In general mechanical tests are carried out at ambient temperature, which is usually room temperature. In those cases which concern applications of materials at higher or lower temperatures, suitable corrections based on experience may be applied to the room temperature test results, or special tests are run simulating the actual conditions under which the material is to be used. It must be realised that new phenomena sometimes appear at temperatures below room temperature, (refer to the Impact Test), or at elevated temperatures (refer to the Creep Test), which cannot be predicted from room temperature tests.

3.3 TENSILE TESTING

Specification

AS1391-1974 Methods for tensile testing of metals

References

These are listed at the beginning of Section 3.2 Mechanical Properties.

Introduction

This is a static test because the uniaxial force is applied over a relatively short time and yet is applied slowly enough so that the speed of testing can be considered to have a practically negligible effect upon the results.

In a simple tensile test the operation is accomplished by gripping opposite ends of the piece of material and pulling it apart. Observations of applied force for appropriate elongation are recorded during the test. Stresses, strains, % elongation, % reduction of area are all computed on the basis of the original dimensions. A stress-strain diagram is then plotted and the information obtained from this diagram allows the comparison of the appropriate mechanical properties of different materials with one another.

Typical tensile testing machines are shown in figures 1(a), 1(b) and 2.

(a) The stress-strain diagram

Stress is the intensity of the internally distributed forces or component of forces that resist a change in the form of a body. It is measured in terms of force per unit area. There are three basic kinds of stress:

- tension
- compression
- shear

\[
\text{Stress} = \frac{\text{force (N)}}{\text{area (mm}^2\text{)}}
\]

Unit: pascal (Pa), or more commonly megapascal (MPa)
indicated in a tensile test by the amount of permanent deformation that is possible until fracture occurs, and can be described by the percentage elongation after fracture and the percentage reduction of area after fracture.

\[
\text{% elongation after fracture (A)} = 100 \left(\frac{L_u - L_o}{L_o}\right)
\]

\(L_u\): final gauge length after fracture  
\(L_o\): original gauge length

\[
\text{% reduction of area (Z)} = 100 \left(\frac{S_o - S_u}{S_u}\right)
\]

\(S_o\): original cross-sectional area within the gauge length  
\(S_u\): minimum cross-sectional area after fracture

- **Stiffness** This is associated with the magnitude of deformation which occurs in a material under applied force. It is the indication of resistance offered to deformation below the elastic limit and is measured by the modulus of elasticity i.e. Young’s modulus, where \(E\) (Young’s modulus) = increment of stress/increment of strain.

  Unit: pascal

- **Toughness** This is the ability of a material to absorb large quantities of energy before fracture occurs. It can be represented by the area under the complete stress-strain curve. Thus the larger is this area then the tougher is the material. This is illustrated in figure 5.

\[E = \frac{\text{increment of stress}}{\text{increment of strain}}\]

Unit: pascal

\[\sigma = \frac{F}{A}\]

\(\sigma\): stress  
\(F\): force  
\(A\): cross-sectional area

\[\epsilon = \frac{\text{increment of strain}}{\text{increment of length}}\]

\(\epsilon\): strain  
\(\Delta L\): increment of length

**Fracture surface**
An examination of the fracture surface of a tensile test piece may give a clue to low values of tensile strength or ductility exhibited by the material.

Typical tensile fractures are shown in figure 7.

**Examples of stress-strain curves**
The stress-strain curves for various steels are shown in figure 6. It should be noted that no matter what is the steel composition and treatment, the modulus of elasticity is a constant value.

**Figure 6** Stress-strain curves for the following steels:  
A. Heat treated Cr/W alloy B. Heat treated Ni alloy C. Heat treated 0.62%C D. Normalised 0.62%C E. Normalised 0.32%C F. Normalised 0.11%C. Note: Modulus of elasticity of all these steels is \(225 \times 10^3\) MPa

**Figure 7** Typical tensile fractures of metals from Davis, Troxell and Wiskoci (1964)
TABLE 2
Hounsfield tensometer variables

