

## CHAPTER 3 - MECHANICAL PROPERTIES

Mechanical properties are the characteristic responses of a material to applied stresses. Selection of mechanical tests for a particular application is based primarily on experience that many lots of a particular grade of material having properties falling within a certain range have performed satisfactorily in service. It can then be anticipated that new lots of this same material having the same mechanical properties will also perform satisfactorily in the same application.

### 3.1 Definitions

1. Strength - ability of a material to resist applied forces.
2. Ductility - ability of a material to undergo permanent shape change (plastic deformation) without rupturing.
3. Toughness - ability of a material to absorb energy.
4. Tension test - simultaneously measures strength and ductility. There are several types of tensile machines and test specimens.
5. Modulus of elasticity (Young's modulus) - the proportionality constant between stress and strain - the slope of a plot of stress vs. strain within the elastic range - 30M psi for steel.
6. Yield Strength - 0.2% offset is normally specified for a tensile test since it is too difficult to accurately measure the elastic limit. Speed of loading affects yield strength but not tensile strength.
7. Yield point - the stress in a material at which a marked increase in strain occurs without an increase in stress.
8. % elongation in 1" or 2" is usually determined by fitting the fractured specimen back together and measuring the distance between scribe marks - % elongation increases with shorter gage lengths.
9. % reduction of area (RA) is the ratio of the minimum cross-section of a tensile specimen after fracture to its original cross-section.
10. Shear stress is approximately half of the ultimate tensile strength for steel.
11. Hardness - resistance to deformation or penetration by a much harder indenter.

### 3.2 Mechanical Property Testing

The tests most commonly used in evaluating the quality of metal products include the tension, hardness, notched-bar impact, creep, and fatigue tests. Other types of tests (e.g. bend, cupping,  $K_{IC}$ , etc.) may be used depending on the particular product or its intended application.

One of the primary purposes, in making mechanical property tests of metal products, is to determine conformance or non-conformance with specifications. The data may thus serve as an index to the quality of a product in comparison with similar products obtained previously. Since variations in the methods used in preparing test specimens may have a significant effect on the test data, it is essential that careful and uniform procedures be followed in machining and

### 3.2.1 Hardness Tests

(From R.A. Flinn and P.K. Trojan, Engineering Materials and Their Applications, 2nd Ed., Houghton Mifflin Co., 1981, p. 79-82).

Hardness is usually defined as resistance to penetration. Let us review a few of the most common tests (see Figure 3.1) and see how closely they fit this definition.

Test	Indenter	Shape of Indentation		Load	Formula for Hardness Number
		Side View	Top View		
Brinell	10-mm sphere of steel or tungsten carbide			P	$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$
Vickers	Diamond pyramid			P	$VHN = 1.72 P/d_1^2$
Knoop microhardness	Diamond pyramid			P	$KHN = 14.2 P/l^2$
Rockwell					
A) } C) } D) }	Diamond cone			60 kg	$R_A =$
				150 kg	$R_C =$
				100 kg	$R_D =$
} 100 - 500t					
B) } F) } G) }	1/16-in.-diameter steel sphere			100 kg	$R_B =$
				60 kg	$R_F =$
				150 kg	$R_G =$
} 130 - 500t					
E	1/2-in.-diameter steel sphere			100 kg	$R_E =$

FIGURE 3.1: Hardness Testing Methods

#### 3.2.1.1 Brinell Hardness Number (BHN)

This is one of the oldest hardness tests but is still the most common standard. In this test method, a specimen with a flat upper surface is placed on an anvil. A steel or tungsten carbide ball is pressed into the sample with a load of either 500 or 3,000 kg. The lighter load is used for the softer nonferrous metals such as copper and aluminum alloys, and the heavier load is used for cast iron, steel, and other hard alloys. The load is left in place for 15 sec. for steels or 30 sec. for softer materials, and then removed. The diameter of the impression in millimeters is then read with a low-power microscope with a Filar (measuring) eyepiece. Next the observer reads the Brinell hardness number (BHN) that corresponds to the impression's diameter from a table of values for the load used. The more difficult the penetration,

### 3.2.1.2 Vickers Hardness Number (VHN) or Diamond Pyramid Hardness (DPH)

This is an improvement on the Brinell test. Here, a diamond pyramid indenter is pressed into the sample under loads much lighter than those used in the Brinell test. The diagonals of the square impression are read, and averaged, and the Vickers hardness number (VHN) is read from a chart for the specific load. As shown in Fig. 3.2, the VHN is close to the BHN from 250 to 600. The figure does not show that the VHN climbs steadily with hardness at higher values, whereas the BHN is not used above 600. The advantages of the Vickers test are in greater accuracy, capability of obtaining hardness measurements at high levels, and in measuring the hardness of a small region. On the other hand, the BHN gives a better averaging effect because of the larger impression.

