Experiment 1 Prepared by*: Mukesh Bhardwaj*

Tensile Properties of Aluminum using Lloyds Testing Machine

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)

Objective

Characterization of cylindrical shaped aluminum sample for tensile properties using engineering strain rate controlled testing.

Theory

Engineering stress and engineering strain

$s = P/A_0$

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

True stress and true strain

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

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

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.

$\sigma = K (\varepsilon + \varepsilon_0)^n, \Rightarrow \log \sigma = \log K + n \log (\varepsilon + \varepsilon_0)$

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.

Experiment 2 Prepared by: *Gadadhar Sahoo*

To Study Upper and Lower Yield Points in Mild Steel using Universal Testing Machine

Objective: Characterization of mechanical properties of the mild steel and noting the upper and lower yield points in the flow curve.

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

Specimen geometry

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

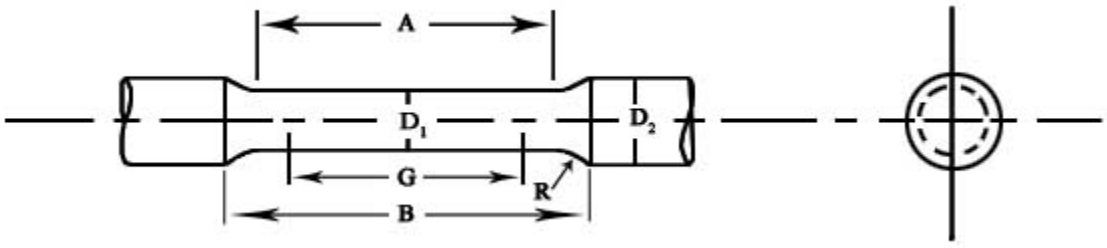


Fig.1 : Tensile specimen

Gauge length (G) = 16mm, Distance between shoulders (B) = 28 mm,
Length of reduced section (A) = 20 mm, Diameter of reduced section (D_1) = 4 mm,
Grip diameter (D_2) = 8 mm, Radius of curvature (R) = 4 mm.

Brief Description of the Equipment/Machine

Universal Testing Machine (UTS) used for this experiment is Hounsfield extensometer, model H 20 K-W of 20 kilo Newton 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.

Important Parameters and Equations

a) *Original Gauge Length* (L_o): 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) : $\sigma = s(1+e)$, $(\varepsilon) = \ln(1+e)$

e) Tensile Strength or *Ultimate Tensile Strength*: Stress corresponding to the maximum force

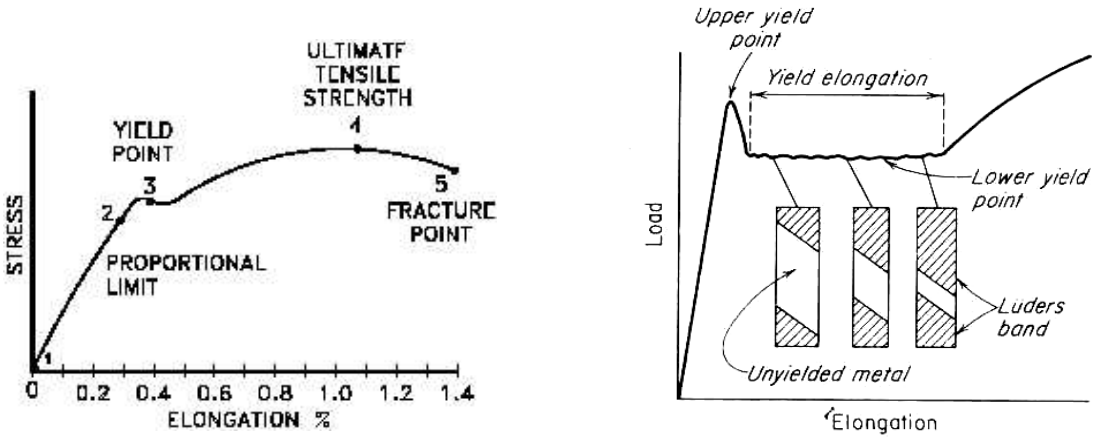


Fig. 2 : Typical yield point behavior

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 = $(L_u - L_o)/L_0$

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

Maximum change in cross-sectional area which has occurred during the test (S_o-S_U) expressed as a percentage of the original cross-sectional area (S_o).
Where S_u is the final cross-sectional area.

l) Strain hardening co-efficient (n):

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

n = strain hardening co-efficient

Experimental procedure :

a) If sample dimension is made by ASTM A 370 as reported above, then mark 16 mm gauge length by pen.
b) Punch the specimen on the pen mark on punching stand by light hammering and finally measure gauge length by caliper within the mark.
c) Measure original diameter atleast four times along the reduced section (gauge length) of the specimen. Find cross-sectional area and average area.
d) Turn on computer, turn of UTM, open software to collect data
e) 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.
f) Check the cross-head speed of the extensometer (It is kept fixed for mild steel) and calculate strain rate by dividing gauge length with cross head speed.
g) Apply a little force (within 20 N) by clicking extension button to make sure of proper fixing of specimen.
h) Make zero force and zero extension by clicking corresponding button on the machine.
i) Click Test button then extension button.
j) As sample get fractured, click stop button then click print button
k) Collect data in software by exporting to excel.
l) Measure final gauge length and final diameter after fracture by carefully holding the sample on the punching stand.
m) Measure diameter of the specimen at 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 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 engineering stress strain curve with true stress strain curve.
b) Why true stress strain curve can't be plotted beyond UTS ?
c) Why yield point phenomena is observed ?

Experiment 3 Prepared by: *Gouthama*

To Study Mechanical Behavior of a Polymer (Teflon) using Instron Testing Machine

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

Requirements for the experiment

f) Tensile specimen correct dimensions
g) Instron Mechanical Testing Machine
h) 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 ºC. It does not soften appreciably on heating but retains its strength up to 300 ºC, and its flexibility down to -200 ºC. 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/m^2; Elastic modulus = 414MN/m^2; 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 creepy 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

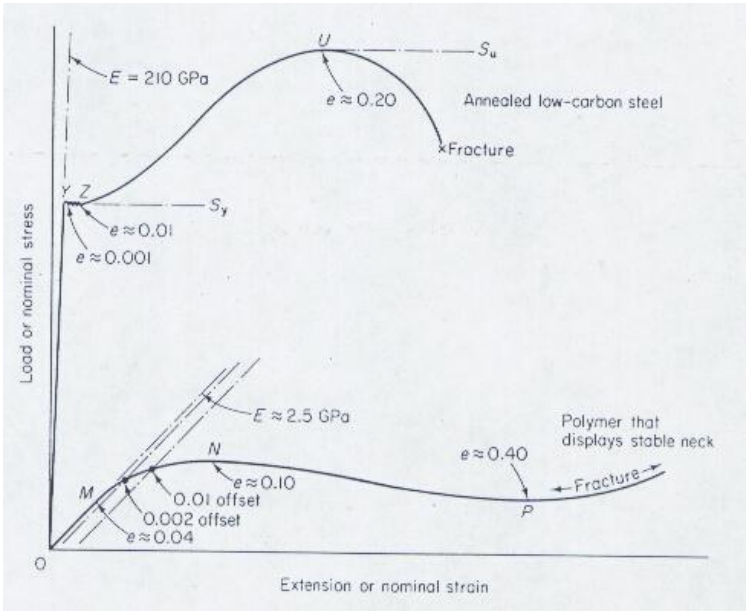


Fig. 1 engineering stress-strain curves for a polymer that displays stable neck propagation (‘cold drawing’) as compared with annealed plain low-carbon steel that exhibits a pronounced yield point.