<table>
<thead>
<tr>
<th>Sample material</th>
<th>Sample treatment</th>
<th>Code reference (i)</th>
<th>Spring beam (ii) (kN)</th>
<th>Scale (iii) (ii)</th>
<th>Grips</th>
<th>Chart No.</th>
<th>Magnification factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel 0.1% carbon</td>
<td>as drawn</td>
<td>B</td>
<td>10</td>
<td>&quot;</td>
<td>A&amp;B</td>
<td>W402</td>
<td>8:1</td>
</tr>
<tr>
<td>Steel 0.1% carbon</td>
<td>normalised</td>
<td>A</td>
<td></td>
<td>&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel 0.4% carbon</td>
<td>normalised</td>
<td>D</td>
<td></td>
<td>&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70/30 brass</td>
<td>cold drawn</td>
<td>X</td>
<td>20</td>
<td>A220-1</td>
<td>A&amp;B</td>
<td>W402</td>
<td>4:1</td>
</tr>
<tr>
<td>60/40 brass</td>
<td>cold drawn</td>
<td>Q</td>
<td>20</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>16:1</td>
</tr>
<tr>
<td>Aluminium alloy (iii)</td>
<td>solution treated</td>
<td></td>
<td>20</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>16:1</td>
</tr>
<tr>
<td>Naturally aged</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium alloy (iv)</td>
<td>solution treated</td>
<td>U</td>
<td>20</td>
<td>A220-3</td>
<td>Wire</td>
<td>A260-2</td>
<td>4:1</td>
</tr>
<tr>
<td>Tobin bronze</td>
<td>(v)</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes on Table 2 —
(i) The code reference is that used by Tecquipment Ltd., the suppliers of the test pieces.
(ii) Different spring beams are used in this experiment to give experience in changing over the beams. In addition attention is drawn to the fact that different scales are required for different beams.
(iii) Aluminium alloy BS1476-HE15T is equivalent to ADC2014.
(iv) Aluminium alloy BS1476-HE15W is equivalent to ADC2014.
(v) A 20mm length of brazing rod is to be used.

Report
- From the results obtain as much information about each material as possible.
- Discuss the results and compare the properties of the materials tested.
- Comment on typical engineering applications of these materials and indicate how these applications are related to the tensile test results.
- Comment as to the reason why modulus of elasticity cannot be evaluated directly from the chart record.

3.4 COMPRESSION TESTING

References
These are listed at the beginning of Section 3.2 Mechanical Properties.

Introduction
Because of difficulties in obtaining accurate information from a compression test on ductile material, very little compression testing is done on metal. Difficulty arises from two causes, namely compression instability and frictional restraint.

Compression testing is carried out in a universal testing machine and it is not common practice in the metallurgical field to have machines intended for compression testing alone.

Compression specimens are limited to such a length that bending due to column action is not a factor. Thus (with certain exceptions), attempt is made to obtain a uniform distribution of direct stress over critical cross sections normal to the direction of the force. The attainment of these ideal conditions is limited by the form and trueness to form of the test piece, by the effectiveness of the holding or bearing devices, and by the action of the testing machine.

The compression test finds greatest use in testing brittle materials such as mortar, concrete brick and ceramic products, (see Assignment 53), whose tensile strengths are low compared with their compressive strengths and which are principally employed to resist compressive forces.

The tensile strength of wood is relatively high, but it cannot always be effectively utilized in structural members because of low shear resistance, which causes failure at the end connections before the full tensile resistance of a member can be developed. Thus in so far as direct stresses are concerned the compression test of wood is of greater practical significance than the tensile test (see Assignment 54). Some materials, like cast iron, although having a lower tensile than compressive strength, are used to resist either type of stress, and both types of test are sometimes carried out.

PRACTICAL WORK

ASSIGNMENT 4
COMPRESSION TESTING OF METALS

Aim
The aim of this experiment is to show how different metals behave under a steadily increasing compressive force.

Specification

Procedure
1. Set the universal tester dial to 300000N maximum capacity.
2. Set up the graph paper in the universal tester.
3. Measure the height and diameter of the standard compression test piece.
4. Place the specimen at the centre of the platen.
5. Place the protective guard around the specimen.
6. Set the dial indicator between the two crossheads so that it reads zero when the crosshead just touches the specimen.
7. Increase force, taking dial indicator readings at each 30 000N increment.
8. If the material is ductile remove the force when it reaches 290 000N and record this value. If the material is brittle record the maximum force.

Report
- Include all results.
- If the material is ductile, place a straight edge along the force-extension graph (either plotted or recorded) to determine the limit of proportionality. If the material is brittle calculate the modulus of rupture by dividing the maximum force by the original cross-section area.
- Sketch the mode of failure including angles or fracture.
- Comment on any discrepancies.
- Discuss the importance to structural design of compression testing of metals.

3.5 HARDNESS TESTING

Specifications
These are given with the appropriate test.

Reference
O'Neill H *Hardness Measurement of Metals and Alloys* 2nd ed Chapman and Hall 1967

The Significance of Hardness

Hardness is not a fundamental property of a metal and it varies in meaning with the method of measurement. However it is a resultant effect of several basic properties and appears to be fairly closely related to the nominal strength. Measurement of hardness provides a very useful non-destructive method for checking on the nominal strength of a material and it is therefore also useful for checking on the quality of various metallurgical treatments, for example heat treatment, cold working.