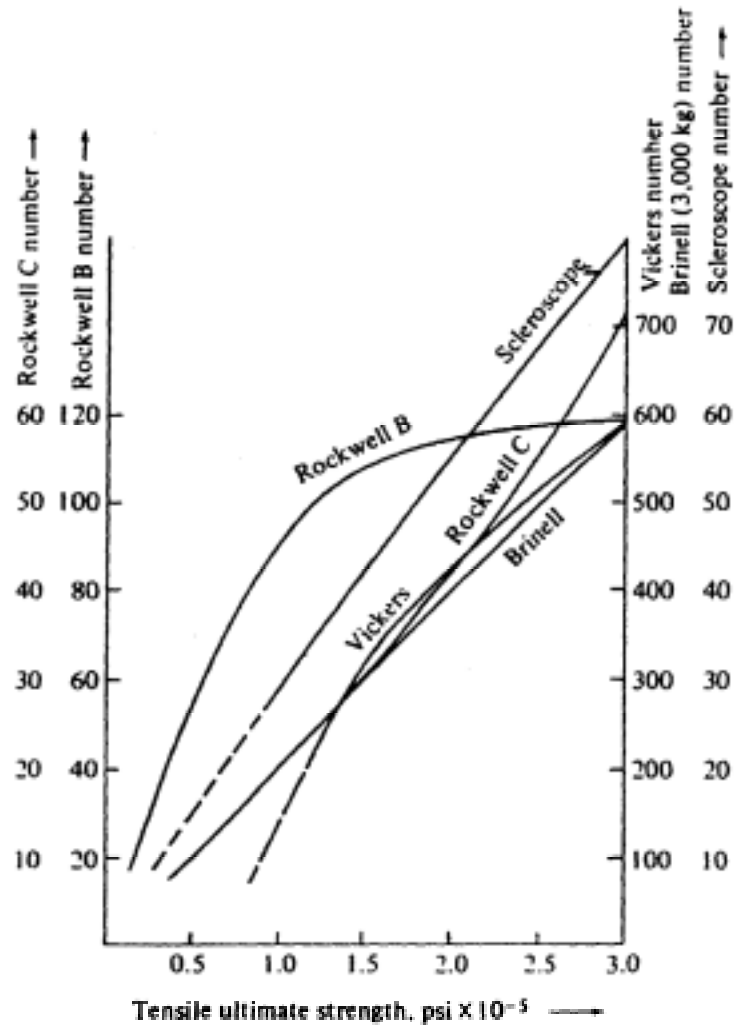


FIGURE 3.2: Conversion values for Brinell, Vickers, and Rockwell Tests

### **3.2.1.3 Rockwell Hardness Testing ( $R_A$ , $R_B$ etc.)**

The chief advantage of the Rockwell test is that the hardness is read directly from a dial. The indenter for the  $R_C$  test is a suitably supported diamond cone or "Brale". The observer first turns a handle which presses the diamond cone a slight standard amount into the sample. This is called the "preload". Next the standard  $R_C$  load of 150 kg is released. This forces the diamond farther into the sample. The same lever is used to remove the load. At this point the observer reads the  $R_C$  hardness from the dial and then unloads the specimen. The principle of this test is that the dial, through a lever system, records the depth of penetration between the preload and the 150-kg load and reads directly in  $R_C$ . The  $R_C$  is approximately 1/10 BHN. The  $R_B$  scale is used for softer materials. It employs a 1/16 -in. diameter ball and a 100 kg load. It is also direct reading. The  $R_A$  scale is similar to  $R_C$  except a 60 Kg load is employed; likewise, the  $R_F$  scale is similar to  $R_B$  except a 60 Kg load is used. There are also Rockwell Superficial tests utilizing 15, 30, or 45 Kg loads and either a diamond (N scales) or a 1/16" steel ball (T scales) as the indenter.

### **3.2.2 Tension Tests (by M. Stevens)**

The tension test is the most common characterization method used for determining design information on the strength and ductility of metals as well as for acceptance determinations in quality assurance applications. In a tension (or tensile) test, a specimen is subjected to a continually increasing uniaxial tension force while simultaneous observations are made of the elongation of the specimen. This is physically accomplished by mounting a machined specimen of the material of interest into mechanical "grips" which are attached to a load frame. One of these grips is mounted to a moving crosshead which is operated by two vertical lead screws which are rotated in a suitable direction by a servo-motor. Electronic instrumentation provides control signals to the servo-motor in order to control crosshead speed, direction of test, etc.... An additional feature included in the load train is a highly sensitive electronic load weighing system with load cells that use strain gages for detecting tensile or compressive load on the specimen. Similar strain gages are used on extensometers which may be attached to the specimen during testing in order to accurately measure elongation (strain). The load, or stress, on the specimen is subsequently plotted as a function of elongation or strain to constitute a stress-strain curve.

The shape and magnitude of the stress-strain curve of a metal will depend on its composition, prior thermomechanical processing, strain rate, temperature and state of stress. The important parameters which can be deduced from a stress-strain curve include the yield strength, tensile strength, and percent elongation. These are indicated on the representative stress-strain curve shown in Figure 3.3.