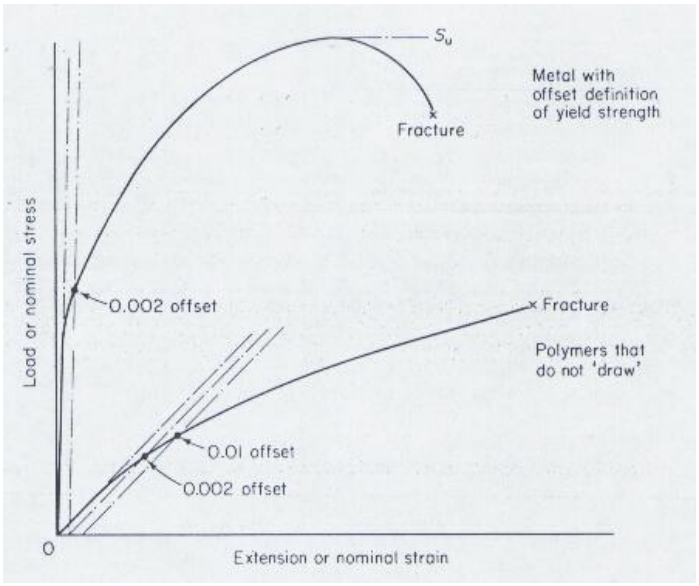


Fig. 2 engineering stress-strain curves for a polymer that does not display localized necking (does not ‘cold drawing’) as compared with a ductile metal that does not exhibit a pronounced yield point.

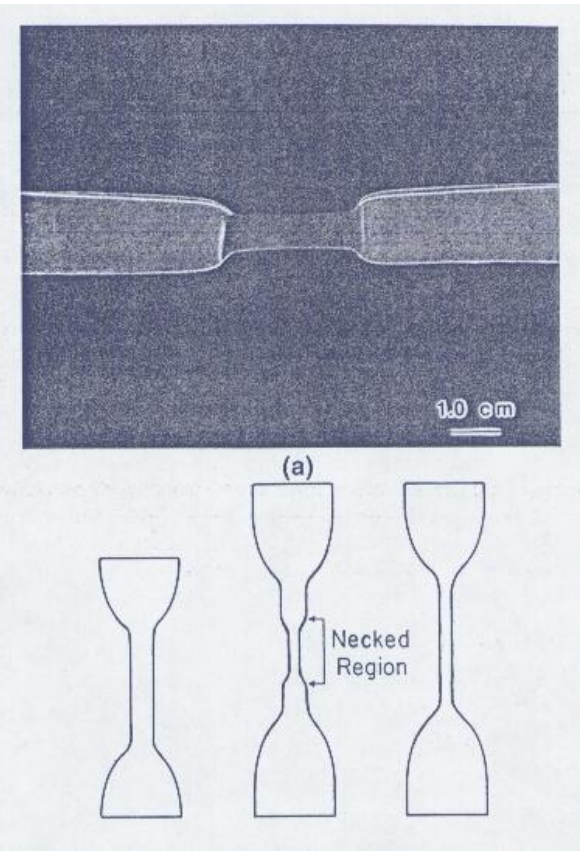


Fig. 3 Neck propagation in a sheet of linear polyethylene.

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 form 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 $(A-A_0)/A_0$ or true strain $\varepsilon = \ln(A/A_0)=2\ln(d_0/d)$. 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 look like the one shown in Fig.2. Here there are 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_o): 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) :* $\sigma = s(1+e)$, $\varepsilon = \ln(1+e)$

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 =* $(L - L_o)/L_0$

g) *Percentage Reduction of Area* = $(A_o - A)/A_0$
Maximum change in cross-sectional area which has occurred during the test (A_o-A) expressed as a percentage of the original cross-sectional area (A_o), where A is the final cross-sectional area.

Experimental procedure:

n) 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.
o) 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.
p) Let the Instron testing machine be switched on and stabilized for at least 30 mins.
q) Fix the specimen into the testing machine with appropriate grips.

r) Select the cross-head speed. Select appropriate scales for the "strip chart recorder".
s) Start applying the load.
t) As sample get fractured, note down the total extension from the chart. Immediately after fracture there will be a large elastic recovery.
u) Measure final gauge length after fracture by carefully.
v) 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 stree). 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 Poison's ratio.

Questions

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

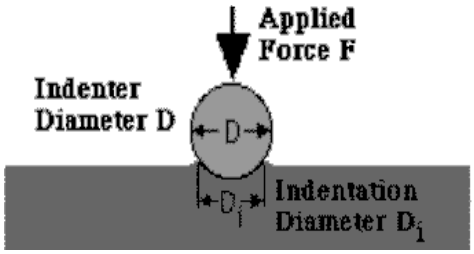
Experiment 4 Prepared by: *T. Harikishan*

To Measure the Hardness of Mild steel, Aluminum and Brass

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 harness number is calculated by dividing the load applied by the surface area of the indentation.



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

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 *F0* (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 reach, 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.

$$HR = E - e$$

F0 = preliminary minor load in kgf, *F1* = 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 F1 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

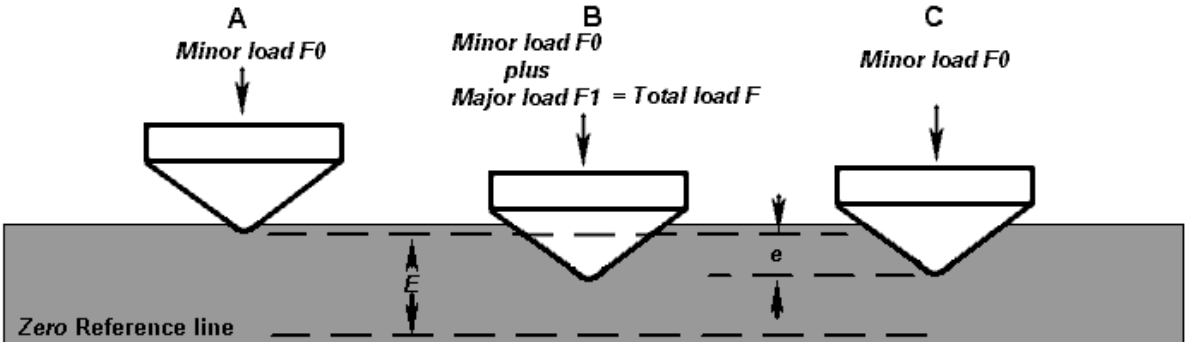


Fig. 1.Rockwell Principle

Rockwell Hardness Scales

Scale	Indenter	Minor Load *F0* kgf	Major Load *F1* 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 *F0* (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 reach, 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.

$$HR = E - e$$

F0 = preliminary minor load in kgf *F1* = 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 *F1*, measured in units of 0.001 mm
E = a constant of 100 units for diamond and ball indenters
D = diameter of steel ball