A number of different arbitrary ‘definitions’ of hardness form the basis for the various hardness tests now in use. Some of these definitions are:
- Resistance to permanent indentation under static or dynamic force — *Indentation Hardness*.
- Energy absorption under impact force — *Rebound Hardness*.
- Resistance to scratching — *Scratch Hardness*.
- Resistance to abrasion — *Wear Hardness*.
- Resistance to cutting or drilling — *Machinability*.

Of these, only indentation hardness is to be considered in this text.

Applicability of Hardness Tests

The results of a hardness test may be utilised as follows:

Similar materials may be graded according to hardness, and a particular grade as indicated by the test may be specified for one type of service.

The quality level of materials or products may be checked or controlled by hardness tests. Thus both uniformity of samples of a metal or uniformity within the one sample may be determined.

By establishing a correlation between hardness and some other desired property, for example tensile strength, the simpler hardness test will give a measure of the desired property. However, correlations apply only over a range of materials on which tests have been previously made; extrapolation from empirical relations should rarely be made and then only with great caution.

Accuracy of Penetration Hardness Tests

Some of the factors that influence the accuracy of these tests, apart from those mentioned later in the section on limitations of the various tests are:

1. Condition of indenter:
   - Ball flattened or worn.
   - Diamond chipped.
2. Applied force:
   Forces greater than those recommended for the particular metal should not be used.
3. Impact application:
   - Can possibly give a greater force than required.
   - Can damage the indenter.
4. Surface of specimen must be:
   - Flat, unless correction factors are available.
   - Representative of the material as a whole.
   - Polished to the appropriate finish.
5. Specimen thickness must be at least ten times the depth of the indentation.
6. Location of indentation:
   - At least 2½ times the indentation diameter from the specimen edge.
   - At least 5 times the indentation diameter from adjacent indentation.
7. The performance of each machine should be tested with standard block of appropriate hardness before testing the sample.

Convention for Reporting Hardness Results

Brinell: Symbol HB with the addition of ball size and load force used. eg 250 HB10/3000.
Vickers: Symbol HV with the addition of load force used. eg 250 HV30.
Rockwell: Symbol HR with the letter designating the particular scale. eg 45 HRB.

Note
The terms ‘load’ and ‘force’ are not synonymous. The unit for load is kilogram while that for force is Newton.
2. A finer surface finish is required than with the Brinell test.
3. It is unsuitable for coarse grain metal where a representative hardness value is required.
4. The testing machine is more intricate than the Brinell testing machine.

3.5.3 The Rockwell Hardness Test

Specification


Introduction

This is one of the most rapid and convenient hardness tests, but unfortunately the results are related to arbitrary scales which are not directly comparable with each other because the indenter shape or the loading conditions differ. A Rockwell hardness testing machine is shown in figure 13 though this machine also can be used to carry out Rockwell superficial hardness tests.

Figure 13. Wilson-'twin tester' Rockwell hardness testing machine. This particular machine is designed for use with low loads such as 15 kgf

The system is direct reading by virtue of the fact that the depth of the indentation is measured and shown on an indicator dial which is graduated, inversely, into 100 or 120 hardness units, each unit representing a depth of 2 micro metres.

The hardness number is based upon the increase in depth which occurs when an initial load (usually 10 kg) is augmented by a second load. There are nine Rockwell hardness scales, each scale representing a different combination of load and indenter. They are shown in Table 4.

<table>
<thead>
<tr>
<th>Scale symbol and prefix letter</th>
<th>Indenter</th>
<th>Total load (kg)</th>
<th>Dial Numerals</th>
<th>Typical applications of scales</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Diamond cone</td>
<td>60</td>
<td>Black</td>
<td>Cemented carbides, thin steel, shallow depth case-hardened steel.</td>
</tr>
<tr>
<td>B</td>
<td>1.588 mm dia. steel ball</td>
<td>100</td>
<td>Red</td>
<td>Copper alloys, soft steels, aluminium alloys, malleable iron.</td>
</tr>
<tr>
<td>C</td>
<td>Diamond cone</td>
<td>150</td>
<td>Black</td>
<td>Steel, hard cast iron, pearlitic malleable iron, high depth case-hardened steel.</td>
</tr>
<tr>
<td>D</td>
<td>Diamond cone</td>
<td>100</td>
<td>Black</td>
<td>Thin steel, medium depth case-hardened steel.</td>
</tr>
<tr>
<td>E</td>
<td>3.175 mm dia. steel ball</td>
<td>100</td>
<td>Red</td>
<td>Cast iron, aluminium and magnesium alloys, bearing metals.</td>
</tr>
<tr>
<td>F</td>
<td>1.588 mm dia. steel ball</td>
<td>60</td>
<td>Red</td>
<td>Annealed copper alloys, thin soft sheet metals.</td>
</tr>
<tr>
<td>G</td>
<td>1.588 mm dia. steel ball</td>
<td>150</td>
<td>Red</td>
<td>Phosphor bronze, beryllium copper, malleable iron.</td>
</tr>
<tr>
<td>H</td>
<td>3.175 mm dia. steel ball</td>
<td>60</td>
<td>Red</td>
<td>Aluminium, lead, zinc.</td>
</tr>
<tr>
<td>K</td>
<td>3.175 mm dia. steel ball</td>
<td>150</td>
<td>Red</td>
<td>Soft bearing metals.</td>
</tr>
</tbody>
</table>

The diamond indenter has a cone angle of 120° with a spherical tip ground to a radius of 0.2 mm. The cone is given the name BRALE. The most commonly used scales are A, B and C. The procedure in using a Rockwell hardness tester is illustrated in figure 14.

