Experiment 1

1. **Title:** Determination of the tensile properties of different class of materials

2. **Objective:** To characterize and compare the mechanical behavior of Teflon (polymer) and aluminium (metal)

3. **Requirements of the experiment**

   - Tensile specimen
   - Llyod Mechanical Testing Machine
   - Vernier caliper

4. **Introduction**

4.1. Brief description of the equipment/machine: The Universal Testing Machine in the Materials Testing Lab is shown in Fig. 1. It is a 10KN capacity testing machine and is screw driven. While the lower cross head is fixed, the upper cross head is movable and is fitted with the transducer type 'load cell'. This testing machine can also be used for compression, torsion, bend/flexural and for high temperature tensile tests.

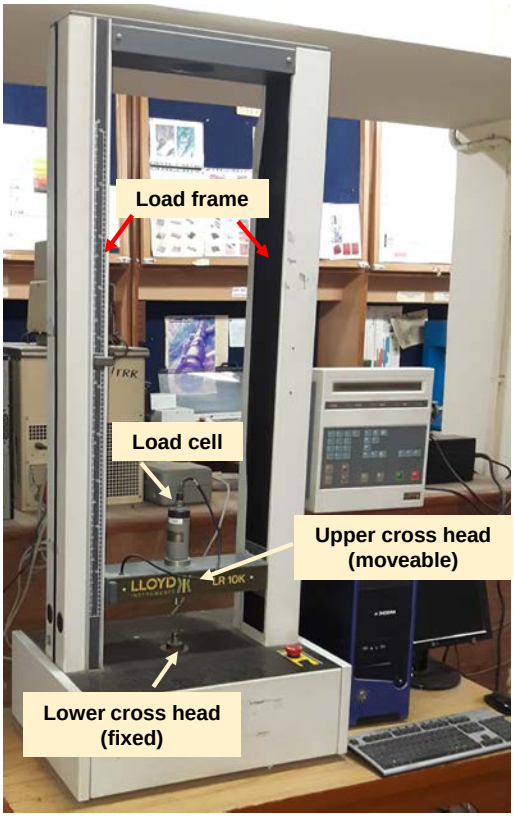


Fig. 1: *Llyod testing machine in Materials Testing Lab*

4.2. Mechanical behavior of metallic materials: Typical stress-strain curve for a polycrystalline metal is shown in Fig. 2. The common definitions of yield strength S_y and tensile strength S_u of ductile metals are illustrated in the Fig. 2. OA is the elastic regime. The maximum load point (u), at which an unstable neck initiates, gives the ultimate tensile strength (or tensile strength) S_u. The sample fractures at F.

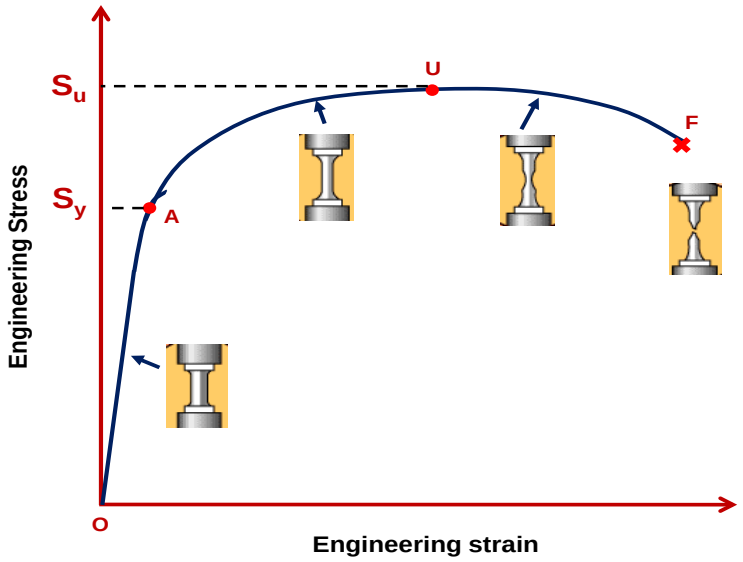


Fig. 2: *Engineering stress-strain curve for a polycrystalline metal.*

4.3. Mechanical behavior of polymers: 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. Fig. 3 shows typical stress-strain curve for a thermoplastic polymer.

'OA' is the elastic regime, where Hook's law is valid. There is a departure from linearity at A and the load curve rises to a local maximum at N, at which point the stable neck initiates. The **yield stress** of the polymer is poorly defined since the stress-strain curves bends over at the top of the elastic region. Generally, the value at the top of the curve (point B) is used as '**yield point**'. Typical polymers yield at 5-10% strain, whereas, a metal yields at less than 0.1% strain.

The load then falls as the neck is reduced in cross-sectional area, until stability is reached (point C), and the neck propagates along the test piece at the essentially constant stress (till point D). The process in the region 'CD' is also called "**cold drawing**". Subsequently, after neck has propagated along the length of the test bar, the stress increases again due to strain hardening, till fracture occurs at point F.