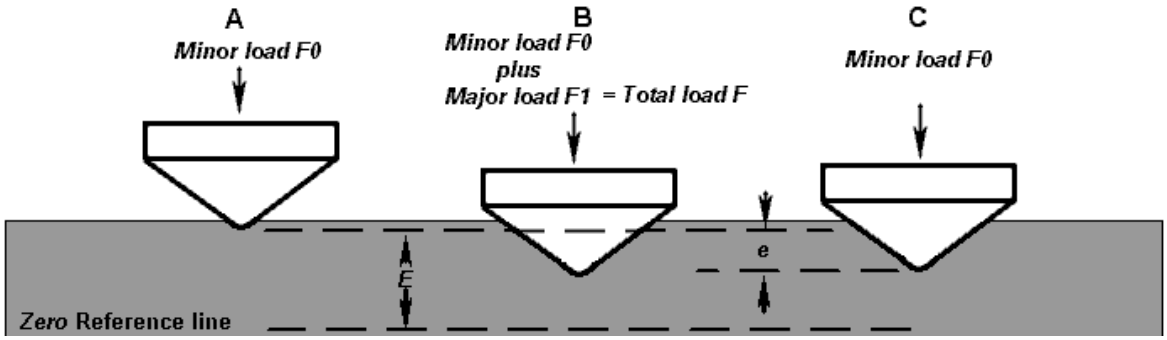


Fig. 2.Rockwell Superficial Principle

Rockwell Superficial Hardness Scales

Scale	Indenter Type	Minor Load *F0* kgf	Major Load *F1* kgf	Total Load *F* 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 is 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 dimensions produce by brinell and Rockwell techniques. Take mean of the three readings in each of the three cases.

Experimental date 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, aluminum 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 hard ness test would you recommend for mild steel casting?

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Experiment 5 Prepared by: *Bijayani Panda*

To Study the Fatigue Behavior of Mild Steel

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)]

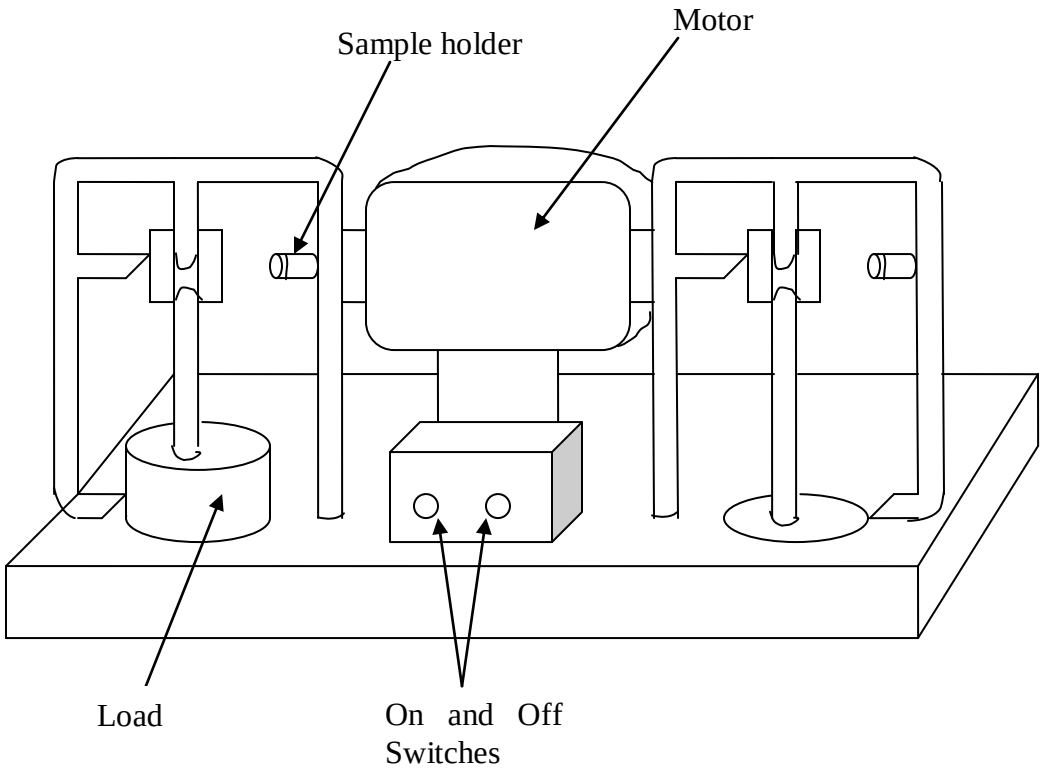


Fig.1 Schematic diagram of Fatigue testing machine

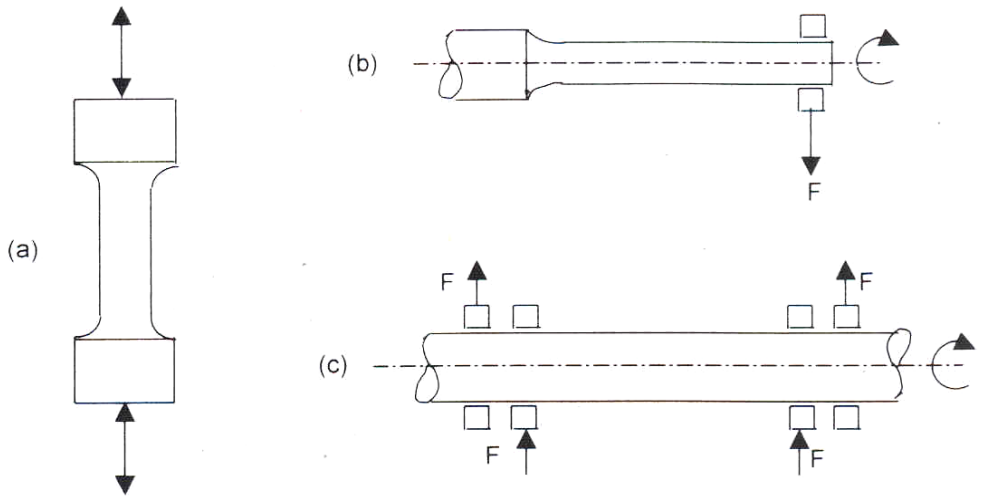


Fig.2 Loading schemes for laboratory scale fatigue testing: (a) Axial loading of the specimen, (b) single-end rotating cantilever testing machine and (c) Four-point rotating cantilever testing machine

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:

$$\text{Stress Ratio (R)} = \frac{\sigma_{min}}{\sigma_{max}} \qquad \text{Amplitude ratio (A)} = \frac{\sigma_a}{\sigma_m} = \frac{1-R}{1+R}$$

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 ration becomes zero. If the stress is cycled between two tensile stresses, the stress ratio becomes a positive number less than 1.

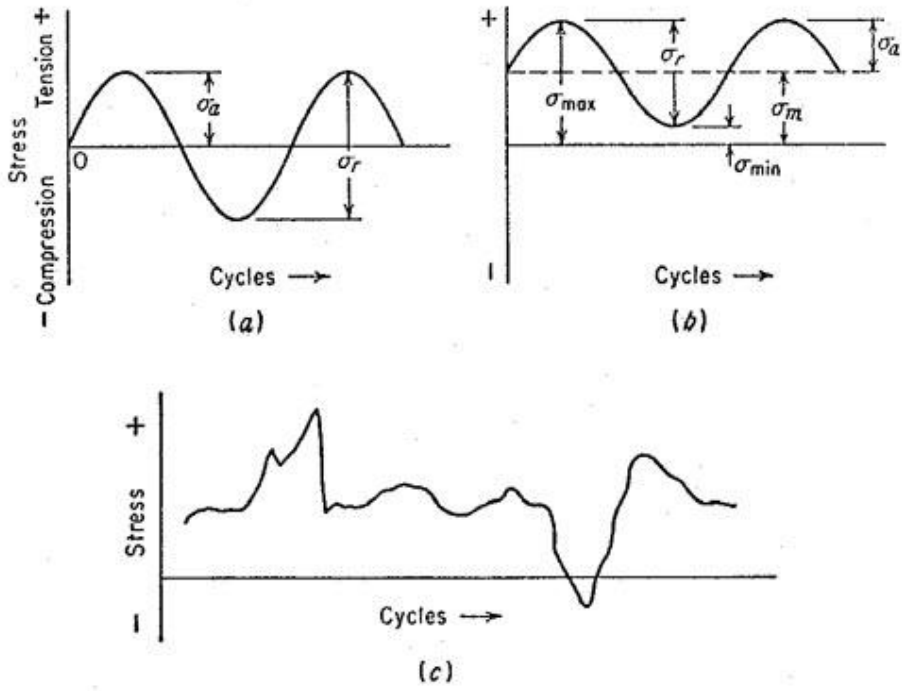


Fig 3. Typical fatigue stress cycles. (a) Reversed stress; (b) repeated stress; (c) irregular or random stress cycle

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.