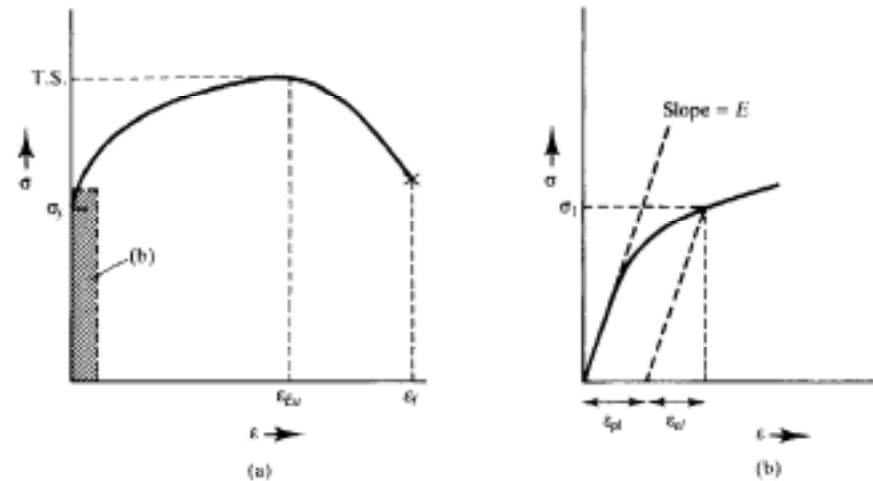


Figure 1.6

A schematic tensile stress-strain curve. (a) Following linear elastic deformation, plastic flow commences at a stress approximately equal to the yield strength,  $\sigma_y$ . Following yielding, the material work hardens; the stress required to continue deformation increases with increasing strain. The maximum engineering stress a material can withstand in a tensile test is the tensile strength, T.S. The strain at T.S. ( $= \epsilon_{Tu}$ ) represents the maximum strain for which plastic deformation is uniform along the sample length. For strains greater than this, stress decreases; the phenomenon is associated with nonuniform material deformation (necking). Fracture, denoted by X, takes place at the engineering strain,  $\epsilon_f$ . (b) An expanded view of the low-strain (shaded) region of (a). Plastic flow initiates at a stress less than  $\sigma_y$ . At  $\sigma_y$ , the total strain is the sum of the elastic ( $\epsilon_{el}$ ) and plastic ( $\epsilon_{pl}$ ) components;  $\epsilon_{el}$  is given by  $\sigma_y/E$ . It can be found graphically by subtracting from the total strain the strain not recovered; the latter is obtained by drawing a line of slope  $E$  downward from  $\sigma_y$ . The plastic, or permanent strain is represented by the intersection of the unloading line with the strain axis. The 0.2% yield strength can be obtained by offsetting a strain of 0.002 on the strain axis, and drawing a line parallel to the initial loading line. The intersection of this line with the stress-strain curve defines the stress required to cause a permanent strain of 0.002.

FIGURE 3.3: Stress-strain curve, after Courtney

The initial part of the curve represents the elastic regime of the material. If the load is released, the strain of the specimen will return to zero and no permanent deformation occurs. The slope of this part of the curve is called Young's modulus or Modulus of Elasticity.

Further imposed strain results in a bending over in the curve and this denotes the onset of permanent plastic deformation. The yield strength is a measure of the stress required for permanent plastic flow. The usual definition of this property is the offset yield strength determined by the stress corresponding to the intersection of the curve and a

only slightly affected by the shape of the tensile test specimen. As long as the ratio of the width to thickness does not exceed about 5:1, for a rectangular cross-section, the percent reduction of area remains the same as for circular cross-sections.

*Elongation* to fracture is usually measured by fitting the broken specimen back together and measuring the distance between punch or scribe marks. Elongation may also be taken from an autographic record of the load-extension diagram; the two do not necessarily agree. Elongation is so much affected by the gage length over which it is measured that the gage length must always be specified when reporting data.

Variations in ductility from specimen to specimen, and from point to point and with direction in the same specimen are often considerable and are almost always greater than variations in the other tensile properties. Tests taken transverse to the direction of greatest elongation in working are generally inferior in ductility, often considerably so.

Some useful definitions:

ENGINEERING STRESS

$$s = P/A_0$$

where

P = Load

A<sub>0</sub> = Original cross-sectional area

ENGINEERING STRAIN

$$E = \frac{L-L_0}{L_0}$$

where

L is instantaneous length and L<sub>0</sub> is original

length of specimen

### 3.2.3 Charpy Impact Testing

The Charpy test is the most widely used evaluation technique for measuring the toughness of materials; it utilizes impact loading conditions. Standard-sized specimens (10 mm sq x 60 mm long) containing a sharp notch (2 mm deep with a .015 mm radius) to localize the stress, are hammer-impacted and the energy absorbed during this fracture process is measured. As the pendulum hammer has a fixed weight and drops the same distance each time (see Figure 3.4) its kinetic energy when it strikes the specimen is always the same. Part of this energy is consumed in breaking the specimen; the energy remaining in the hammer causes the pendulum to continue its upward swing. By measuring the difference in the height of the upward swing after the pendulum has fallen freely and after it has broken the sample, the energy absorbed in breaking the sample may be calculated. This energy is the impact strength of the material and

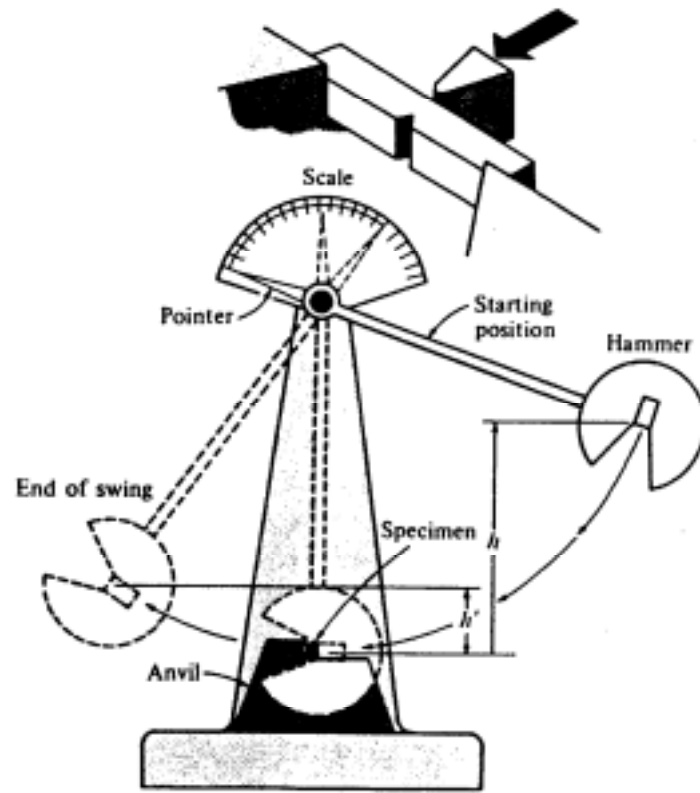


FIGURE 3.4: Operation of a Charpy impact test (from Hayden et al. The Structure and Properties of Materials, Vol. 3 Mechanical Behavior, John Wiley and Sons, 1965)