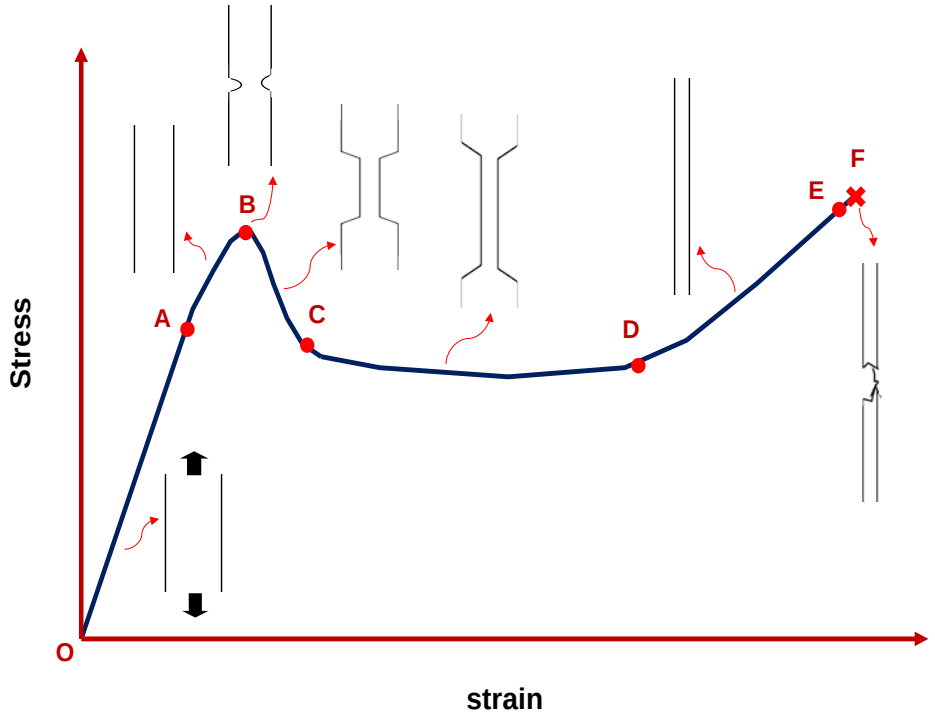


Fig. 3: *Engineering stress-strain curves for a thermoplastic polymer.*

4.4. 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_y: 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

$$S_y = P_{(\text{strain offset} = 0.002)}/A_o$$

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

$$U_R = 0.5 * S_o e_o$$

4.5. 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_o) are used to characterize material in plastic range

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

Ultimate tensile strength (S_u): The maximum engineering stress before rupture of specimen

$$S_u = P_{max}/A_o$$

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

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

4.6. Important Experimental Parameters

a) ***Original Gauge Length*** **(L_o):** Gauge length before application of force

b) ***Final Gauge Length*** **(L):** Gauge length after rupture

c) ***Engineering Stress (S) and Engineering Strain (e):*** $S = P/A_o$, $e = (L - L_o)/L_o$

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 in 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.

4.7. 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_o	Yield strain
e_f	Strain at failure
ε	True strain
ε_o	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)

4.8. Formulas

a) Engineering stress and engineering strain

$S = P/A_0$

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

b) True stress and true strain

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

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

5. Experimental procedure

a) Dogbone samples of Teflon (polymer) and aluminum (metal) will be tested in tension.

b) Using marker, mark the gauge length reference points. The gauge length should be marked within the parallel section portion of the dogbone sample.

c) Measure original width and thickness of the sample at least four times along the reduced section (gauge length) of the specimen. Find average value of cross-sectional area.

d) Switch on the Lloyd testing machine and let it get stabilized for at least 30 mins.

e) Fix the specimen into the testing machine with appropriate grips.

f) Select the cross-head speed. Select appropriate scales for the "strip chart recorder".

g) Start applying the load.

h) As soon as sample gets fractured, note down the total extension from the chart. Immediately after fracture there will be a large elastic recovery.

i) Carefully, measure final gauge length after fracture.

j) Measure cross sectional dimensions of the specimen after fracture.

k) Use excel to convert collected data (load in Newton and extension in mm) to engineering strain (e) and engineering stress (S), and then to true stress and true strain.

6. Data reporting and Analysis

a) Report the following in the given format with units.

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

b) Report the following in the given format (attach excel sheet) with units

Serial #	$(L-L_0)*10^3$	Load (Newton)	e	s	ε	σ
1						
2						

c) Report the following in sequence as shown below (with units)

E	
s_0	
e_0	
s_u	
e_f	
K	
n	
ε_0	
U_R	
U_T	

d) Report % of elongation at fracture, % of reduction in area at fracture

e) Calculate and report the yield stress (2% proof stress). Compute the value of Young's modulus and compare it with the standard value.

f) Calculate and report the elastic recovery part of the strain.

g) Calculate the Poison's ratio.

h) Plot true and engineering stress strain curves in excel. Also, plot log-log graph to determine determining K, n and ε_o. For determining ε_o, change its value starting from 0 such that you obtain straight line.

i) Report the difference between engineering stress/strain and true stress/strain plots. Explain the reason of the difference.

7. General Questions

1. Why do we use dogbone sample to test?
2. In Fig. 2, why is engineering stress continuously decreasing in the region 'UF'?
3. What is strain hardening in metals? Show the region where strain hardening is happening in Fig. 2.
4. What would be the change in the curve in Fig. 2 if it was plotted in terms of true stress and true strain?
5. In Fig. 3, describe the mechanisms of region 'CD' and 'DE'.
6. Which properties you think are sensitive to strain rate?

7. Which properties are engineered for a) S pring b) Metal working c) machine component subjected to constant load?
8. Although Young's modulus of elasticity for glass is more than steel, steel is preferred for designing engineering components. Why?