Advantages of the test

1. There is no error resulting from distortion and deformation around the indentation as occurs with Brinell and Vickers tests.
2. It is faster than the Vickers and Brinell tests because it gives arbitrary direct readings.
3. It is a simple test since neither calculation nor table reference is required to obtain the hardness number.
4. Due to the influence of the minor load, it is claimed that poor surface finish does not adversely influence test results to the same extent as in other test systems.
5. As with the Vickers test the diamond indenter permits testing of very hard metals.

Limitations of the test

1. For accuracy, the number should be between 20 and 70 on the C scale but 0 to 100 can be used on the A and B scales.
2. Any oil or dirt on the support faces of the specimen or anvil of the machine can cause inaccurate reading.
3. The size of specimens limited by the size of the anvil.
4. There is no direct relation between the various scales.
5. The hardness number has no significance if the scale letter is omitted from the result.

Figure 14 Procedure in using Rockwell hardness tester
(From Davis, Troxell and Wiskocil The Testing and Inspection Materials 3rd ed McGraw-Hill 1964)

3.5.4 The Rockwell Superficial Hardness Test

Specification


Introduction

The superficial Rockwell hardness test was developed for testing the hardness of very thin metals, for example, razor blades, and thin surface hardened cases, such as nitrided cases.

The principle is the same as that of the Rockwell test except that lower loads are used to produce smaller indentations. In order that the depth of these small indentations may be determined, one unit of hardness on the superficial Rockwell scale represents a depth of 1 micrometre.

Three loads are used, 15, 30 and 45 kg and two indenters, the Brule indenter and a 1.588 mm diameter ball. Thus there are six scales, and these are shown in Table 5.

Table 5

<table>
<thead>
<tr>
<th>Rockwell Superficial Hardness Scale</th>
<th>Indenter</th>
<th>Total Load (kg)</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>15N</td>
<td>Brule</td>
<td>15</td>
<td>nitrided and thin case-hardened steels</td>
</tr>
<tr>
<td>30N</td>
<td>cone</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>45N</td>
<td></td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>15T</td>
<td>1.588mm</td>
<td>15</td>
<td>thin sheet metal</td>
</tr>
<tr>
<td>30T</td>
<td>dia. steel</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>45T</td>
<td>ball</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

PRACTICAL WORK

Specifications

Refer to previous parts that describe the individual tests.

AS B161 Tables for comparison of hardness scales.

ASSIGNMENT 5

THE BASIC PRINCIPLES OF HARDNESS TESTING

Aim

To investigate the basic principles of hardness testing.

Note

Before carrying out the hardness tests the samples should be ground to 400 grade silicon carbide paper and thence etched to remove the deformation layer.

Part 1 - Brinell Hardness - Effect of Load

Introduction

The variation of indentation diameter with load is given by Meyer's Law, which states that, for a given ball indenter

\[ P = Kd^n \]

where 'K' and 'n' are constants, 'P' is the load in kilograms and 'd' is the diameter in millimetres of the indentation.

The value of 'n' usually lies between 2 and 2.5, being nearer 2.0 for severely work hardened metals and 2.5 for fully annealed metals. The value of 'K' varies with the diameter 'D' of the ball indenter in such a way that:

\[ KD^{n-2} = \text{constant} \]
Rockwell and Vickers hardness testing machines while the nonferrous specimens are to be tested using the Rockwell and Vickers machines.

Report
- The results are to be recorded in tabular form, for example:

<table>
<thead>
<tr>
<th>Material</th>
<th>Brinell</th>
<th>Vickers</th>
<th>Rockwell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel</td>
<td>123HB 10/3000</td>
<td>125HV30</td>
<td>44HRA</td>
</tr>
</tbody>
</table>

- Comment on the advantages and limitations of these three types of hardness test, as you have observed in carrying out the tests.
- Comment on the industrial applications of these three types of testing machine.

ASSIGNMENT 7
MICROHARDNESS TESTING

Aim
- To give students experience in the operation of a microhardness tester.
- To demonstrate a method for determining the total and effective case depths of a case-hardened steel.

Specification
AS1982-1977 Methods for the measurement of case depth in steels.