"The types of data obtained are shown schematically in Figure 3.5. FCC metals show high impact values and no significant change with temperature; however, BCC metals, polymers, and ceramics show a transition temperature below which brittle behavior is found. It should be emphasized that the actual transition temperatures for different materials vary greatly. For metals and polymers it is generally between -200 and 200°F (-129 and 93°C), while for ceramics it is above 1000°F (538°C).\*\*\*\*

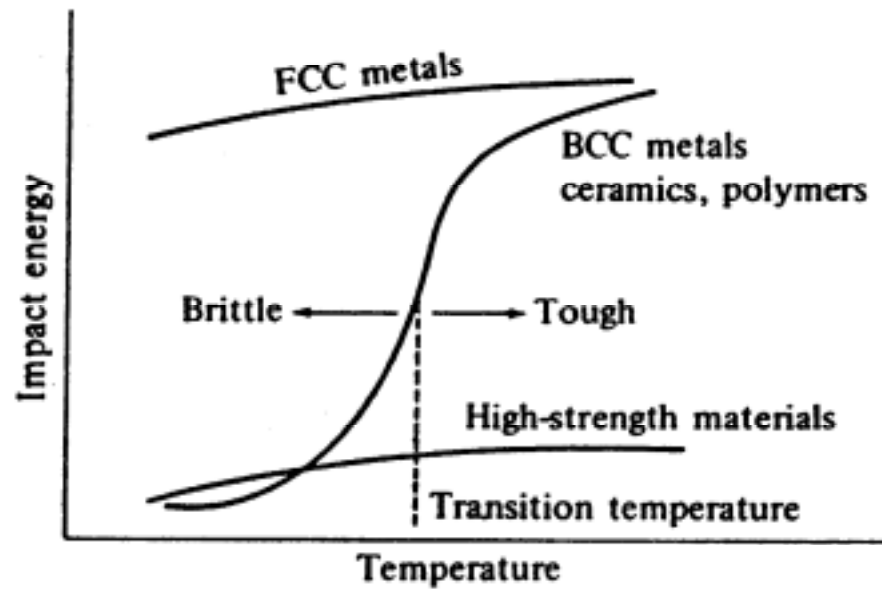


FIGURE 3.5: Effect of temperature on the impact strength of various materials (schematic). From H.W. Hayden, et al., The Structure and Properties of Materials, Vol. 3: Mechanical Behavior, John Wiley & Sons, 1965

"There is a distinct difference in the appearance of the fractures of low-carbon steels, depending on whether the specimen was tested and broken below or above the transition temperature. As indicated in Figure 3.6, the fracture appearance of Charpy V-notch specimens varies from ductile to brittle as the specimen temperature is reduced from 200 to -321°F (92 to -196°C). Careful observation shows that a shear type fracture, as shown by the presence of a shear lip, is characteristic of the specimens tested at higher temperatures, while shear is absent in the specimens tested at the lowest temperatures, i.e., the fracture appearance is 100% cleavage."\*\*\*

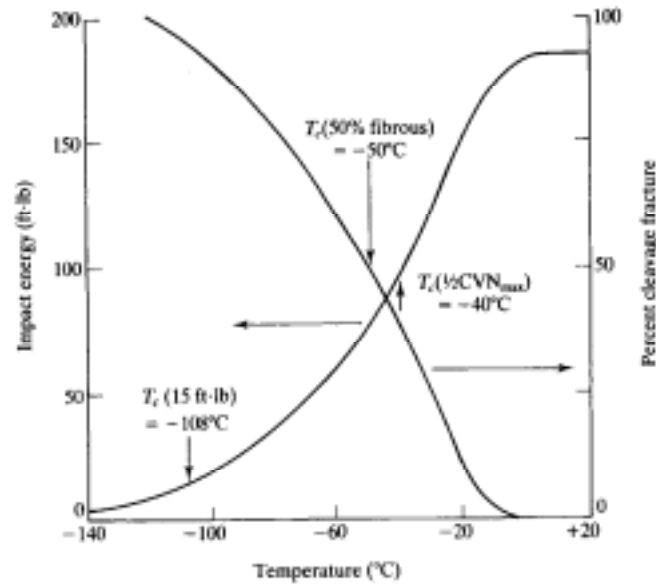


Figure 9.25

Impact energy and percentage cleavage fracture as a function of temperature for a 3.5% Ni, 0.1% C steel. The transition temperature varies, depending on the criterion used to define it. The 15 ft-lb transition temperature is  $-108^{\circ}\text{C}$ , whereas  $T_r$  defined by the half shelf-energy criterion is  $-40^{\circ}\text{C}$ . This temperature is close to that obtained using a 50% fibrous–50% cleavage fracture criterion ( $-50^{\circ}\text{C}$ ). (Adapted from A. S. Tetelman and A. J. McEvily, Jr., *Fracture of Structural Materials*, Wiley, New York, 1967.)