Experiment 2

1. **Title:** Stain aging and yield point phenomenon

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

3. **Requirements of the experiment**

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

4. **Introduction**

4.1. Brief description of the equipment/machine: Universal testing machine used for this experiment is Hounsfield extensometer, model H 20 KW of 20 K-N capacity, shown in Fig. 1. The specimen is held at ends by means of grips attached to the crossheads. One of the crossheads is fixed while other moves by means of an electric motor. The equipment has a provision to simultaneously measure the applied load and extension.

Fig. 1: *UTM in Materials Testing Lab*

4.2. Specimen geometry: Round tensile specimen, as shown in Fig. 2, is used to study strain aging behavior. This is according to ASTM A-370, where gauge length to diameter ratio is 4:1. The terminologies of the parameters shown in Fig. 2 and the values used in this experiment are as follows:

Gauge length (G) = 16 mm, *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.

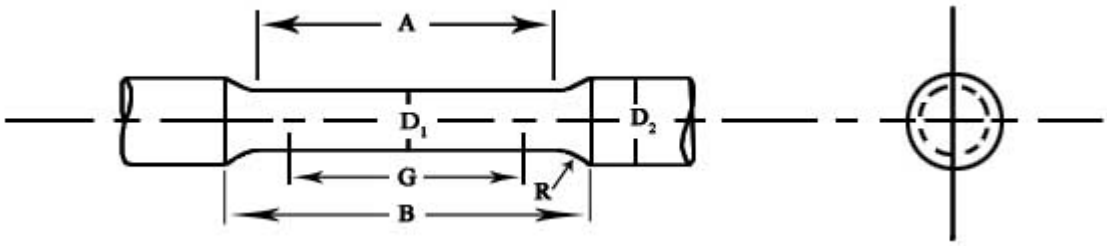


Fig. 2: *Tensile specimen according to ASTM A-370*

4.3. Yield point phenomenon: Some steels and other materials exhibit the tensile stress-strain behavior as shown in Figure 3. The elastic-plastic transition is very well defined and occurs abruptly in what is termed a *yield point phenomenon*. The normal elastic extension (region OA) is terminated at a stress level known as the upper yield point (σ_u). Plastic deformation is initiated at Point 'A' with an actual decrease in stress. Continued deformation fluctuates slightly about some constant stress value (region BC), termed the lower yield point (σ_L). Deformation at this stage is not homogeneous: the specimen is divided into regions, known as Lüders bands (shown in Fig. 4), where the strain has the value ε_L (shown in Fig. 3), and other regions which are not yet deformed with zero strain. The upper yield stress may be regarded as a nucleation stress, and the lower yield stress as the growth stress, of the Lüders bands themselves. Thus, at the lower yield stress, deformation proceeds by the growth of Lüders bands, which spread along the specimen, until at the point 'C' the entire surface of the test specimen is covered, and all areas of the test length have been strained by an amount ε_L. Beyond this point, from C to the ultimate tensile stress at M, deformation is essentially homogeneous and thereafter necking develops, leading to normal ductile fracture at F.

(write down mechanism)

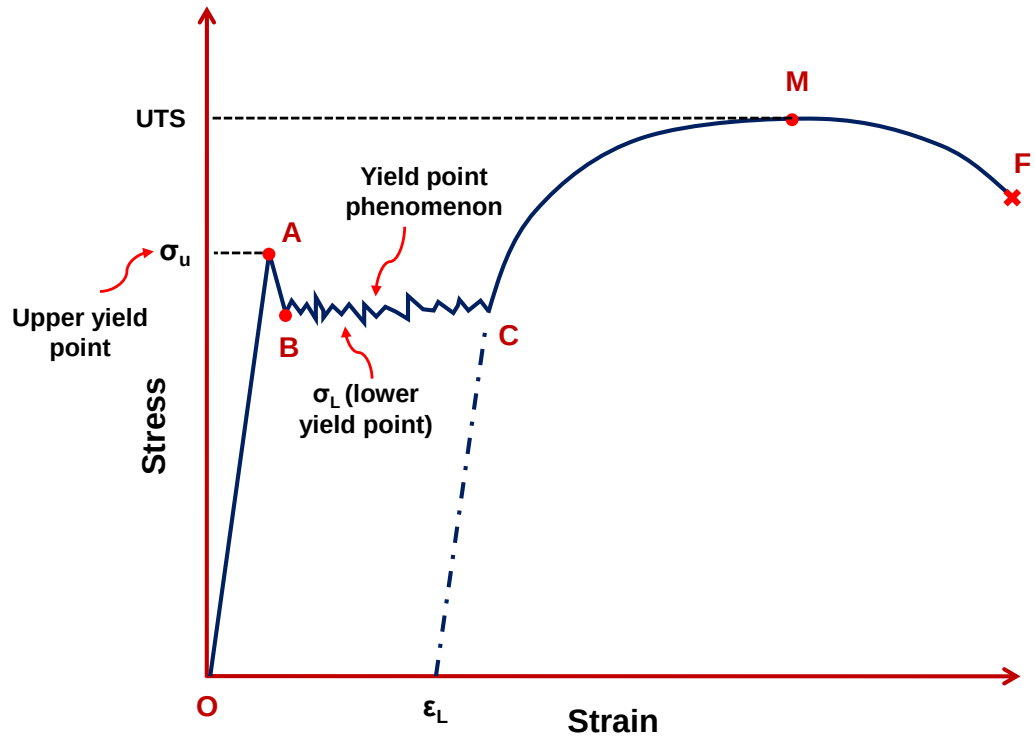


Fig. 3: *Schematic stress-strain curve of a mild steel showing the yield point phenomenon*