Procedure
1. Polish metallographically the mounted sample to 0.1 micron finish, taking care not to round the edge of the sample.
2. Place the sample in the vice of the microhardness tester, ensuring that it is level.
3. Position the vice so that crosswise motion under the microscope, by using the vernier micrometer, is along a diameter of the sample.
4. Do microhardness tests (load 500 g) along the diameter, commencing 0.15 mm from the surface edge.
5. Record the hardness obtained.
6. Make further indentations at 0.1 mm intervals until a constant hardness value is obtained.
7. Plot hardness value against distance from the edge.
8. From the graph in (7), determine the effective case depth, assuming this to be where the hardness value is 500HV. Also determine the total case depth, which is the depth at which the lower plateau begins.
9. Etch the sample in 2% nital. Examine it under a microscope and determine the distance from the edge to the position where the microstructure has 50% surface constituent. Report this as the case thickness.

Report
- Compare the case values obtained and explain any discrepancies.
- Discuss the advantages and limitations of microhardness testing.

3.6 IMPACT TESTING

Specification
AS1544 Methods for impact tests on metals

References
These are listed at the beginning of Section 3.2 Mechanical Properties.

Introduction
Although many structures are at some time subject to dynamic forces, many machines and machine parts are frequently subjected to such forces. The behaviour of materials under dynamic forces may sometimes differ markedly from their behaviour under static or slowly applied forces.

An important type of dynamic force is that in which the force is applied suddenly, as from the impact of a moving mass. In the design of many types of structures and machines that must take impact force, the aim is to provide for the absorption of as much energy as possible through elastic action and then to apply upon some kind of damping to dissipate it.

In most tests used to determine the energy-absorption characteristics of materials under impact force, the object is to utilize the energy of the blow to cause rupture or fracture of the test piece.

The property of a material relating to the work required to cause rupture has been designated toughness and was shown, in the notes on Tensile Testing, to be determinable from the area under the stress-strain curve. However, the rate at which the energy is absorbed by a material undergoing stress, may markedly affect the behaviour of a material. Thus different measures of toughness may be obtained from impact loading than from static loading.

Test pieces
In order to induce fracture to take place under a single blow, especially with ductile metals, test pieces are notched. The use of a notch causes high localised stress concentrations, artificially tends to reduce ductility, causes most of the energy of rupture to be absorbed in a localized region of the piece, and tends to induce a brittle type of fracture. The tendency of a ductile material to act like a brittle material is sometimes referred to as notch sensitivity. Materials that have practically identical properties in static tension tests, or even in impact tension tests when unnotched, sometimes show marked differences in notch sensitivity.

Notch impact tests do not yield much quantitative information, but do yield qualitative results under conditions which approximate to the severity of loading likely to be encountered by engineering structures in certain conditions. In addition, there is a very marked energy drop between ductile and brittle fracture with this type of test, that makes the limits of a transition range relatively easy to determine. For both these reasons, in conjunction with the speed and simplicity of most of these tests, they are much used as check and acceptance tests.
Types of impact test

The most commonly used impact tests for steels in Australia are the Charpy and the Izod tests, both of which use the pendulum system and a single-blow. The principal features of a single-blow pendulum impact machine are:

(i) A moving mass whose kinetic energy is great enough to cause rupture of the test specimen placed in its path.
(ii) An anvil and a support on which the specimen is placed to receive the blow.
(iii) A means for measuring the residual energy of the moving mass after the specimen has been broken.

The effect of testing temperature

In contrast with the relatively small effect of temperature on the static strength and ductility of metals, at least within the atmospheric range, temperature has a very marked effect on the impact resistance of notched bars. This is illustrated by the plot of energy to produce rupture in the impact test against 'testing temperature' as given in figure 15 for the following steels:

A - SAE3140 oil quenched then tempered at 700°C
B - SAE3140 oil quenched then tempered at 560°C
C - SAE2340 oil quenched then tempered at 650°C
D - SAE2340 air quenched not tempered
E - SAE2340 oil quenched then tempered at 600°C
F - SAE2340 quenched into a lead bath.

3.6.1 Izod Impact Testing

Specification

AS1544 Methods for impact tests on metals: Part 1 – 1977

Introduction

The Izod impact testing machine as shown in figure 16(a) has 27.2 kgf weight hammer swinging from a height of 0.6m above the striking position. The specimen is supported as a cantilever with the notch facing the hammer. The energy absorbed on impact, when the specimen is either broken or bent, is found by subtracting the arc of swing beyond the striking position from the original arc of lift of the hammer before release. The actual value in 'joules' is usually indicated directly on a scale, by a maximum indicating pointer carried forward by the hammer pendulum.