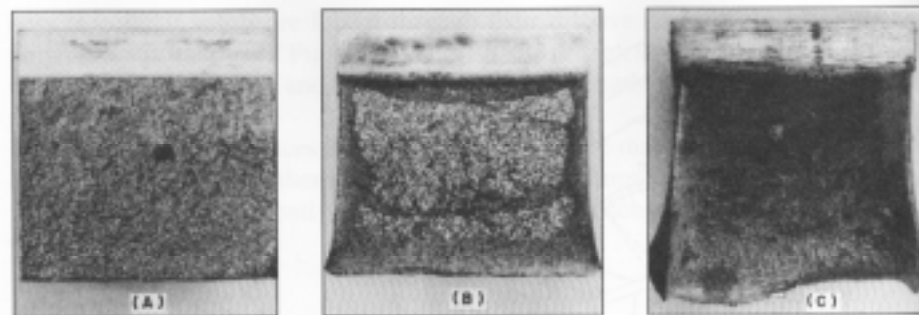


Figure 9.20

The fracture appearances of Charpy impact samples, broken at different test temperatures, of a steel that undergoes a ductile-to-brittle transition. (A) At low temperatures, the fracture surface is flat and shiny, indicative of cleavage fracture. (B) At intermediate temperatures, the interior of the sample still manifests a shiny “crystalline” appearance, but the periphery is dull, indicative of fibrous or ductile frac-

### 3.2.4 Fatigue Testing (Extracted from Introduction to Engineering Materials, V.B. John)

"If a material is subjected to repeated, or cyclic, stressing, it may eventually fail even though the maximum stress in any one stress cycle is considerably less than the fracture stress of the material, as determined by a tensile test. This type of failure is termed *fatigue failure*."

"Very many components are subjected to alternating or fluctuating loading cycles during service, and failure by fatigue is a fairly common occurrence. The mechanism of fatigue in metals has been thoroughly investigated. When a metal is tested to determine its fatigue characteristics, the test conditions usually involve the application of an alternating stress cycle with a mean stress value of zero. The results are plotted in the form of an S-N curve (Figure 3.7), where S is the maximum stress in the cycle, and N is the number of cycles to failure. Most steels show an S-N curve of type (i), with a very definite *fatigue limit*, or *endurance strength*. This means that if the maximum stress in the stress cycles is less than this fatigue limit, fatigue failure should never occur. Many non-ferrous material show S-N curves of type (ii) with no definite fatigue limit with these materials it is only possible to design for a limited life, and a limit of  $10^6$  or  $10^7$  cycles is often used."

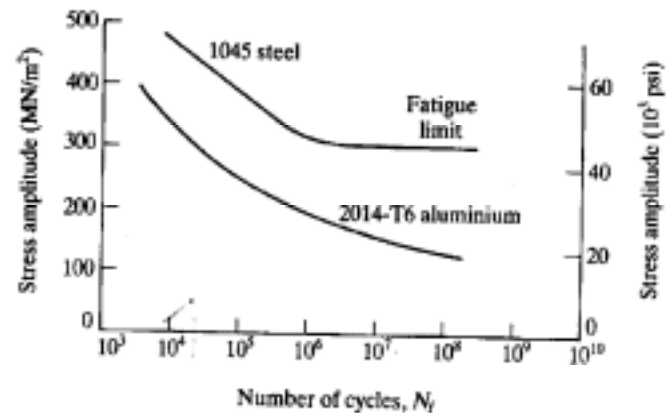


FIGURE 3.7: S-N curves for (i) metal showing fatigue limit (steel),

(ii) metal showing no fatigue limit (aluminium),

Hayden et al., *The Structure & Properties of Matter*.

Although maximum stress under fatigue conditions is nominally below the elastic limit of the material, it has been established that some plastic deformation by slip takes place. During continued cyclic stressing, slip bands appear on

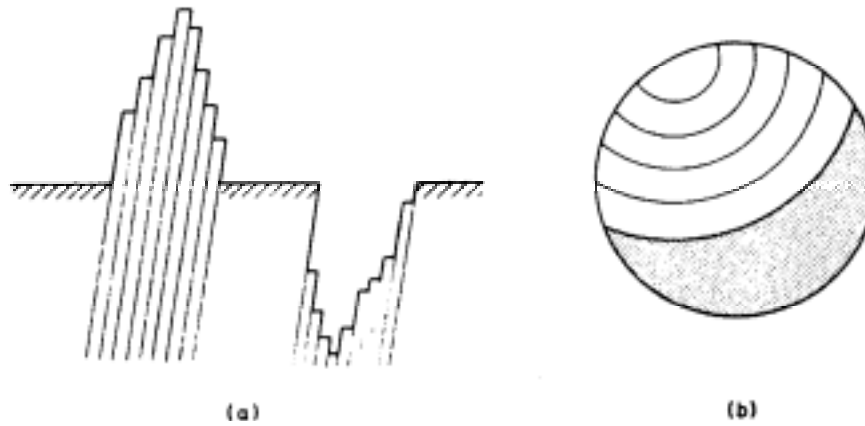


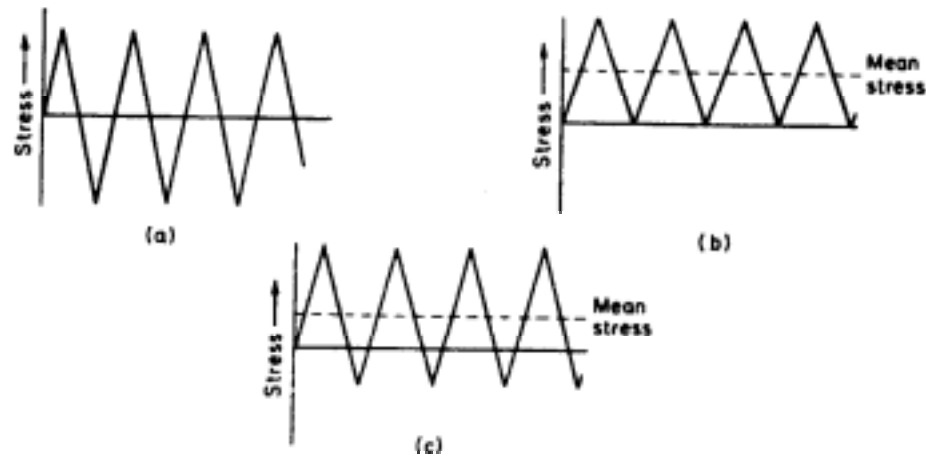
FIGURE 3.8:  
 (a) Intrusion and extrusions formed in early stages of fatigue.  
 (b) Fatigue fracture surface showing both smooth and crystalline (conchoidal) fracture zones.