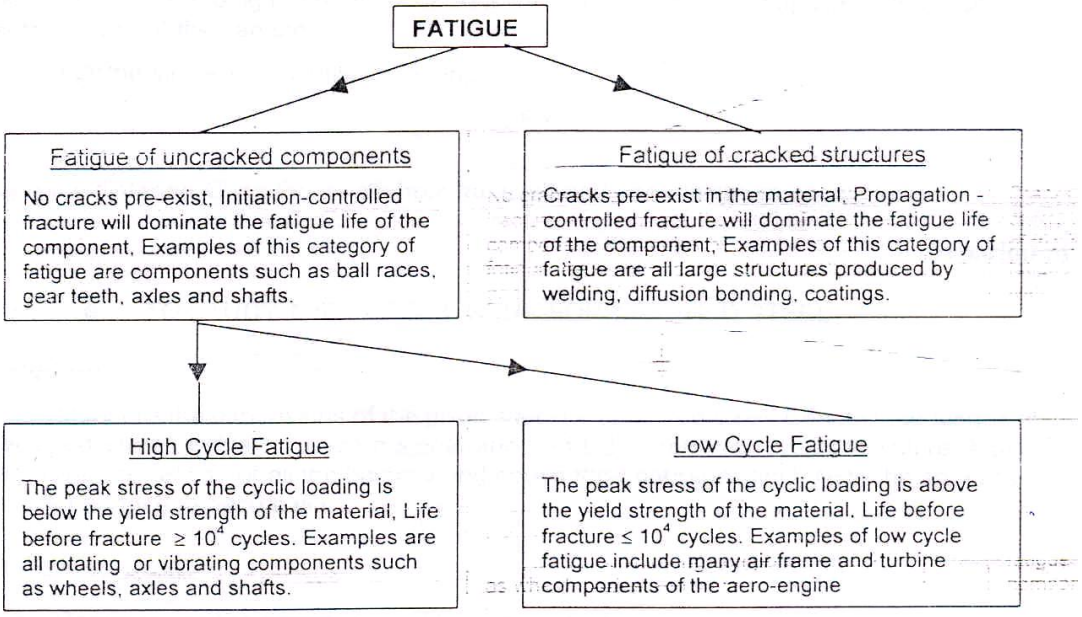


Fig5. Some of the important characteristics of fatigue

The peak stress in case of cantilever bar testing is obtained by the following formula. For the four-point cantilever bending the peak stress, $\sigma_a$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 1

Experimental Procedure

a) 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.
b) Measure dimensions of the given specimen of mild steel.
c) Fit the specimen is in the sample holder such that it passes through the opening provided in the rod on which the loads are seated.
d) After fitting the sample, keep the desired load on the seat provided for the loads.
e) Switch on the instrument to conduct the fatigue test and record the time for the failure, when it occurs,.
f) Note the appearance of the fractured surface in each case.

Experimental Date 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 = RPM x time for failure(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

Metal working and fabrication of tensile samples by cutting shearing and rolling

Aim: To prepare the tensile samples by using metal working and fabrication techniques like cutting, shearing and rolling.

Principle: Mechanical working of a metal is simply plastic deformation performed to change dimensions (shapes) ,properties and /or surface condition.

Characteristics:

1) Achieves shapes difficult by other methods.
2) Breaks down the cast structure.
3) Imparts desirable dimension and surface finish.
4) Economy of process, minimal wastage.
5) High speed automated production is possible.

Mechanical working process can be distinguished as cold working and hot working processes. Plastic deformation of metal above the recrystallisation temperature but below the melting or burning points called hot working whereas plastic deformation of metal below its recrystallisatuion temperature is known as cold working.

Purpose of hot working:

1) To shape the metal in to useful objects.
2) To improve the properties of the metal.
3) To produce raw material to be used for subsequent cold working operations.

Purpose of cold working:

1) Cold working is widely applied as a forming process for finish metal products.
2) To obtain good surface finish.
3) To obtain greater dimensional accuracy.
4) To obtain increased mechanical properties rolling.

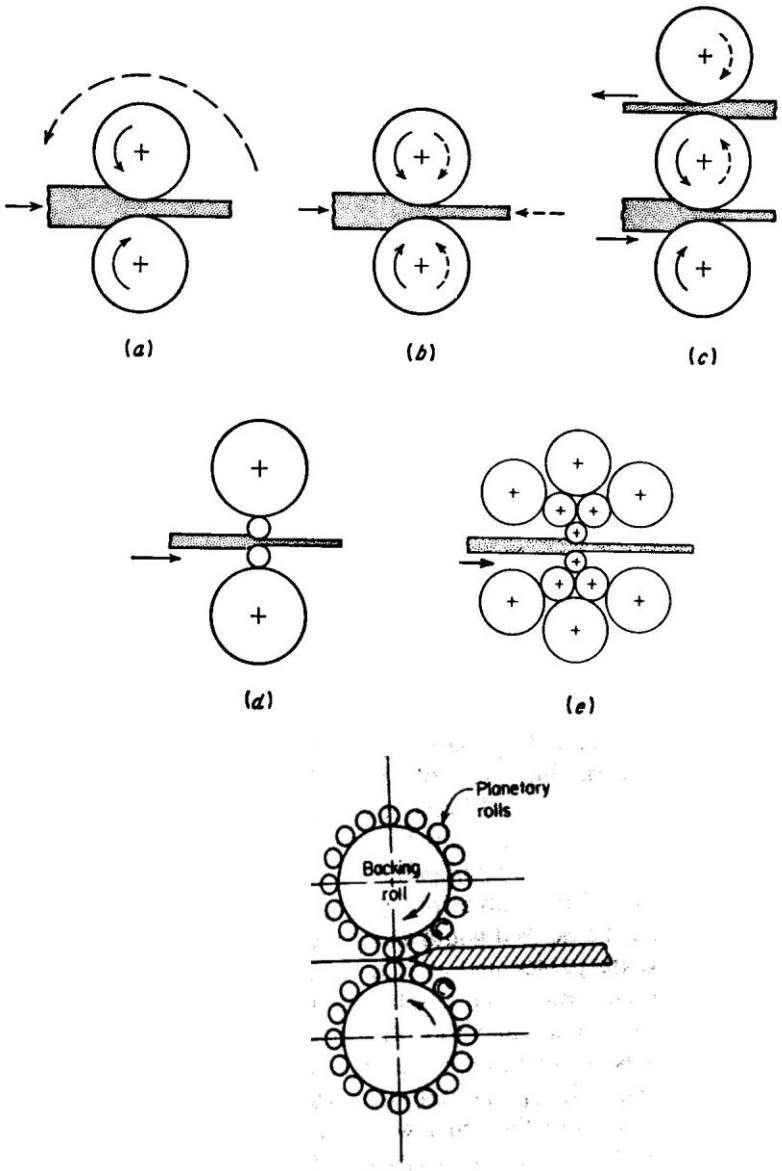
Rolling: Rolling a pair of cylindrical rollers made of iron or steel rotate in opposite direction with a gap between them which is smaller than the cross section of the piece which is to be rolled.