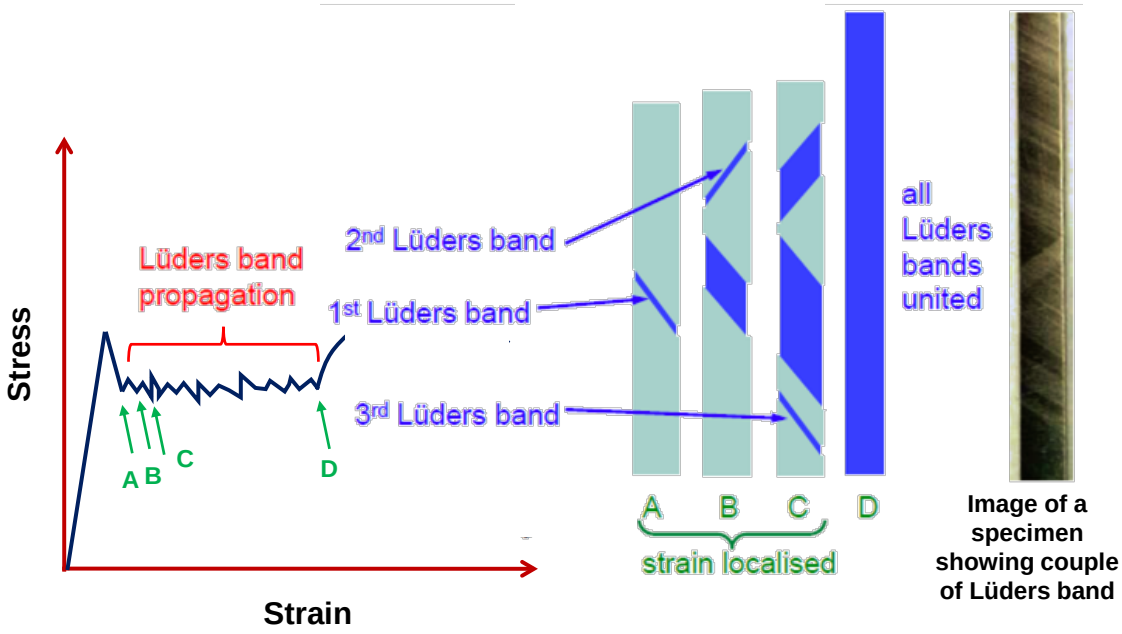


Fig. 4: *Propagation of Lüders band in a tensile sample*

4.4. Strain aging: 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. 4 shows the effect of strain aging on the flow curve for a low-carbon steel.

The low-carbon steel shows yield point phenomenon when load is applied (region A). Straining the specimen to point X, then unloading and retesting without appreciable delay or any heat treatment does not show any yield point phenomenon (region B) since dislocations have been torn away from the atmosphere of carbon and nitrogen atoms and there is not sufficient driving force (time/temperature) for them to pin again. 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, the yield point will reappear and will be now higher than the initial yield point (region C). 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.

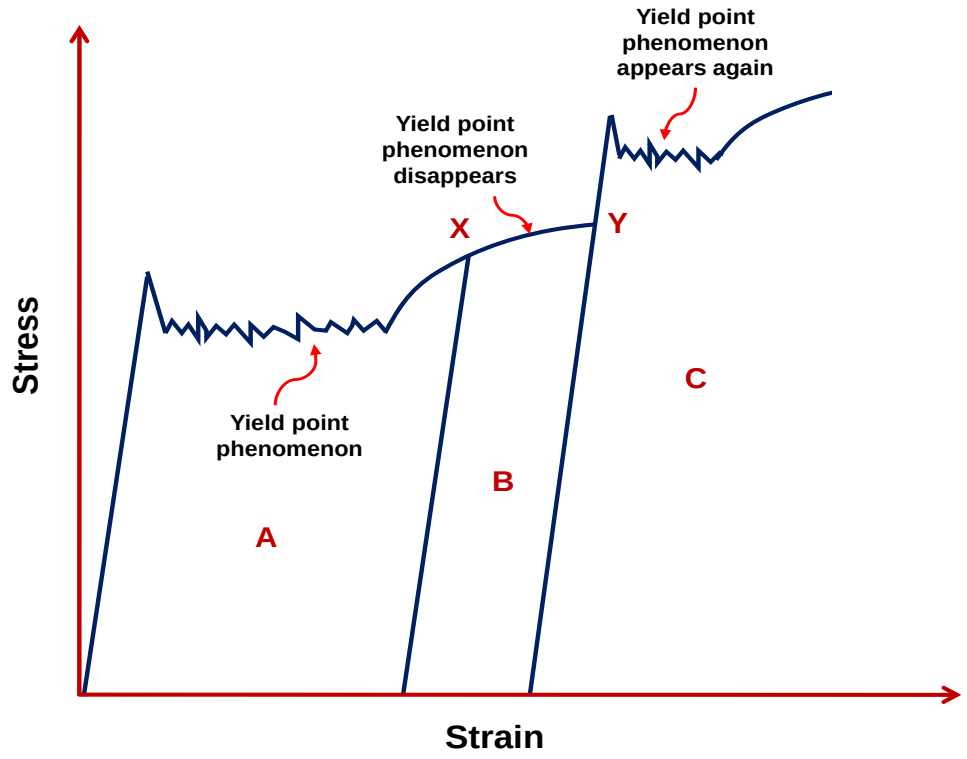


Fig. 2: *Stress-strain curves for low-carbon steel showing strain aging behavior.* ***Region A:*** *showing conventional yield point phenomenon when strained initially.* ***Region B:*** *unloaded after straining till point X and immediately retesting.* ***Region C:*** *reappearance and increase in yield point due to aging.*