"A fatigue fracture surface is distinctive in appearance and consists of two portions, a smooth portion, often possessing conchoidal markings showing the growth of the fatigue crack up to the moment of final failure, and the cleavage or shear final fracture zone (Figure 3.8(b))."

"The type of stressing cycle to which a material in service is subjected may be classed as alternating, repeating, or fluctuating. In an alternating stress cycle the value of the mean stress is zero. A repeating stress cycle is one in which the stress varies from zero to some maximum value, and a fluctuating stress cycle is one in which neither the minimum stress nor the mean stress value is zero. There are many factors that affect the fatigue strength of a material; these include surface condition, component design, and the nature of the environment. Specimens for fatigue testing are usually prepared with a highly polished surface, and this condition will give the best fatigue performance. The fatigue limit for highly polished steels is approximately one-half of the tensile strength. If the surface of the specimen contains a scratch or notch, or is ground rather than polished, the fatigue limit of the material will be reduced. The presence of scratches or notches act as small defects from which fatigue cracks can be initiated. Similarly, a sharp change in section with a small fillet radius can act as a stress raiser, and fatigue cracks can commence from such points. Keyways and oil holes in shafts are often points at which fatigue commences. The effect of a notch or scratch is not the same for all materials; a ductile metal is much less sensitive to the presence of surface flaws than is a brittle

"Materials other than metals are also subject to failure by fatigue, but comparatively little work has been done in this area. For concrete and polymers, as with metals, the number of stress cycles necessary for failure is increased as the maximum stress in the loading cycles is decreased, but there does not appear to be a definite fatigue limit with these materials. There are difficulties in the fatigue testing of polymers, because of their low thermal conductivities and high damping capacities. Furthermore, there is an increase in the temperature of a polymer test-piece during a test."

"Fatigue tests are carried out by cycling the material either in tension compression or in rotating bending (Figure 3.9). The stress, in general, varies sinusoidally with time, though modern servo-hydraulic testing machines allow complete control of the wave shape."



Types of stress cyclic: (a) alternating, (b) repeating, (c) fluctuating

FIGURE 3.9: Fatigue testing

### 3.2.5 Creep Testing

(From J.F. Shackelford, Introduction to Materials Science for Engineers, Macmillan, 1985).

The tensile test alone cannot predict the behavior of a structural material used at elevated temperatures. The strain induced in a typical metal bar loaded *below* its yield point at *room temperature* can be calculated from Hooke's law. This strain will not generally change with time under a fixed load (Figure 3.10). Repeating this experiment at a "high" temperature ( $T$  greater than one-third to one-half times the melting point on the Absolute temperature scale) produces dramatically different results. Figure 3.11 shows a typical test design, and Figure 3.12 shows a typical "*creep*" curve in which the strain,  $\epsilon$ , gradually increases with time after the initial elastic loading. *Creep* can be defined as plastic (permanent) deformation occurring at high temperature under constant load over a long time period. After the initial elastic deformation at  $t \approx 0$ , Figure 3.12 shows three stages of creep deformation. The *primary stage* is characterized by a decreasing strain rate. The relatively rapid increase in length induced during this early time period is the direct result of enhanced deformation mechanisms. A specific example is *dislocation climb* as illustrated in Figure 3.13. This enhanced deformation comes from thermally activated atom mobility, giving dislocations additional slip planes in which to move. The *secondary stage* is characterized by straight-line, constant strain-rate data (Fig. 3.12). In this region the increased ease of slip due to high-temperature mobility is balanced by increasing resistance to slip due to the buildup of dislocations and other microstructural barriers. In the *final (tertiary)* stage, strain rate increases due to an increase in true stress resulting from cross-sectional area reduction due to necking or internal cracking. In some cases, fracture occurs in the secondary stage, eliminating this final stage.

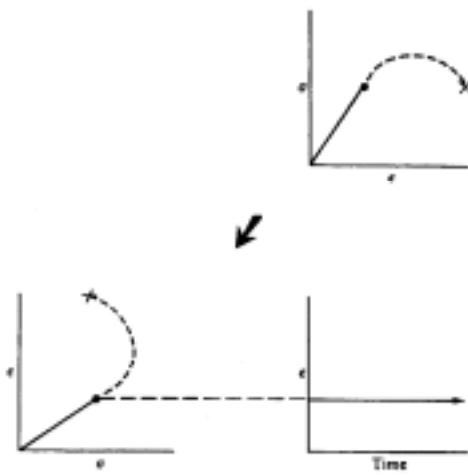


FIGURE 3.10: Elastic strain induced in an alloy at room temperature is independent of time

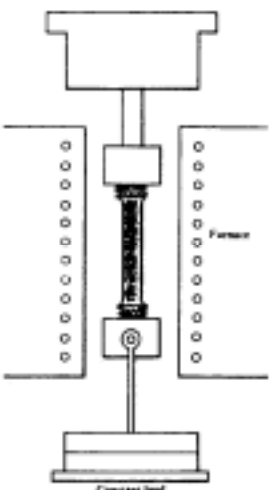


FIGURE 3.11: Typical Creep Test

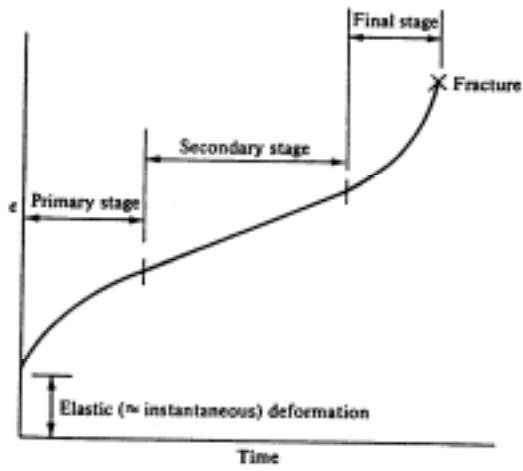


FIGURE 3.12: Creep curve. In contrast to Figure 3.10, plastic strain occurs over time for an alloy stressed at high temperatures (above about one-half the Absolute melting point.)