The reduction accomplished in one pass is commonly with in the range 10 to 30%. The amount of deformation that can be achieved by a pass between a given pairs of rolls is determined by the angle of bite and the strength of the material if the angle of bite is

too great leads to tearing away of the metal. If the angle of bite is too low, no of passes needed will be increased.

Types of rolling mills:

a)&b) Two –high rolling mills
c) Three-high rolling mills
d) Four-high rolling mills
e) Cluster rolling mills
f) Planetary rolling mills.



Shearing: Shearing is the cutting operation that is performed with out the creation of chips or waste products this operation leaves a clean edge on the piece of metal that is sheared or cut.

The basic shearing operations are cutting, trimming, notching piercing blanking. Shearing operations has three basic stages plastic deformation shear and fracture the shearing operation is noted by small deformation on the surfaces of the metal which extends in to the material from 5 to 40%of its thickness the same shearing operation takes place when a punch and die are used the only difference in punch and die work is that the shear part is pushed completely through the die the part is called either a slug or a blank, and the term blank refers to an item that requires further operation in order to make washers pots and other formed products

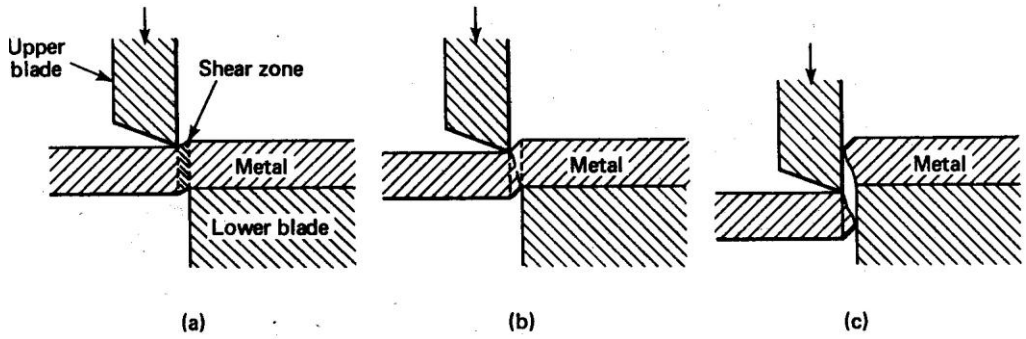
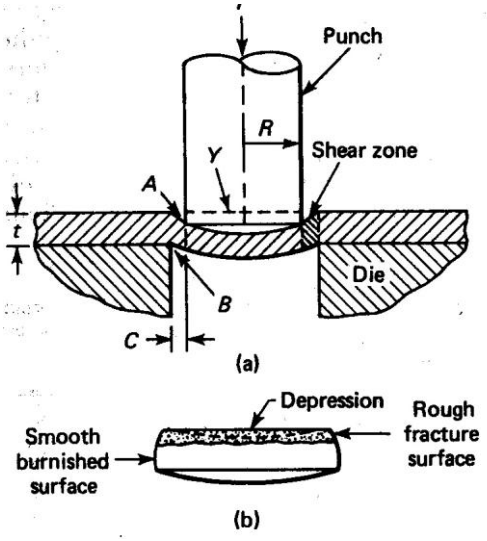


Fig: a) plastic deformation b) shear deformation c) fracture

Shearing equipment can be classified in to two categories hand shears and machine shears, hand shears commonly known as snips and punches .shearing machines are divided according to the thickness of the metal they cut, shearing machines that are capable of cutting metal 10gage or thinner are called sheet metal machine shearers those machines that shear metal 10 gage length and thicker are called plate shearers.



EXPERIMENT 7

To Study the Creep behavior of Lead

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 ($d\varepsilon/dt$), 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, $d\varepsilon/dt$, in the steady-state regime. This minimum creep rate is considered as the engineering design parameter in selecting a material for high-temperature applications.

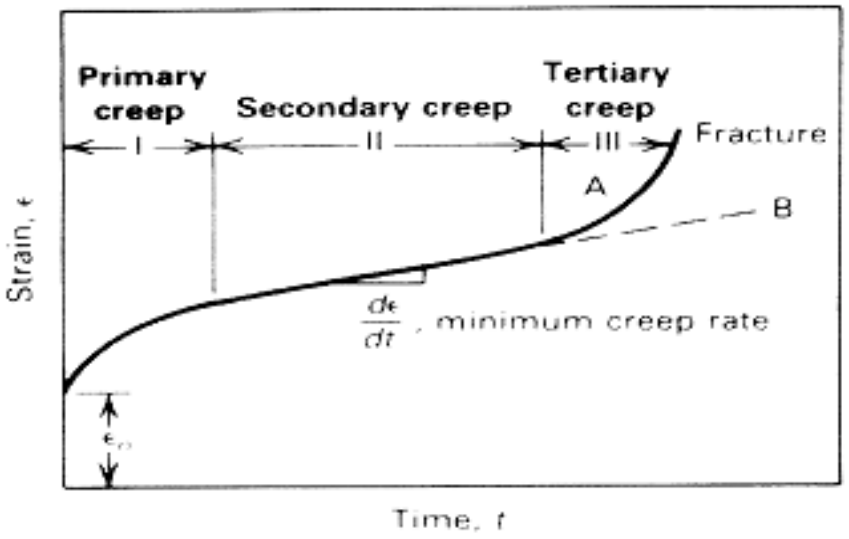


Fig. 1 Schematic illustration of Creep-curve shapes

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.

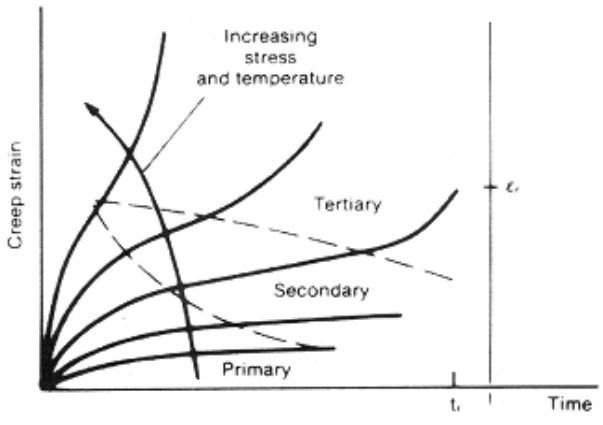


Fig 2 Creep curves obtained at different temperatures and/or stress

Equipment:

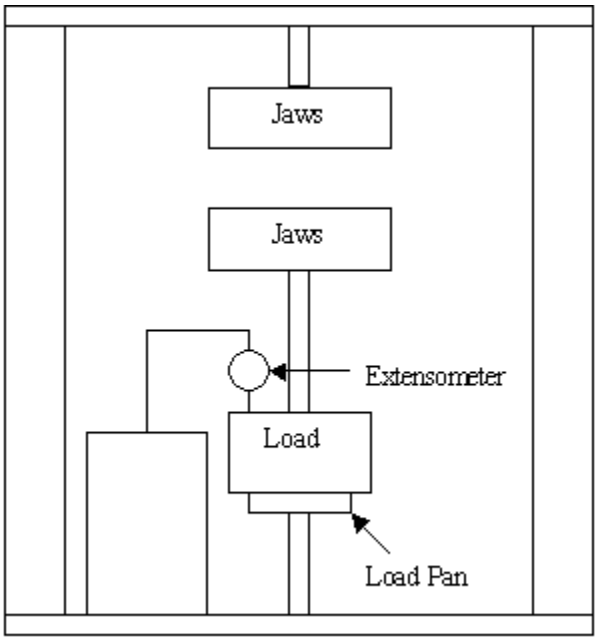


Fig. 3 Schematic of the Creep testing Machine

Important Parameter and Equation:

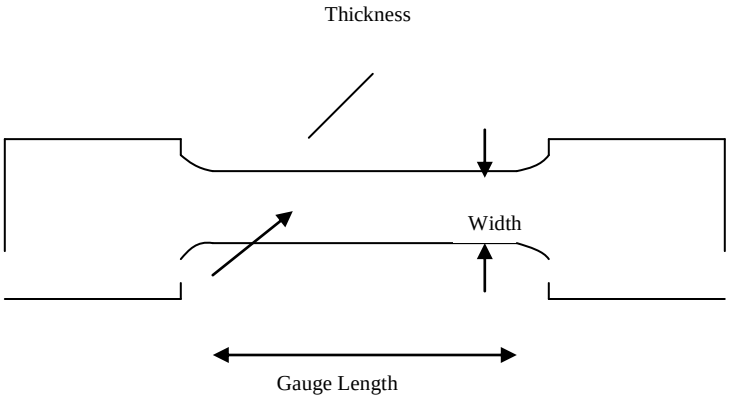


Fig. 4 Lead Sample

Engineering Stress σ (N/mm^2)= Load (in Kg)*9.81(m/sec^2)/(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 8

Effect of cold rolling on the tensile properties of Steel(3 samples with 20%, 40%, & 60% reduction)

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

Theory

Engineering stress and engineering strain

$s = P/A_0$

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

True stress and true strain

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

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

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 (Lo): Gauge length before application of force.

b) Final Gauge Length (Lu): 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) : $s = P/A0$, $e = (Lu - L0)/L0$,

d) True Stress (σ) and True Strain(ε) : $\sigma = s(1+e)$, $\varepsilon = \ln(1+e)$

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 = (Lu - Lo)/L0

k) Percentage Reduction of Area = (*So* - SU)/*S0*

Maximum change in cross-sectional area which has occurred during the test (*So*-SU) expressed as a percentage of the original cross-sectional area (So).

Where Su is the final cross-sectional area.

l) Strain hardening co-efficient (n):

$\sigma_t = K\varepsilon_t^n$, 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.

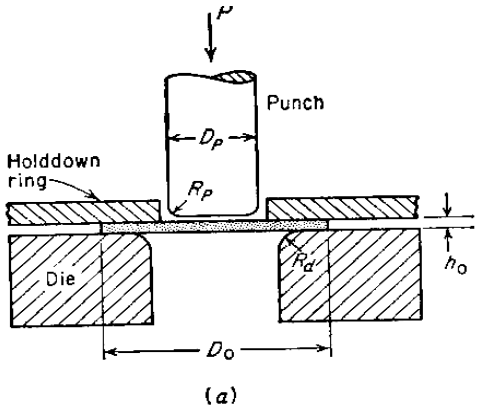
EXPERIMENT NO. 9

PLASTIC ANISOTROPY

Objective: To find the plastic anisotropy ratio for the Aluminum tensile samples.

Requirements: 3 Aluminum sample (0^0, 45^0 and 90^0 from rolling direction), Screw gauge, Vernier calliper

Principle: In our daily's life we use many metallic structures that look to be in the form of cup or tube, like all types of vessels, utensils, automobile panels etc. They all formed by sheet metal deep drawing operation. Deep drawing is done by placing a blank of appropriate size over a shaped die and pressing the metal the metal into the die with a punch (Fig 11.1). In the deep drawing of a cup the metal is subjected to three different types of deformations. Fig 11.2 represents the deformation and stress developed in a pie-shaped segment of a circular blank during deep drawing. The metal at the center of the blank under the head of the punch is wrapped around the profile of the punch and in doing so wall thickness is reducing.



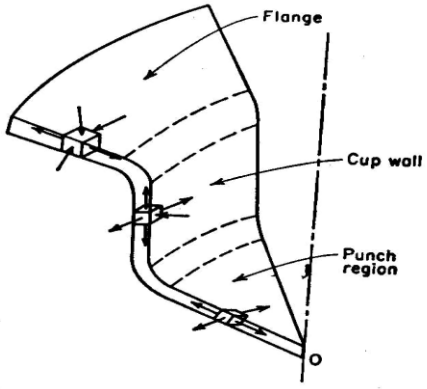


Fig 11.1 Deep Drawing of a cylindrical cup a) before drawing b) after drawing Fig 11.2 Stress and deformation in a section from a drawn cup

Drawing operation classified into drawing with appreciable decrease in wall thickness called ironing and drawing with little change in wall thickness, called *sinking.* The

ironing process is basically the same as tube drawing with a moving mandrel. The predominant stress in ironing is the radial compressive stress developed by the pressure of the punch and the die. Drawing without reduction in wall thickness is basically the same as tube sinking or tube drawing without a mandrel. The predominant stresses are an axial tensile stress from the action of the punch and a circumferential compression from the drawing in of the metal.

To improve drawability, the potential failure site near the bottom of the cup wall must be strengthened relative to the metal deforming by radial drawing near the top of the cup wall. Roughening the punch or withholding lubrication to the punch may also help in this regard. It would also be possible to weaken the metal in the flange relative to the failure site by selectively heating the metal in the flange area. However, by far the greatest improvement in drawability comes about by the control of *crystallographic texture* in the sheet that is to be drawn. The correct texture gives the proper orientation of slip systems so that the strength in the thickness direction is greater than that in the plane of the sheet.

The resistance to through thickness thinning was measured by *R*, the plastic strain ratio of width to thickness in a sheet. *R* measures the *normal anisotropy.* A large value of *R* denotes high resistance to thinning in the thickness direction (direction normal to the plane of the sheet).

$R = \ln (w_o/w)/\ln (h_0/h)$

Where w_0 and w are the initial and final width and h_0 and h are the initial and final thickness. Since thickness measurements are difficult to make with the precision on the thin sheets, the equation can be rewritten using the constancy-of-volume relationships.

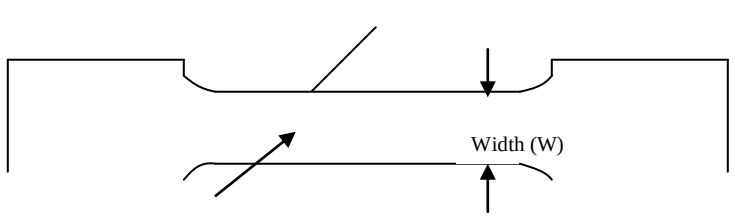
$R=\varepsilon_w/\varepsilon_h = \varepsilon_w/-(\varepsilon_w+\varepsilon_l) = \ln (w_o/w)/-\ln (w_0L_0/wL) = \ln (w_o/w)/\ln (wL/w_0L_0)$

Where L_0 and L are the initial and final gauge length

Since most rolled sheets show a variation of elastic and plastic properties with orientation in the plane of the sheet, it is usual to allow for this planar anisotropy by $\overline{R}$ averaged over measurements taken at different angles to the rolling direction of the sheet.