Figure 15 Variations in transition range for various steels in the Charpy test

Figure 16(a) Izod impact testing machine

The standard Izod test piece, is either 10 mm square in section or 11.43 mm in diameter. The notch has a 45° included angle, is 2 mm deep (0.33 mm for the round specimen) with 0.25 mm root radius. The standard test set up is shown in figure 16(b).

Figure 16(b) Izod specimen arrangement
There is some difficulty in varying the temperature conditions of the test and mainly because of this, but also, partly because of defects inherent in the cantilever loading system and partly because of the low striking velocity (3 to 4 m/s), the test is not used as much as it was. However, it is still used for acceptance testing at room temperature because a round specimen is easier to prepare than is a square section specimen.

3.6.2 Charpy Impact Testing

Specification


Introduction

In this test a machine similar in principle to the Izod is used. A typical Charpy impact testing machine is shown in figure 17 (a). The pendulum has a striking velocity of 5 to 5.5 m/s.

The standard Charpy test piece is 10 mm square in section and has a 2 mm deep notch. The specimen is supported as a simple beam with the notch facing away from the hammer. The standard test set up is shown in figure 17(b). Since the specimen rests on its side in the striking position it can be positioned very rapidly; thus tests at different temperatures particularly at sub-zero temperatures, are easily arranged.

PRACTICAL WORK

ASSIGNMENT 8
IZOD AND CHARPY IMPACT TESTS

Aim

The aim of this experiment is to give to the student basic information on the principles of impact testing by carrying out the following:

- Calibration of the machines.
- Determination of the Izod and Charpy impact values of various metals.

Specifications

Refer to sections 3.5.1 and 3.5.2.

Procedure

WARNING
EXTREME CAUTION IS TO BE OBSERVED AT ALL TIMES.

No student is to stand in front of the pendulum at any time. Only one student at a time is to carry out the test. All other students are to stand well back from the machine.

Part 1 – Calibration

Specification


(i) Pendulum length

In order to determine the pendulum length ‘L’, which is the distance between the pendulum axis and the centre of percussion of the pendulum, it is necessary first to calculate the period of the pendulum. This is done by allowing the pendulum to swing through an angle of approximately 10° and recording the time taken for 50 to-and-fro oscillations.

The pendulum length ‘L’ is then calculated from the formula:

\[ T = 2\pi \sqrt{\frac{L}{g}} \]

T: pendulum period i.e. \( \frac{\text{time}}{\text{number of oscillations}} \)

\( \frac{\text{time}}{\text{number of oscillations}} \)

g: acceleration due to gravity.
3.7 FATIGUE

Specification


References

These are listed at the beginning of Section 3.2 Mechanical Properties.

Introduction

It is an observed fact that a stressed member will begin to fracture at a stress intensity very much lower than its nominal breaking stress, and even lower than its yield strength, if the stress is applied and removed often enough. This phenomenon is called fatigue.

Much is known about the relative strengths of materials under differing standardised fatigue conditions. This information gives a guide to service behaviour.

The alternating stress may be:

(a) an increase and decrease of a tensile or compressive force;
(b) alternate compressive and tension forces;
(c) alternating torsional force;
(d) bending in opposite directions;
(e) repeated impact force.

The stress at which a metal fails by fatigue at N cycles is called the fatigue strength at N cycles. It is sometimes known as the endurance limit.

It has been found that for many materials there is a limiting stress below which a force may be repeatedly applied an indefinitely large number of times without causing failure. This limiting stress is called the fatigue limit. Unless qualified, the fatigue limit is usually understood to be that for completely reversed bending.

3.7.1 Fatigue Test Methods

There are three basic types of test. These are:

(a) those in which the mean stress is zero and the range of stress is varied as in figure 19(a);
(b) those in which there is a positive constant mean stress and the strength range is varied as in figure 19(b);
(c) those in which the range of stress is kept constant but the mean stress is varied as in figure 19(c) and (d).

In each case, for a complete assessment at one temperature, a whole range of individual tests must be made at different stress intensities but otherwise under similar conditions, to find the number of cycles required to cause failure. The maximum stress intensity or the range of stress (the difference between the maximum and minimum stress to which the specimen is subjected during the test) is then plotted on a base of number of cycles to failure. This gives the S/N or Wohler curve. Typical forms of S/N or Wohler curves are shown in figure 20.

![Figure 18](image-url)

**Figure 18 (left)** Types of fatigue test cycles of stress
- (a) Alternating
- (b) Repeating
- (c), (d) Oscillating

![Figure 20](image-url)

**Figure 20 (above)** Typical forms of S/N curves of fatigue stress versus cycles to failure, (a) for a metal with a fatigue limit, and (b) for a metal without a fatigue limit
Typical S/N curves for metals are given in figure 21. It should be noted that some non ferrous alloys have no endurance limit.