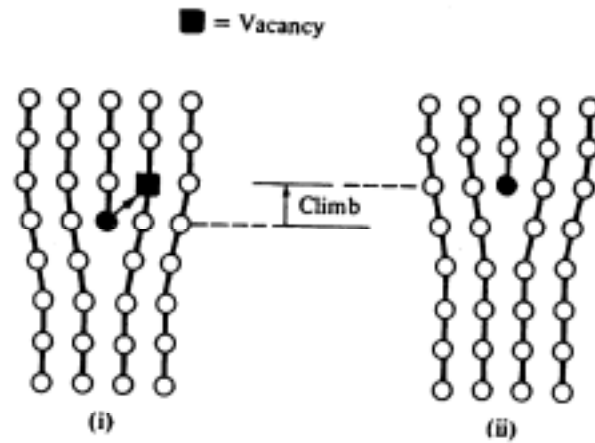


FIGURE 3.13: Mechanism of dislocation climb. Obviously many adjacent atom movements are required to produce climb of an entire dislocation line.

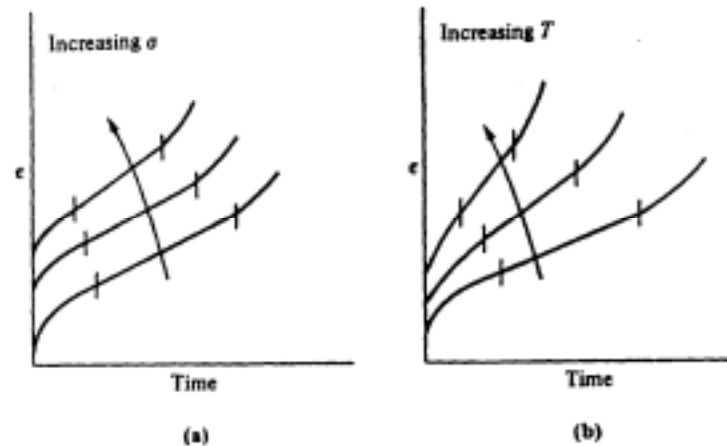


FIGURE 3.14: Variation of the creep curve with (a) stress, or ,  
 (b) temperature. Note how the steady-state creep rate ( $\dot{\epsilon}$ )  
 in the secondary stage rises sharply with temperature

Figure 3.14 shows how the characteristic creep curve varies with changes in applied stress or environmental temperature. The thermally activated nature of creep makes this process another example of Arrhenius behavior. A demonstration of this is an Arrhenius plot of the logarithm of the steady-state creep rate ( $\dot{\epsilon}$ ) from the secondary stage against the inverse of Absolute temperature (Figure 3.15). As with other thermally activated processes, the slope of the Arrhenius plot is important in that it provides an activation energy for the creep mechanism. Another powerful aspect of the Arrhenius behavior is its predictive power. The dashed line in Figure 3.15 shows how high-temperature strain rate data, which can be gathered in short-time laboratory experiments, can be extrapolated to predict long-term creep behavior at lower, service temperatures. This extrapolation is valid as long as the same creep mechanism operates over the entire temperature range. Many elaborate semi-empirical plots have been developed, based on the principle, to guide design engineers in material selection.

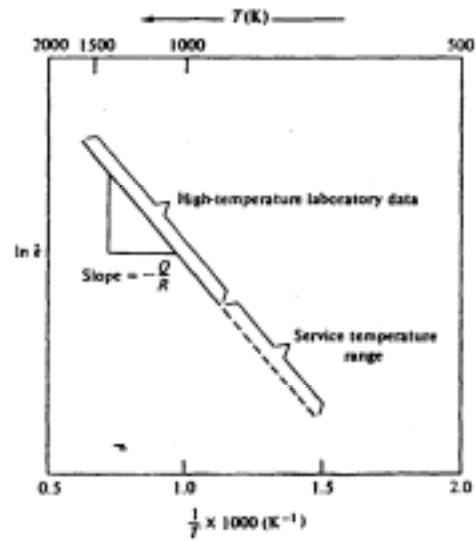
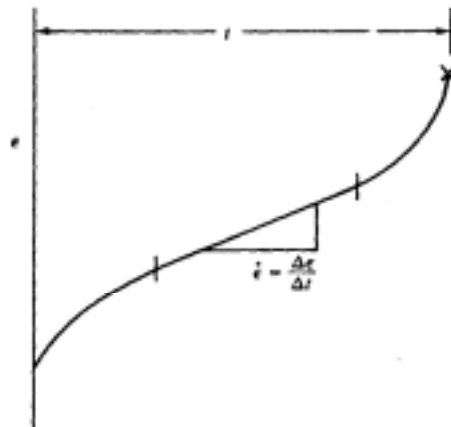


FIGURE 3.15: Arrhenius plot of  $\dot{\epsilon}$  versus  $1/T$ , where  $\dot{\epsilon}$  is the secondary-stage creep rate and  $T$  is the Kelvin temperature. The slope gives the activation energy for the creep mechanism.

