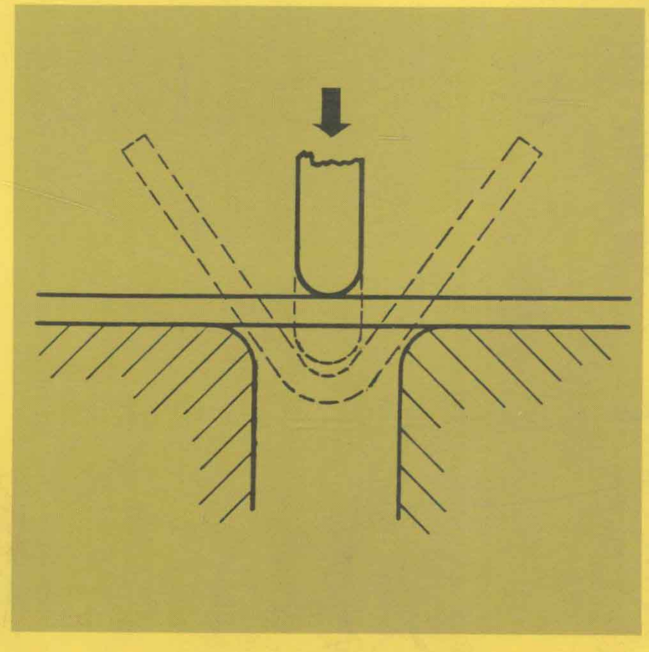
TESTING *of* MATERIALS



VERNON JOHN

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MACMILLAN

First published 1992 by
MACMILLAN EDUCATION LTD
Houndmills, Basingstoke, Hampshire RG21 2XS
and London
Companies and representatives
throughout the world

Typeset by
TecSet Ltd, Wallington, Surrey

ISBN 0–333–56814–1 hardcover
ISBN 0–333–44783–2 paperback

A catalogue record for this book is available from
the British Library

Printed in Hong Kong

TESTING OF MATERIALS

Other titles of interest from Macmillan

Hull & John: *Non-destructive Testing*
John: *Introduction to Engineering Materials, 2nd edition*
Hall: *Polymer Materials, 2nd edition*
John: *Engineering Materials (College Work Out)*
Ryder: *Strength of Materials*

Note on standards

The majority of testing methods for material properties are standardised. Each major country possesses its own standards institutions. The standards for a particular test procedure, for example the testing of metals in tension, will be similar from one country to another but may differ on some points of detail such as the specific dimensions of test pieces. In general, references in the text are made to British Standards but in some cases, where there is no appropriate British Standard, an ASTM (American) standard is quoted. A list of relevant British and American standards is given in the Appendix. Extracts from British Standards are reproduced by permission of BSI. (Complete copies of the standards can be obtained from them at Linford Wood, Milton Keynes, MK14 6LE.)

Acknowledgements

I would like to thank Harry Beasley for the time and effort he put in to produce the photographic illustrations for this book. I would like also to thank my wife, Gillian, for her full support throughout the preparation of this text and for converting my barely legible scrawl into type.

Vernon John

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1

The Requirements for Testing

1.1 Introduction

Testing is an essential part of any engineering activity. Inspection and testing must take place at many stages in the complex process of producing engineering materials, be they metals, polymers, ceramics or composites, and during the forming of these materials into components and assembling the components to create an engineering product to satisfy some specific requirement. The requirement for testing does not automatically cease when the product has been manufactured. It is frequently necessary to check and test the article during its service life in order to monitor changes, such as the possible development of fatigue or corrosion damage.

The types of test used can be broadly classified into two categories

(a) tests to establish the properties of the material, and
(b) tests to determine the integrity of the material or component.

Those tests in the first category are generally of a destructive type. They are performed on samples of a material and the test-piece is damaged or broken in the process, as is the case when determining the tensile strength of a material in a tensile test to destruction. If the sample test-piece is correctly chosen and prepared the results should be indicative of the properties of the bulk material represented by the sample.

The tests in the second category are of a non-destructive nature and are used to detect the presence of internal or surface flaws in a material, component or finished product. By their very nature, these tests do not damage the parts being tested and sampling is not required as, if necessary, every item can be checked.

1.2 The Need for Testing

Testing is necessary at many points in the engineering process.

(a) As a quality control check in the production of metal semi-finished products, for example sheet, strip, bar stock, etc. Sample destructive property tests are made to ensure that the material can meet the appropriate specification. Non-destructive tests may also be made at this stage to ensure that the product is defect-free.
(b) As an acceptance check by a component manufacturer to ensure that the material will give the required performance. Again this will generally involve sample destructive property tests.
(c) To check finished components prior to final assembly. Non-destructive tests would be used for this purpose. It is also possible to use one form of non-destructive test, namely radiography, on some completed multi-component products to check for the correctness of assembly.
(d) For the in-service checking of components. Non-destructive tests are used here to detect deterioration or damage, for example the presence of corrosion or fatigue cracks.