5. Experimental procedure

a) Turn on the computer, turn on UTM, open software to collect data
b) Fix one end of the specimen with grip attached to the fixed crosshead and fix other end of the specimen by adjusting the movable cross-head.

c) Apply a little force (within 20 N) to make sure of proper fixing of specimen
d) Make zero force and zero extension by click corresponding button on the machine.
e) Click Test button then extension button.
f) Carry out the test to a load value just above the yield point behavior. Stop the experiment and give print command.
g) Collect data in software by exporting to excel.
h) Again bring the sample to zero load. Repeat the steps (f)-(h)
i) Remove this sample and keep it in water (approx. at 100^{o}C) for 30 mins.
j) Repeat steps (b) -(h)

6. Experimental data reporting and analysis

a) Report the experimental plots of stress vs strain for the loaded and reloaded (without delay) condition after combining the two sets of data. Report upper yield point, lower yield point, and yield point elongation.

b) Report the experimental plots of stress vs strain for the loaded and reloaded (with aging treatment) condition after combining the two sets of data. Report obtained values of upper and lower yield points before and after aging.

7. 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. Why will carbon and nitrogen atoms will segregate near dislocations?
4. What is the effect of temperature on the yield point phenomenon (*Portevin-LeChaterlier* effect)?
5. Why yield point phenomenon is detrimental in metal forming? How can yield point phenomenon be reduced?
6. What is Cottrell atmosphere? What is stretcher strains?
7. Why will carbon and nitrogen atoms will segregate near dislocations?

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

a) V-notched specimen
b) Swing pendulum Impact Testing Machine
c) Liquid nitrogen
d) Optical pyrometer
e) Temperature controller heater
f) Water
g) Stopwatch

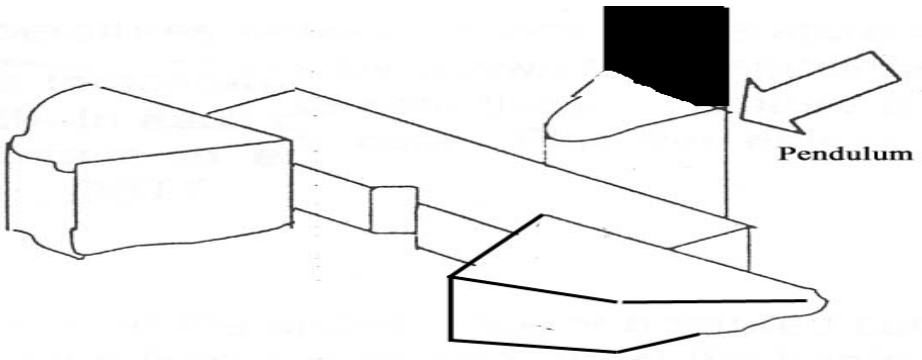
Brief Description of the Equipment/Machine

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.

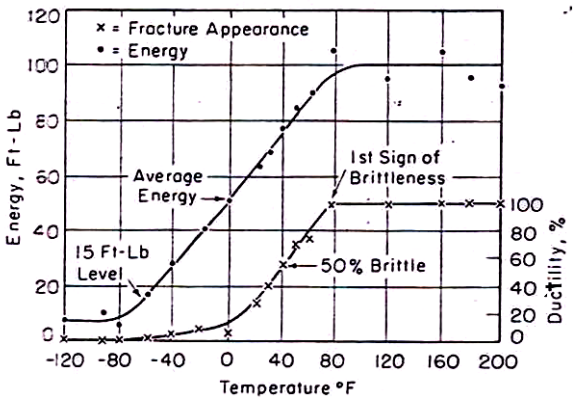
Theory

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.

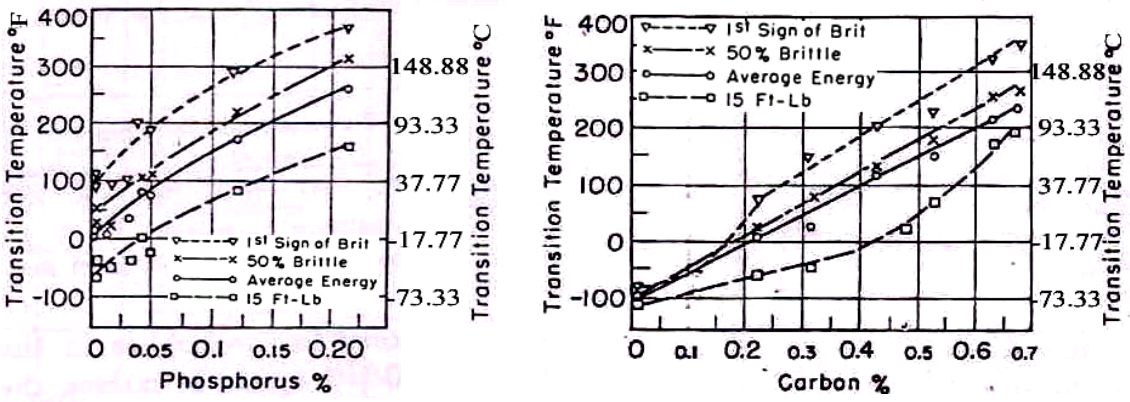
Impact testing machine



Schematic diagram of impact testing



Typical curve showing different transition temperature on steel



(a) (b)

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_σ (energy absorbed in fracturing the material) is given by

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

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 :

a) 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.