A shorthand characterization of creep behavior is given by the secondary stage strain rate ( $\dot{\epsilon}$ ) and the time to creep rupture ( $t$ ) as shown in Figure 3.16.



### **3.3 Experiment 5 - Mechanical Properties**

In this set of experiments, you will learn how to use (i) the Rockwell hardness tester, (ii) a tensile testing machine, (iii) the Charpy V-notch impact tester over a range of temperatures, and (iv) a creep testing machine. Tests will be made on several grades of steel, aluminum alloys, and plastics, and also on a composite material. By this means, the students should gain an appreciation of the techniques and care required to obtain valid measurements of a few material properties and the wide range in properties possible in common structural materials.

Although you will be working in a group of two or three students for each experiment, each student must submit an individual report which encompasses Experiments 1 a, b and c. Raw data sheets may be common, i.e. Xeroxed, to the reports of each member of the group, but graphs and tables of data must be individually prepared. Please record the initials of the individual responsible for each data point.

### 3.3.1 Experiment 5A - Hardness and Tensile Tests

**Objective:** To become familiar with hardness and tensile testing equipment and procedures and to develop an understanding of the range in mechanical properties of various structural materials.

Materials :

Typical Composition

Steels:	C	Mn	Si	Ni	Cr	Mo	Fe
AISI 8620	.18/.23	0.8	0.25	0.5	0.5	0.2	bal
AISI 1045	.43/.50	0.8	-	-	-	-	bal
Aluminum Alloys:	Cu	Mn	Mg	Si	Cr	Zn	Al
2024-T4	4.5	0.6	1.5	-	-	-	bal
7075-T6	1.6	-	2.5	-	0.2	5.6	bal

Plastics:

ABS

Delrin (a type of nylon)

Composite Material:

Fiberglass

#### **Procedure**

1. Measure the Rockwell hardness (3 readings within  $\pm 1$  point) of each material assigned to your group. Each student in the group should test at least two samples.
2. Pull two tensile samples of the steel, aluminum and plastic samples and one of the composite. Determine the yield strength (0.2% offset), ultimate strength, % elongation and % reduction in area for each specimen. Compare your calculated results with those obtained from the computerized Instron Series 9 software. Why aren't they identical? Each student should pull at least one specimen, but no more than one of a given material.

#### **Report**

1. Report all of the hardness and tensile values obtained and the initials of the student responsible for each test.

### 3.3.2 Experiment 5B - Charpy V-Notch Impact Tests

**Objective:** To become familiar with the use of the Charpy V-notch impact test to determine the impact strength and ductile-to-brittle transition temperature of steel.

#### Materials

#### Typical Compositon

	C	Mn	Si	Ni	Cr	MO	Fe
AISI 8620	.18/.23	0.8	0.25	0.5	0.5	0.2	bal
AISI 1045	.43/.50	0.8	--	-	-	-	bal

#### **Procedure**

1. Test two samples at room temperature. Record the ft. lbs. of energy absorbed in breaking each specimen and the percents shear and cleavage fracture observed on each broken specimen.
2. Based on the results of #1, select four other temperatures that would encompass the entire ductile-to-brittle temperature range.
3. Heat or cool two specimens at each of the above temperatures and repeat step #1 for each temperature.
4. Plot the data as shown below and determine the temperature for 50% cleavage fracture (FATT) and 20 ft. lbs of absorbed energy.
5. Incorporate the data in the report for Experiment 5.

### 3.3.3 Experiment 5C - Creep Testing

#### Objective:

To become familiar with the principles of creep testing. For most materials, creep testing is done at elevated temperatures up to 1000°C utilizing a small oven around the specimen during the entire test which may require a week to over a year to run. The same principle can, however, be demonstrated in less than an hour at room temperature for a low melting point material such as a tin-lead solder.

#### Material:

A solder containing 40% tin and 60% lead.

Figure 3.17 shows the Pb-Sn binary phase diagram, which exhibits a eutectic transformation at a composition of 61.9 wt. % Sn and a temperature of 183°C.

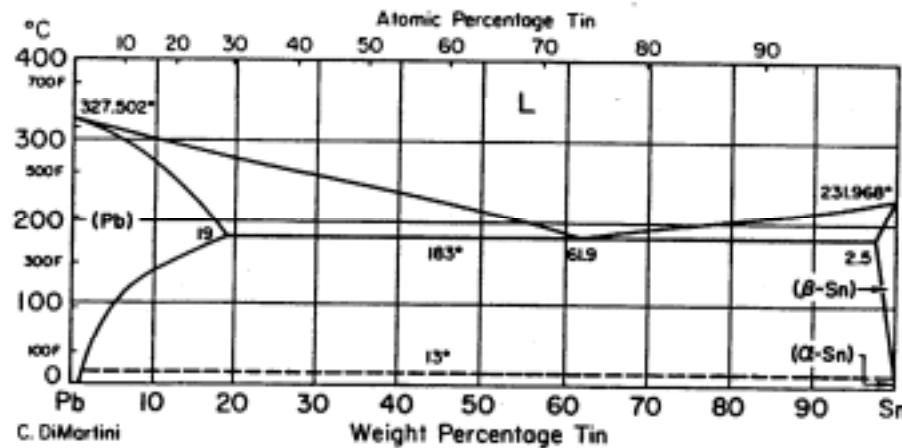


FIGURE 3.17: The Pb-Sn phase diagram

#### Experimental Procedure

By using a Pb-Sn tensile specimen and a creep machine, measure the strain (every 30 seconds for five minutes and then every 60 seconds) at a constant load of 23 lb. Repeat the measurements on a second specimen of the same alloy for a constant load of 20 lb.