$\overline{R} = (R_0+2R_{45}+R_{90})/4$

Where R_0, R_{45} and R_{90} are the normal anisotropy value for the samples in 0^0, 45^0 and 90^0 from the rolling direction



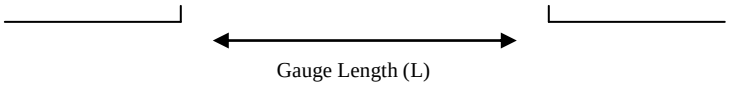


Fig 11.3 Aluminum Sample

Equipment: Instron machine that was used for Experiment no. 3 (Tensile testing of Teflon sample)

Experimental Procedure:

1. Mark all samples for the reduced gauge length (uniform width)
2. Measure all the dimensions (Gauge length and Width by Vernier caliper and thickness by Screw gauge) of the given lead sample
3. Load the 1st sample up to mark in the machine
4. Use crosshead speed as 2mm/min
5. Start tension test till the UTS (ultimate tensile strength) point
6. Unload the sample and measure its dimension again
7. Repeat 4-6 for other 2 samples

Report:

1. Write dimensions reading for all three samples before and after tensile test
2. Calculate Engineering Yield strength and Ultimate tensile strength of all three samples
3. Calculate R of all three samples and Calculate $\overline{R}$
4. Plot Engineering stress vs. engineering strain curve of all three samples in the same graph

Questions:

1. What are the typical $\overline{R}$ values of common engineering Materials and which products can be manufactured by them using sheet metal drawing operation?
2. What is more important, R or $\overline{R}$ and why?
3. What are the precautions to be taken during plastic anisotropy testing?
4. What is effect of Grain size on the $\overline{R}$ value?

Experiment 10

To determine the effect of temperature on impact energy of mild steel using 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

i) V-notched specimen
j) Swing pendulum Impact Testing Machine
k) Liquid nitrogen
l) Optical pyrometer
m) Temperature controller heater
n) Water
o) 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= $264 \times 0.3048\text{m} \times 9.8\text{ms}^{-2} \times 0.45362\text{ Kg} = 343.977$ J. A scale is provided in the machine, which range from 0 – 264 foot pound (ft Lb). An indentor 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 45^0 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 indentor 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.

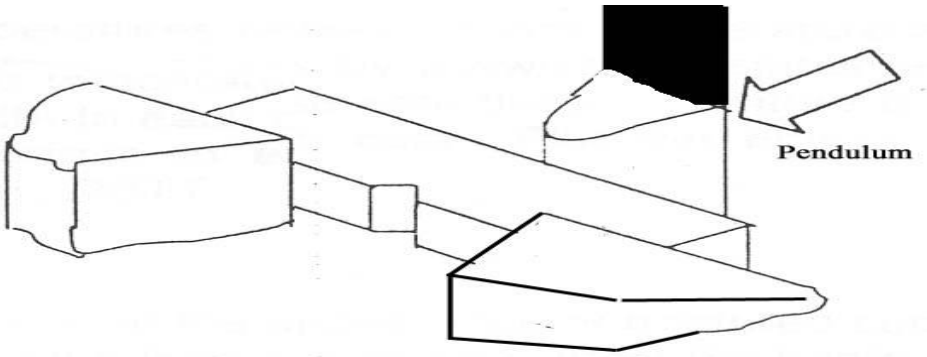


Fig.1 Schematic diagram of impact testing

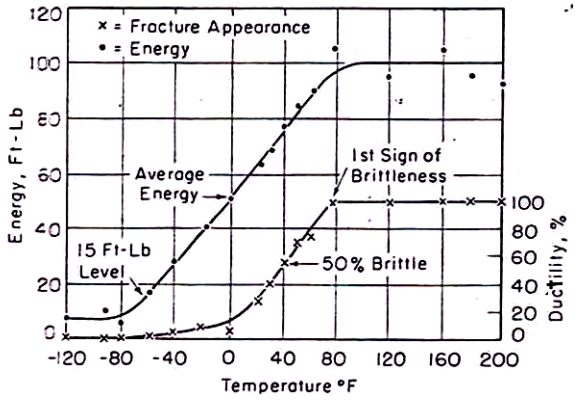
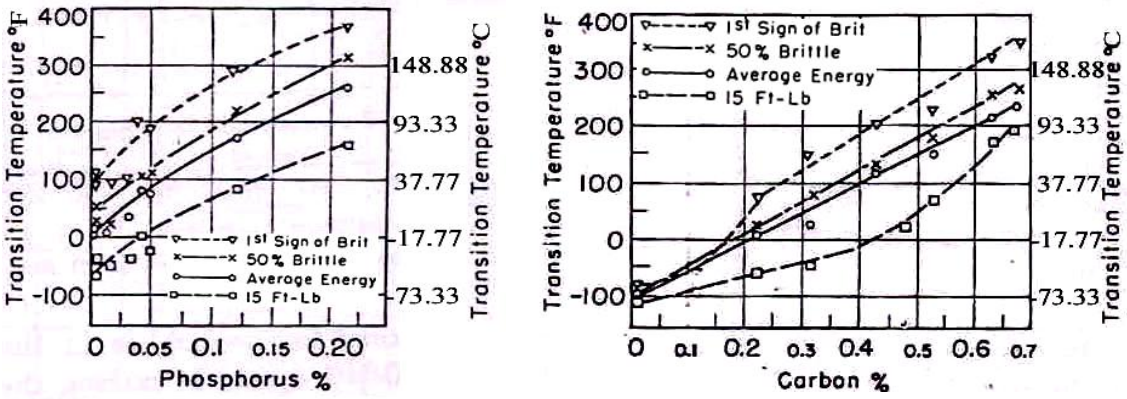


Fig.2 Typical curve showing different transition temperature on steel



(a) (b)

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 :

w) 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.

x) Draw the indentor to the position of 264 ft Lb.

y) 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.

z) Keep your stopwatch ready. Remove the specimen with the help of tung 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.

aa) Now indentor will move towards zero end of the scale. Count the number of division from zero to the position of the indnetor after impact. This will give the energy of the specimen absorbed by impact of the pendulum.

bb) 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.

cc) For determining energy at higher temperature, starting from 35^0C, 50^0C, 65^0C, 80^0C, 90^0C, 100^0C, 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 verses 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

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

Questions

f) Comment on the fracture surface of the specimen
g) 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 11

To study the Stain Aging of steel

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

p) Tensile specimen
q) Universal Testing Machine (UTM)
r) 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 equipement 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.

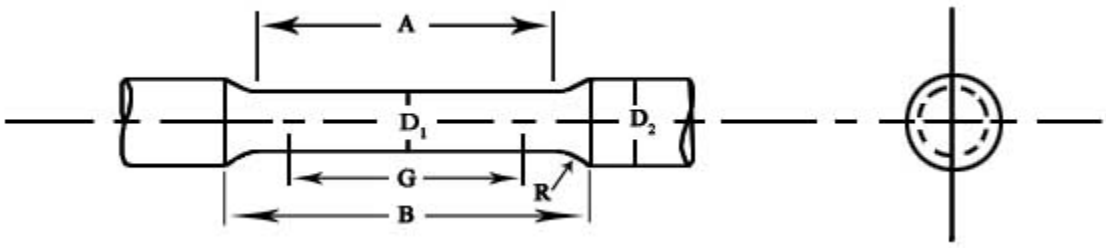


Fig.1 Tensile specimen

Gauge length (G) = 16mm, Length of reduced section (A) = 20 mm, Distance between shoulders (B) = 28 mm, Diameter of reduced section (D_1) = 4 mm, Grip diameter (D_2) = 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.