In addition to the above, property testing of materials is widely used during research and development programmes and also for the compilation of general design data files.

It is of extreme importance that the user of materials be able to obtain reliable information on the properties of those materials. The range of properties which can be considered is extremely large, including strength in tension, compression and shear at ambient temperature and at temperatures other than ambient, stiffness, hardness, impact strength, time-dependent properties such as fatigue and creep phenomena, resistance to oxidation, corrosion and other forms of chemical and microbial attack. It would be extremely expensive and time consuming to fully assess all of these characteristics for any one material and the engineer has to determine which are the properties of significance for the particular application being considered. In this context, it will be necessary for the engineer to determine not only that the material will possess the properties to enable it to give an adequate and reliable performance when in use but also that the material has those properties that will permit it to be readily fabricated into the required shape and form.

The test procedures which have been devised for the determination of some of the characteristic properties of materials, for example the tensile test, will provide much valuable information for the engineer and designer but this data will not necessarily be sufficient to predict accurately how the material will behave when it is fabricated into some end product and put into service. The properties of a metallic material are dependent to some extent on the size and alignment of the crystal grains within the material. The grain structure of a manufactured component may differ from that in the test-piece used in the determination of the tensile properties. The properties of many thermoplastic materials are highly sensitive to changes in temperature and to variations in strain rate. The results obtained from tests on ceramics may show a large variance and a large number of tests may be necessary to show this variance and determine a statistical mean.

For the results of any test to have value, it is important that the tests be conducted according to certain set procedures. To this end, standardised test procedures have been evolved. In the United Kingdom, the British Standards Institution publishes the standards and codes of practice which cover most aspects of the testing and utilisation of materials. All the major developed countries possess standards organisations and while standards for a particular type of test may differ slightly on points of detail from one country to another, the broad principles will be similar. A list of British (BS) and American (ASTM) Standards relevant to the tests covered in this volume is given in the Appendix.

1.3 Material Property Tests

The material characteristics which are most often called for by the engineer and designer are the values of Young's Modulus, E, the tensile yield stress (or proof stress) and tensile strength, ductility and hardness. Dependent on the type of mechanical loading the material may be subject to in service, it may also be necessary to have information on the compressive and shear strengths of the material. Many components are subject to fluctuating loads or cyclic stressing, where the load on the component may rapidly alternate between compressive and tensile values. In this case, a knowledge of the fatigue characteristics of the material will be of great importance. Creep, which is the continued slow deformation of a material with time under conditions of constant load, is a phenomenon which becomes of importance for metallic materials when they are used at elevated temperatures. It should not be thought, though, that creep is only a high-temperature phenomenon, as many polymeric materials will creep at temperatures at or close to ambient values.

Many components are fabricated from sheet metal by plastic deformation processes such as bending, pressing, deep drawing and spinning, and a number of tests have been developed to assess the formability of sheet material.

The succeeding chapters of this book will give details of the various test procedures for determining the types of property listed above together with the manner of result presentation required and the ways in which the engineer would use test data. Many of the tests described conform to British Standards but there is also coverage of some test methods which are commonly used but for which there is no relevant standard.

1.4 Non-destructive Testing

As mentioned above, the materials property data derived from standard destructive tests do not necessarily give a clear guide to the performance characteristics of components which may form part of some larger engineering assembly. Defects of various types and sizes may be introduced to a material or component during manufacture and the exact nature and size of any defect may influence the subsequent performance of the component. Other defects, such as fatigue or corrosion cracks, may be generated within a component during service. It is necessary to have reliable means for detecting the presence of defects at the manufacturing stage and also for detecting and monitoring the rate of growth of defects during the service life of a component or assembly. Using well established physical principles a number of testing systems have been developed which will provide information on the quality of a material or component and which do not alter or damage the components or assemblies which are tested. The main non-destructive systems which are used are

(a) liquid penetrant inspection,
(b) magnetic particle inspection,
(c) electrical (eddy current) testing,
(d) ultrasonic testing, and
(e) radiography,

Correct and effective use of non-destructive testing will result in the identification of defects which, if they remained undetected, could result in a catastrophic failure. This could prove to be very costly in financial terms and possibly in lives and so effective use of suitable inspection techniques could give rise to substantial savings.

These main non-destructive testing techniques are described in Chapter 8 of this book, together with some of the major areas of application for the various tests.