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

c) 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.

d) 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.

e) 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.

f) 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.

g) 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

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

a) Comment on the fracture surface of the specimen

b) 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 Aluminum at temperature 200^{o}C .

Requirements: Al 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.

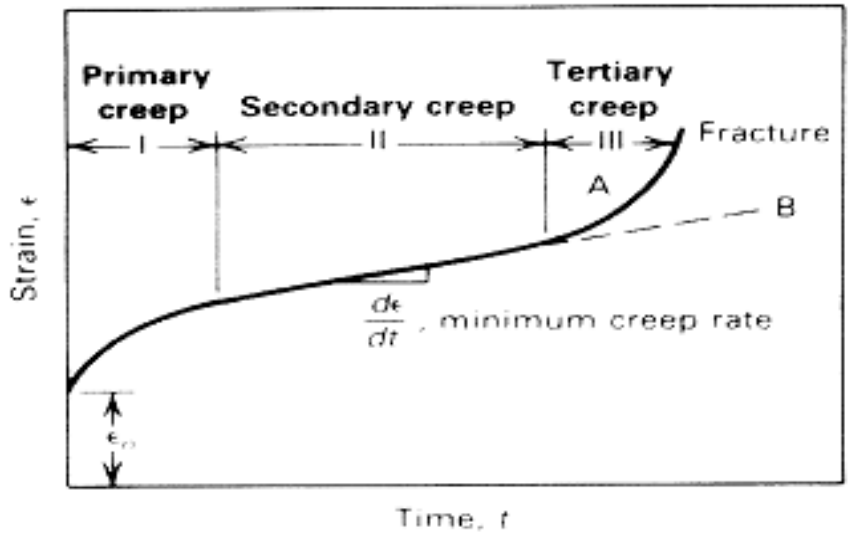


Fig. 1 Schematic illustration of Creep-curve shapes

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.

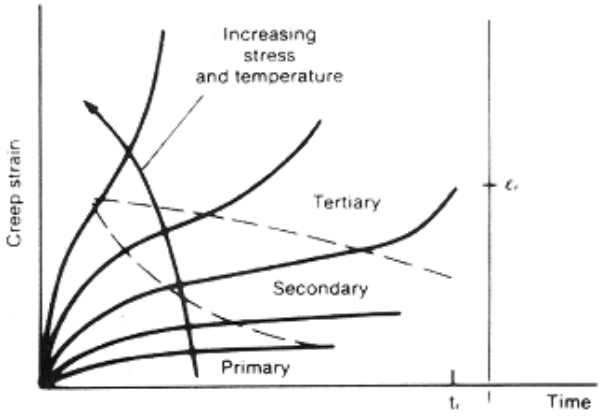


Fig 2 Creep curves obtained at different temperatures and/or stress

Equipment:

Fig. 3 Schematic of the Creep testing Machine

Important Parameter and Equation:

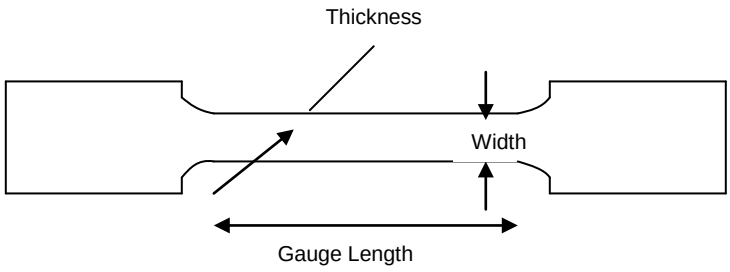


Fig. 4 Lead Sample

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. . Put the specified load on load pan

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

a) Specimen with the correct design
b) Vernier calipers
c) Dead weight as load
d) 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)]

Fatigue Testing Ma

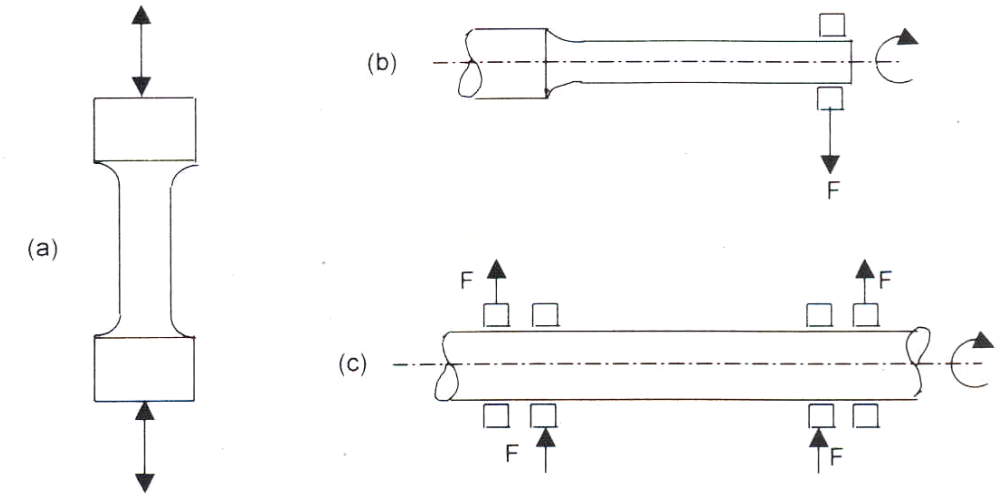


Fig.2 Loading schemes for laboratory scale fatigue testing: (a) Axial loading of the specimen, (b) single-end rotating cantilever testing machine and (c) Four-point rotating cantilever testing machine

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.