![Figure 21](image)

**Figure 21** Typical S/N curves for determining endurance limit of metals under reversed flexural stress. A. 1.20% carbon steel, oil quenched and tempered B. Cr/Ni steel, oil quenched and tempered C. 0.53% carbon steel, oil quenched and tempered D. 0.35% carbon steel, as rolled E. Aluminium-copper alloy F. Copper, cold drawn and annealed G. Grey cast iron

**Development of the fatigue crack**

The following is a simplified explanation of the development of the fatigue crack. In a material undergoing some form of stress cycle, atoms in each crystal slip in one direction and thence in the opposite direction. Work hardening results and the specimen finally becomes so work hardened that it can stand no further deformation and small cracks are formed usually at points where the stress is greatest, that is at points of high stress concentration.

Once the crack forms there is a reduction in cross-sectional area, and so even if the force remains constant the stress increases as the self-propagating crack becomes larger.

While the crack is deepening the adjoining fractured faces rub against each other producing smooth polished surfaces. Eventually the stress, as calculated from the area of still sound metal, will equal the fracture stress of the metal and fracture occurs. The fracture is transgranular and its appearance gave early engineers the impression that fatigue involved the “crystallisation” of the metal. The appearance of a fatigue failure fractured surface is as shown in figure 22.

![Figure 22](image)

**Figure 22** Conchoidal markings, sometimes seen on a fracture face of a fatigue fracture, spreading out from the point of origin of fracture

**Factors which affect fatigue behaviour**

1. **Nature of applied force**
   
   (a) *Flexural and Torsional*: Maximum stress occurs at the surface of the material, hence the crack commences at the surface.
   
   (b) *Axial* (alternate tension and compression): The stress is distributed uniformly over the cross-section and so the crack starts at some defect that acts as a stress concentrator in the material.

2. **Surface finish**

   The importance of surface finish varies with the nature of the material. A soft plastic material is not nearly so sensitive to surface finish as a hard brittle material. In the latter case poor machining may cause much as 20% reduction in fatigue strength.

   It is particularly important that, in fatigue testing, the surface should be as good as possible.

3. **Surface treatment**

   This may take one or both of two forms:
   
   (a) development of a hard layer to prevent onset of fatigue slip;
   
   (b) use of residual compression stress in the surface layer to throw the surface fatigue stress towards the safer compressive range, if the main stress is tensile.

   In producing the hard surface by heat treatment or by peening with shot blast care must be taken to not cause cracking of the surface.

4. **Design geometry**

   Much can be done, in designing a component, to offset the harmful effects of fatigue. If a component’s shape is not arbitrarily determined, then it may be adapted to cause the minimum amount of stress concentration or to develop compression rather than tensile stresses. However, in most cases, the general shape is arbitrary and the best that can be done is to minimise stress concentration by the use of contour blending, radiused corners and other devices such as undercutting the ends of screw threads.

   Obviously, common sources of stress concentration in a fabricated material are holes, grooves, shoulders and keyways.

**PRACTICAL WORK**

**ASSIGNMENT 9**

**FATIGUE FAILURE CHARACTERISTICS**

**Aim**

To examine the factors that affect fatigue behaviour.

**Procedure**

You are provided with several engineering components which you are to examine and then answer the questions listed in the report.
ASSIGNMENT 10

FACTORS CAUSING FATIGUE FAILURE

Aim
To investigate the effects of various factors on the fatigue life of a component.

Introduction
You are provided with a number of fatigue test specimens. One specimen is a standard fatigue specimen which will provide a base against which the results from the other specimens can be compared. The other specimens have the same minimum diameter but have a variety of stress raisers.

Procedure
1. Test the standard specimen at a force which will cause it to fail at a large number, eg 8 000 000, of cycles.
2. Test the other specimens at the same force and note their fatigue life.

Report
• Sketch the specimens, noting the type of stress raiser and features of the fracture surface.
• Comment on the test results taking note of the stress raisers and other conditions that have caused fatigue failure at a lower number of cycles than for the standard specimen.

ASSIGNMENT 11

FATIGUE TESTING

Aim
To carry out a fatigue test and to interpret the results obtained from a series of tests on the same material.

Specification
BS 3518 Methods of fatigue testing: Part 2 – 1962 Rotating bending fatigue test

Introduction
The fatigue test will be carried out using a parallel test piece of normalised 0.25% carbon steel and four-point loading on a ‘METEFEM’ Rotating Bending Fatigue Test Machine. This machine is shown in figure 23 and its major components are illustrated in figure 24.

In this machine the forces are applied through bearings which allow the test piece to rotate freely. The test piece is subjected to pure bending at its centre.

