain,

n = strain hardening co-efficient

Experimental Procedure

1. Measure L_0 , A_0 .
2. Switch on Lloyd tensile testing machine and follow the instruction on its panel.
3. First set the machine in manual mode and accept all other options as default values.
4. Carefully use double arrow button in upward and downward direction to adjust the position and fix the sample in grip. Precautions should be taken to avoid any hitting between grip and sample for load cell safety.
5. Double click icon “GO” on the computer.
6. Set testing machine under remote control mode through its panel.
7. On computer, select menu “New test setup” through arrow keys and press enter.
8. Leave all the options default except for the following

Test type = TENSION

Y axis = 10,000 Newtons

X axis = 30 mm

Speed = 5 – 10 mm/minute

Limit = 30 mm

9. Press Esc.
10. Select menu “Perform test”.
11. Accept all the default options.
12. Empty graph will be displayed.
13. Follow the instructions in the menu given at the bottom.

14. First initialize load and strain to zero.
15. Start your experiment and observe the sample till it fails.
16. Note the graph displayed on the screen.
17. Select "Cursor". Move it from left to right and note down all the coordinates.
18. Save your test results.
19. Press "Esc"
20. On main menu, select "Leave machine control program"
21. Switch off testing machine.
22. Remove sample from the grip
23. Measure L_f and A_f of the failed sample and place it in the scrap container.

Experimental data collection and presentation

- a) Convert collected data, load in Newton and extension in mm to engineering strain and engineering stress and then to true stress and true strain in excel.
- b) Report lower yield stress (yield strength), upper yield stress, ultimate tensile strength, fracture stress from engineering stress strain curve.
- c) Report % of elongation at fracture, % of reduction in area at fracture and strain rate.
- d) Submit true stress true strain curve along with the report by considering points upto UTS in engineering stress strain curve.
- e) Report strength co-efficient and strain hardening co-efficient from the plastic region of true stress strain curve by regression analysis method in excel.(if possible)

Conclusions

- a) Yield point elongation is observed (write if you have observed)
- b) Mechanical properties have been determined.

Questions

- a) Compare the experimental data for the three samples ?
- b) Mention the reason for the deviation in the three plots (i.e values) you have seen.
- c) Some times plastic deformation occurs without slip. Suggests mechanisms of plastic deformation without slip in the following two cases.
 - 1) At elevated temperatures with a very low strain rate .
 - 2) In an H.C.P polycrystalline sample with only 3 independent slip systems.