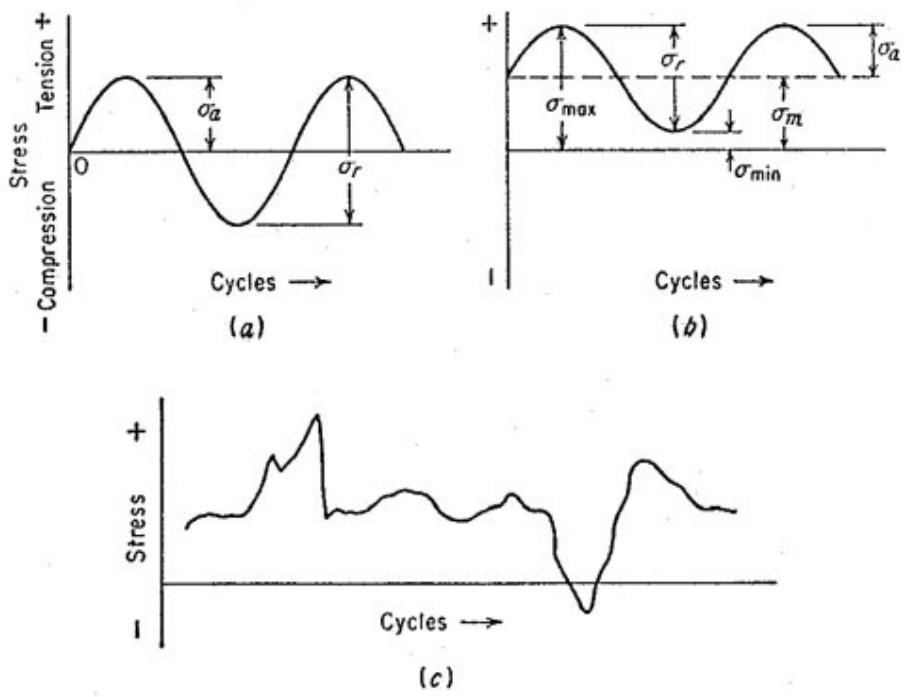


Fig 3. Typical fatigue stress cycles. (a) Reversed stress; (b) repeated stress; (c) irregular or random stress cycle

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.

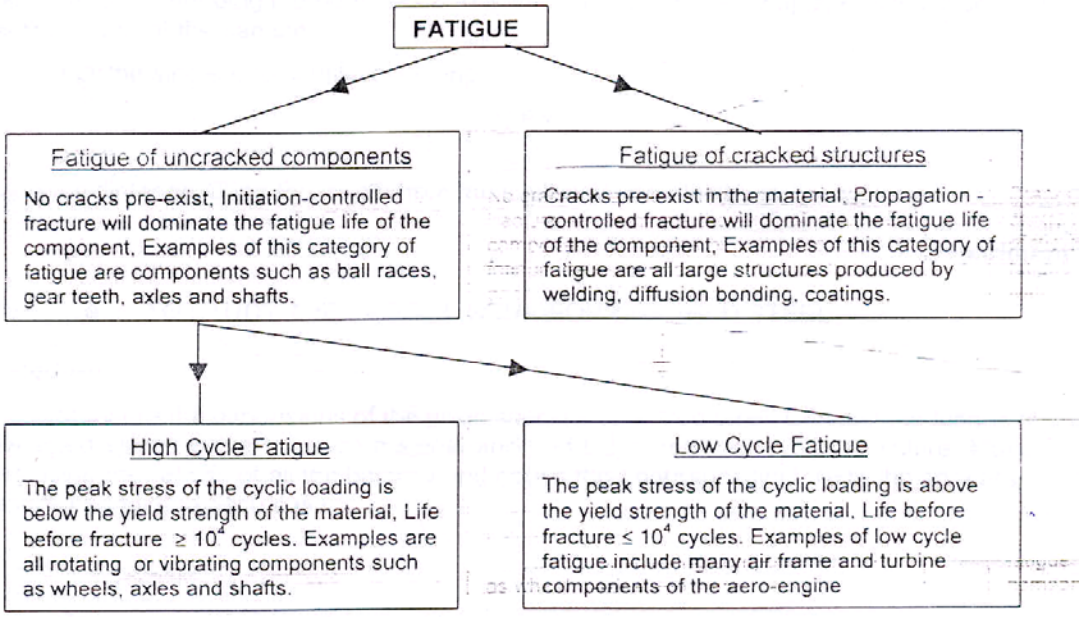


Fig5. Some of the important characteristics of fatigue

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

a) Calculate the peak stress from the formula mentioned above.
b) From the time taken for fatigue failure, calculate the number of cycles to failure [N = RPM x time for failure(min)].
c) Report the value of σ_a and N.
d) Report the appearance of the fractured surface.
e) 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.