Figure 23 Metefem rotating-bending fatigue machine. The side panels are open to show the location of the weights

Figure 24 Mechanical arrangement of fatigue testing machine
As part of the test it is necessary to calculate the maximum fibre stress 'S' in the test piece; the equation involved is derived as follows:

\[ S = \frac{Mr}{I} \]

where 'M' is the bending moment,
't' is the radius of cross-section,
'I' is the moment of inertia of section and equals \( \frac{\pi r^4}{4} \).

hence \( S = \frac{4M}{\pi r^3} \)

Using the symbols given for the machine in figure 24, the bending moment 'M' is given by:

\[ M = P \times L \]

For this machine, \( L_o \) is 100 mm and \( G \) is the force on the pan. Hence the force 'P' at each end of the specimen is equal to \( \frac{10G}{2} \).

Thus the bending moment 'M' = \( \frac{10G}{2} \times 100 = 500G \)

Therefore the maximum fibre stress 'S' = \( \frac{4 \times 500G}{\pi r^3} = \frac{2000 \times 9.8 \times 10^3}{\pi r^3} \)

where 'm' is the mass on the pan.

Procedure

1. Fit the fatigue specimen into the grips and check that it rotates freely.
2. Set the revolutions counter to zero.
3. Start the motor and apply the load by means of the hand wheel.
4. The loads to be used on the 'Metefem' Fatigue Testing Machine range from 3.5 to 4.5 kg.
5. When the specimen breaks note the counter figure.

Report

- Tabulate all results of load versus number of cycles to failure for each test piece. Because of restricted laboratory time you will be provided with test results from other groups to allow you to do this tabulation.
- From the results prepare a Wohler curve for the material and estimate the fatigue limit.
- For each applied load calculate the maximum stress, the minimum stress, the mean stress, the stress amplitude and the range of stress.

3.8 CREEP

Specification

**BS3500 Methods for creep and rupture testing of metals: Part 1 - 1969 Tensile rupture testing.**

References

These are listed at the beginning of Section 3.2 Mechanical Properties.

Introduction

The design of load-bearing structures for service at atmospheric temperatures is based generally on yield stress or sometimes on the ultimate tensile stress. These properties, being determined by testing at room temperature, involve the elastic-plastic behaviour discussed previously.

However, at elevated temperatures the metal behaviour is different and so it is necessary to conduct tests that will reveal the mechanical behaviour at the temperatures at which it is to be used.

At high temperatures of a material, a stress, often much less than that required to cause failure in a few minutes, may cause failure if sufficient time is allowed. The physical process that brings about failure is a comparatively slow but progressively increasing strain called creep.

At any temperature creep may be rapid or slow; its rate decreases rapidly as the stress is lowered. Although at some relatively low stress the possibility of rupture due to creep within a long period may be negligible, such a stress may nevertheless cause undesirable structural distortion in the course of time. The temperature at which creep becomes important will vary with the material. Thus it is important with lead at room temperature, with aluminium alloys at temperatures above 150°C, but does not become significant with steel until the temperature is above 350°C.

Three aspects of creep are important, in differing degrees, according to circumstances:

- total creep strain in a given time, which includes plastic strain due to loading and the slower plastic strain during creep, but excludes elastic strain;
- rate of creep under steady conditions;
- time taken to rupture.

Time dependence of creep

If a graph of 'creep strain' is drawn to a base of 'time' it is likely to take the form shown in figure 25. It is seen that there are three stages:

- (a) **Transient or Logarithmic or Primary creep** (0 to \( t_1 \)).
- (b) **Steady State or Secondary creep** (\( t_1 \) to \( t_3 \)).
- (c) **Creep to Rupture or Tertiary creep** (\( t_3 \) to \( t_4 \)).
3. **Grain size** At temperatures below the lowest temperature of recrystallisation a fine-grained steel possesses the greater resistance, whereas at temperatures above that point, a coarse-grained structure is superior.

### 3.8.1 Creep Testing

A typical creep testing machine is shown in figure 30. A creep testing laboratory would have a number of these machines operating simultaneously either at constant temperature but with different loads or at different temperatures for constant load.

**Factors influencing the creep of steels**

1. **Composition** The desired operating temperature determines the most suitable composition. At temperatures below the lowest temperature of recrystallisation the creep resistance of steel may be increased either by certain elements that largely enter into solid solution in the ferrite, e.g. Ni, Co, Mn, or by the carbide-forming elements, such as Cr, Mo, W and V.

   At temperatures above the lowest temperature of recrystallisation the carbide-forming elements are the most effective. Small additions of Ti and Nb to Cr/Ni stainless steels appreciably improve their creep resistance.

2. **Heat treatment** At temperatures of 500°C or greater, the maximum resistance is usually produced by normalising. The lowest resistance is produced by hardening and tempering. The creep resistance of a steel in the annealed condition is between those for the other two treatments.

**Introduction**

The aim of the stress rupture test is to relate temperature to the time of rupture under the influence of a given stress. Data obtained in this short time test can be extrapolated to predict failure after longer times of loading under different combinations of stress and temperature.