2

Hardness and its Measurement

2.1 The Property of Hardness

The property of hardness is not a fundamental property of a material. The term *hardness* may be defined in more than one way. It may be regarded as the resistance of the material to abrasion, or as the resistance to localised plastic deformation. The various types of hardness test which have been devised are based on the measurement of one or other of these characteristics of a material. The test types which involve localised plastic deformation can, of course, only be used in connection with those materials which are capable of being deformed plastically, namely metals and thermoplastics. These tests are indentation-type tests and may be either static or dynamic. In the static indentation tests, which are the more commonly used, an indentation is made in the surface of the material under a pre-determined load and the size of the indentation measured. The larger an indentation is, when made under standard conditions, the softer is the material, and vice versa. Although indentation tests do not measure the resistance to abrasion, in general, a material of high hardness, as determined by an indentation method, will possess a good resistance to abrasion and wear. Dynamic indentation tests involve a free falling weight or a pendulum impacting with a material. Some of the energy of the striker will be absorbed in causing some plastic deformation of the material while the remainder of the impact energy will remain in the striker causing it to rebound. A hard material will not absorb much energy, as it will not greatly deform plastically, so giving a large striker rebound height. This type of test is particularly suited to extremely hard metals. This type of test is also used for assessing a group of materials which are not usually considered as being very hard materials, namely rubbers. An indentor will cause both elastic and plastic deformation. When the striker in a dynamic test impacts with a rubber, the very rapid rate of elastic strain recovery of the rubber will cause the rebound height of the striker to be great. Despite this apparent anomaly of a soft material giving a large rebound value indicating a high hardness, this type of test is used successfully to assess the properties of rubber-type materials. It is possible also to measure the hardness of steels using an electrical non-contact method. The parameter which is measured is magnetic coercivity but, for each particular type of steel, there is an almost linear relationship between coercivity and hardness.

Indentation-type hardness tests are widely used to check metal samples. The tests are relatively easy to make and do not require elaborately machined test-pieces. The results of the tests will give an indication of the strength of a metal — there are certain empirical relationships between hardness value and tensile strength for a number of metallic materials — and the results of hardness tests can also be a convenient way of checking on the effectiveness of heat treatments.

There are some materials, notably ceramics and glasses, which do not deform plastically when a force is applied and indentation type hardness tests cannot be used for these. For this type of material, the only suitable type of hardness test is one which measures the resistance to abrasion. One such test, and the one most usually used, is Mohs' scale of hardness.

2.2 Mohs' Scale of Hardness

Mohs' scale of hardness was originally devised for assessing the relative hardnesses of rocks and minerals but is now also used for determining the relative hardnesses of industrial ceramic and glass materials. It is based on a set of ten naturally occurring minerals ranging from talc, which is very soft, to diamond, the hardest known substance. The full scale is given in Table 2.1. In this test, attempts are made to scratch the surfaces of the standards with the material which is being assessed. The hardness number of the unknown material lies between the number of the standard mineral which it just fails to scratch and that of the standard which it just scratches.

Table 2.1 Mohs' scale of hardness

Number	*Mineral*
1	talc
2	gypsum
3	calcite
4	fluorite
5	apatite
6	orthoclase felspar
7	quartz
8	topaz
9	corundum
10	diamond

2.3 Static Indentation Tests

The various forms of static indentation test all involve forcing an indentor into the surface of the material being tested under the action of an applied force. The indentor causes localised deformation of the material. When the force is being applied, the deformation of the material is, in part, elastic and, in part, plastic. When the force is removed, the elastic strain in the material is recovered but the plastic strain remains leaving a permanent impression in the surface of the material. A dimension of this impression, either its depth or area, is measured and used in the determination of a hardness number for the material.

The size of the indentation, i.e. the amount of plastic deformation, will vary with the nature of the material being tested, the type and size of the indentor and the magnitude of the indenting force. It is important that the depth of indentation made be small in relation to the thickness of the test-piece otherwise there is the possibility that the zone of elastic deformation or even the zone of plastic deformation may pass through the whole thickness of the test-piece and interact with the support table of the test machine and result in an incorrect value of hardness. As a general rule, the depth of impression generated should not exceed one-eighth of the thickness of the material. Similarly, a hardness indentation should not be made close to the edge of the test-piece or to another impression otherwise an incorrect result may be obtained.

Many metallic alloys are not homogeneous in structure and a single hardness determination may not yield a result representative of the material as a whole. Several hardness determinations should be made. Generally, the minimum number of tests to be made per test-piece should be three. If close agreement is not obtained with three results then further hardness checks should be made. Some alloys possess a duplex structure of hard and soft constituents and, when small hardness impressions are made, there may be a considerable variation in the results. In general, the larger and deeper a hardness impression is, the more representative it will be of the average hardness of the material. There are, however, circumstances when it is either not practicable or unwise to attempt to make a large impression. If the material is of thin section or the component is very small, it would be impractical to make a large indentation. Also, if it is required to measure the hardness of the skin of a component which has been surface hardened then a small indentation only must be made if the result is to have any meaning.