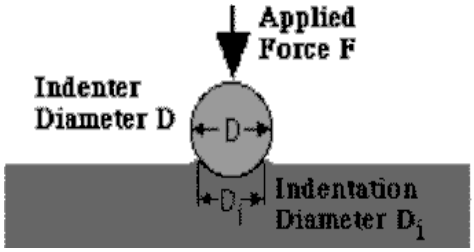
Experiment 6

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 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.

Brinell Hardness Tester.

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

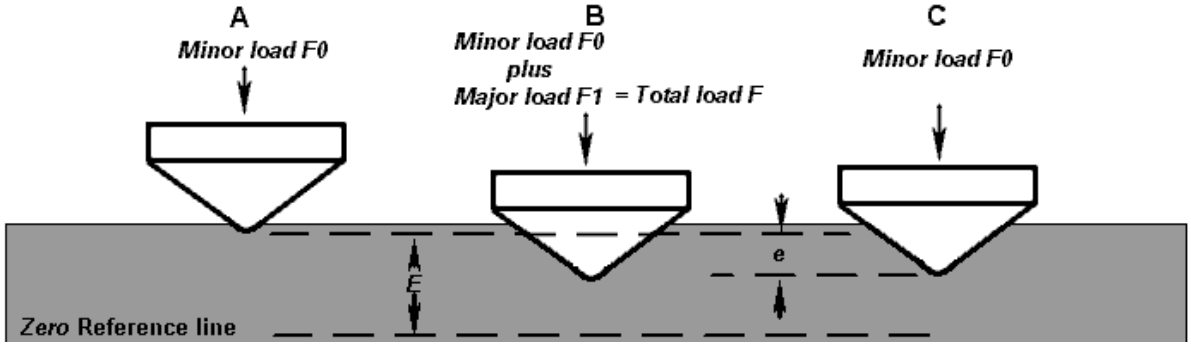


Fig. 1.Rockwell Principle

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 Hardness Tester.

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.

$$\mathbf{HR} = \boldsymbol{E} - \boldsymbol{e}$$

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

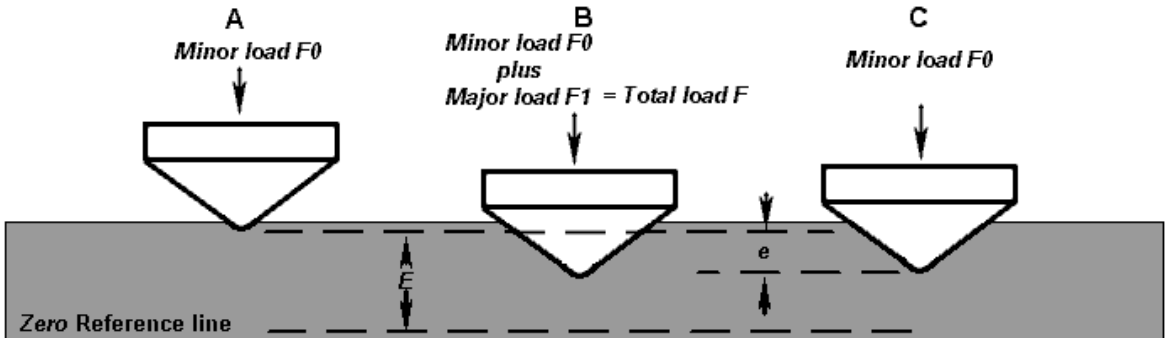


Fig. 2.Rockwell Superficial Principle

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 7

Effect of work hardening on the tensile properties of metals

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

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

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

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

Experimental Setup

Instron universal testing machine.

Requirements for the experiment

a) Tensile specimen
b) Universal Testing Machine (UTM)
c) Vernier caliper
d) Cold rolled Al 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 (□) and True Strain (□) :* □ = ln(1+e)

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

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):*
□t = K□tn , Where □t = true stress, □t= true strain,
n = strain hardening co-efficient

Experimental Procedure

Measure L_0, A_0.

1. Open the bluehill software of Instron UTM from the shortcut icon in the desktop.
2. If the method for performing tensile test is already prepared, then go directly to test.
3. Select your appropriate method.
4. Prepare a folder where the data will be stored.
5. Then input the sample dimensions viz. width, thickness for a rectangular sample or diameter for a cylindrical sample. Then click next.
6. Before starting the test, ensure that balance load and elongation are both zero. This can be achieved by clicking on the icons ' Balance load' and 'Zero extension' at the top.
7. Then click on the start button to perform the test.
8. After the test gets over, ensure that sample is first removed before pressing "OK" at the screen.
9. After the sample is removed, click 'OK' and then click 'Save'.
10. After saving your data, click 'finish'.
11. If further tests are required then press 'yes' and continue from step 4.
12. After performing all the tests, click 'No' and 'exit' to close the software.
13. Shutdown the computer and ensure that everything is in order before leaving the place.

Experimental data collection and presentation

a Report % of elongation at fracture, % of reduction in area at fracture and strain rate.
b) Submit true stress true strain curve along with the report by considering points up to UTS in engineering stress strain curve.
c) 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) Mechanical properties have been determined.

b)
c)

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) Sometimes plastic deformation occurs without slip. Suggests mechanisms of plastic deformation without slip in the following two cases.