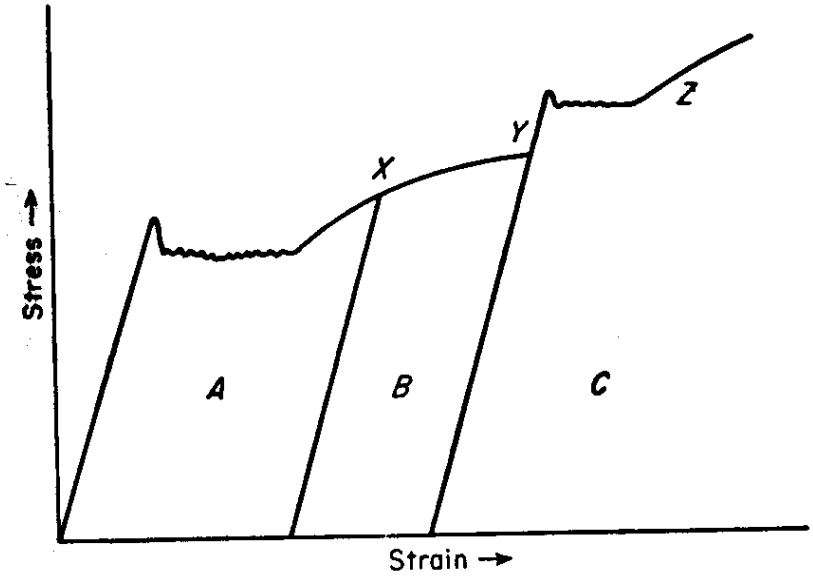


Fig 2. Stress-strain curves for low-carbon steel showing strain aging. Region A, original material strained through yield point. Region B, immediately retested after reaching point X. Region C, reappearance and increase in yield point after aging at 300°F

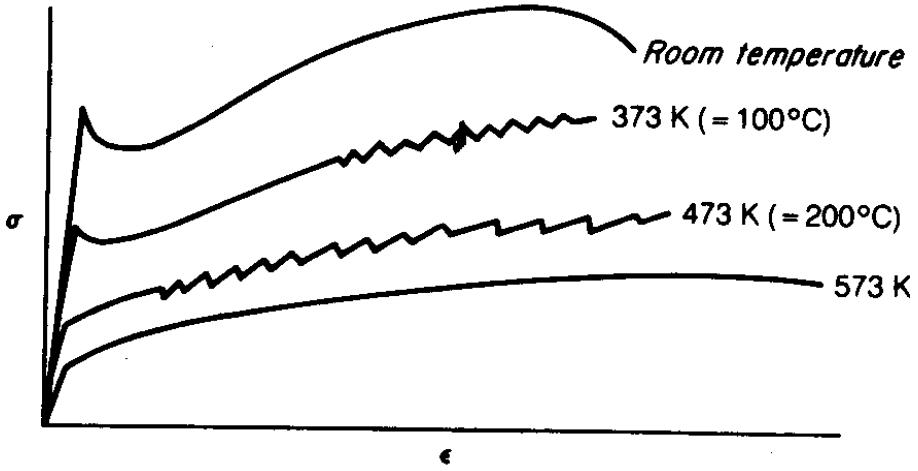


Fig. 3 Portevin-LeChaterlier Effect

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:

dd) Turn on computer, turn on UTM, open software to collect data
ee) 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.
ff) Apply a little force (within 20 N) to make sure of proper fixing of specimen
gg) Make zero force and zero extension by click corresponding button on the machine.
hh) Click Test button then extension button.
ii) Carry out the test to a load value just above the yield point behavior. Stop the experiment and give print command.
jj) Collect data in software by exporting to excel.
kk) Again bring the sample to zero force and zero load. Repeat the steps (f) -.(j)
ll) Remove this sample and keep it in water (approx at $100^{o}C$) for 30 mins.
mm) Repeat steps (a) -(k)

Experimental date 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-12

Hydrogen Embrittlement

OBJECTIVE

To study the phenomenon of hydrogen embrittlement in a rolled steel sample.

THEORY

In many corrosion processes, atomic hydrogen is produced in the cathodic reaction. A part of this atomic hydrogen frequently diffuses into the metal while the rest combine with other hydrogen atoms to from hydrogen molucule and diffuse away from the surface into the electrolyte. Many metals, specially high strength steels, are embrittled in the presence of this atomic hydrogen in the material. This embrittlement is encountered most commonly electroplating, electro cleaning, electroplishing, pickling and corrosion.
One convenient way to study this effect is to charge hydrogen cathodically using impressed current in an acid solution and monitor the degradation in the mechanical behavior.

MATERIALS AND EQUIPMENT

- Two tensile test specimans (one for reference properties and another for hydrogen charging experiment)
- Electrolyte for charging hydrogen (to which some drops of solution containing sodium arsentite are to be added). The arsenite ions lower the rate of hydrogen re-combination reaction on the surface, thereby enchancing the residence time of atomic hydrogen on the surface. The electrolyte is XXXNH2SO4.
- Glass beaker
- Stainless steel counter electrode
- DC power supply
- Hounsefield tensile testing machine

PROCEDURE

- Clean the central part of the tensile test specimens with emery papers
- Degrease the specimen with methanol.
- Coat one end grip of the specimen (that is to be charged with hydrogen) with Teflon tape so that hydrogen will not be liberated from these areas.
- Connect one end of this specimen with wire using suitable clips and immerse specimen in the electrolyte, taking care that the connecting wire is not immersed. Moreover, care should be taken such that only the region up to the gage length is immersed in the solution.
- Set up an electrochemical cell with specimen as cathode and stainless steel as the counter electrode (here in this case, anode).
- Charge hydrogen at given current density ($0.1 Amp/cm^2$) for 60minutes.

OBSERVATIONS

- Record the initial dimensions of the specimens (gage length, cross sectional area of the gage section, etc.).
- Perform tensile tests in the Housefield tensile testing machine, one test for reference properties (without any hydrogen charging) and another is the hydrogen charged sample.
- Record the dimensions of the specimens after tensile testing. Based on these, estimate the ductility using% reduction in area and % elongation.
- Plot the engineering stress-engineering strain curve from the load-elongation curves that you obtained for the two specimens.
- Estimate the mechanical properties from the tensile stress-strain curves. The properties to be estimated are Young's modulus, yield strength, ultimate tensile strength, total strain to failure, elastic strain, total plastic strain, and plastic strain before necking.

CONCLUSIONS

- Record the above data in a neat table for the two conditions.
- Calculate the Hydrogen Embrittlement Index (HEI) for each of the above properties that you determined. HEI is expressed as a percentage change of the property after hydrogen charging with respect to the original value before hydrogen charging .
- How does HEI vary for the various properties ?
- Why does the properties vary or does not vary with hydrogen charging ?
- What is the possible role of hydrogen in causing the changes, if any, in the mechanical properties ?

QUESTIONS

- How is the hydrogen picked up in metallic materials in industrial practice?
- Describe some methods to minimize hydrogen embrittlement?
- Why did the color of the charging solutions change with charging time?
- What is the gas evolving on the ciunter electrode?