There are three types of static indentation test commonly used. These are the *Vickers Diamond* test, the *Brinell* test and the *Rockwell* test. For each of these methods, the surface to be tested must be aligned normal to the line of action of the indenting force and the test-piece positioned in such a way that it does not move during the test. The degree of surface preparation of the test-piece is not critical but surface scale and dirt must be removed. A fine ground surface is usually sufficient.

When it is required to determine the hardness of very thin material, such as razor blades, very small components, the thickness of the case on a case hardened component, or perhaps, the separate micro-constituents within an alloy structure, microhardness tests can be used. In these cases, the surface of the material must be prepared to a high polish, as for the preparation of samples for micro-examination. There are two types of microhardness test in general use, these being the *Vickers Diamond* test and the *Knoop Diamond* test. Microhardness test results tend to be somewhat less reliable than those obtained from indentation tests producing larger indentations. They also tend to indicate somewhat higher hardness values.

2.4 The Brinell Hardness Test

The Brinell test was the first static indentation test to come into general use. In its original form, it utilised a hardened steel ball indentor of 10 mm diameter forced into the surface of the metal being tested under a static load of 3000 kg (29.43 kN) and the load maintained for 10 to 15 seconds. (A load of 3000 kg, in conjunction with a ball indentor of 10 mm diameter, is suitable for use with steels and cast irons. For softer non-ferrous metals and alloys lower values of static load are used.) The diameter of the resulting impression is then measured with the aid of a calibrated microscope. It is customary to measure two values of the impression diameter at right angles to one another and to use the mean of the two values for the determination of the hardness number. The Brinell hardness number, H_B, is given by

$$H_B = \frac{\text{Applied load (kg)}}{\text{Surface area of the impression (mm}^2\text{)}}$$

There are some problems associated with the Brinell test. Impressions made by a spherical indentor are not geometrically similar. Figure 2.1 shows two impressions, one shallow and one deep. Because they are not similar geometrically, the plastic flow pattern in making a deep impression will differ from that in the shallow impression and so the resistance to plastic deformation will differ slightly between the two impressions. It follows that the hardness number obtained from a Brinell test will not be independent of the load used. In other words, if two tests are made on the same material, one using a large static load and one using a small load the hardness values obtained will differ. The recommended values of F/D^2, where F is the load in kg and D is the diameter of the ball indentor in mm to be used in the testing of various materials are given in BS 240(1986) (Table 2.2).

After making a Brinell hardness impression, the parameter that is measured is the diameter, d, of the impression (Figure 2.2). With a shallow impression, the diameter d is small in relation to the ball diameter, D. The angle made between the surface of the material and the tangent to the ball is

Table 2.2 Recommended ratios of F/D^2 for the Brinell hardness test on various materials

Material	F/D^2
Steels and cast irons	30
Copper alloys and aluminium alloys	10
Pure copper and aluminium	5
Lead, tin and tin alloys	1

very small and the edge of the impression is ill-defined when viewed through a microscope, making it difficult to measure the diameter accurately. In the case of a deep indentation, the impression is clearly defined but, although the diameter can be measured accurately, a significant increase in the depth of indentation, and hence increase in the surface area of the impression, would not be reflected in a major change in the diameter, *d*. This, again, leads to a reduction in the accuracy with which the hardness can be

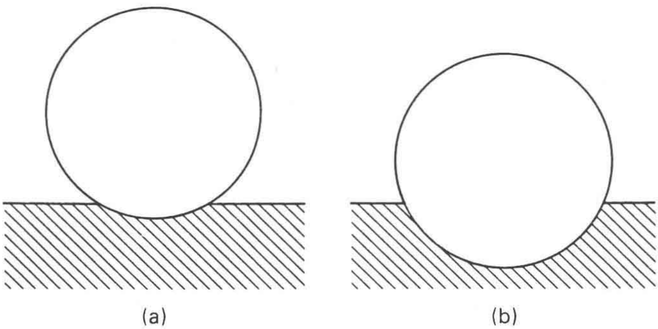

Figure 2.1 (a) Shallow impression, (b) Deep impression. The impressions are not geometrically similar and hence the plastic flow patterns within material differ.

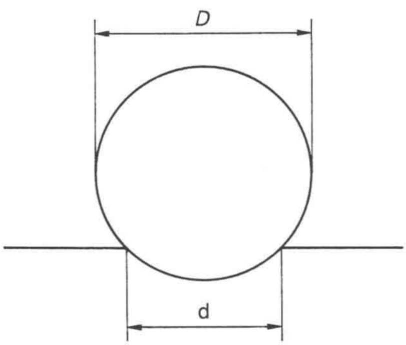

Figure 2.2 Diameter of impression, *d*, in relation to diameter of ball, *D*.