POLYMERS
PHYSICAL TESTING

for post 16 physics courses

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## CONTENTS

**Introduction**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background to materials testing</td>
<td>1</td>
</tr>
<tr>
<td>Compression testing</td>
<td>2</td>
</tr>
<tr>
<td>Hardness testing</td>
<td>4</td>
</tr>
<tr>
<td>Tear testing</td>
<td>6</td>
</tr>
</tbody>
</table>
  - Includes tensile tear, shear tear, and tear initiation tests.      |      |
| Puncture testing                                                      | 10   |
| Adhesion testing                                                      | 12   |
  - Includes cleavage, peel, shear, napkin ring and tape tests.         |      |
| Testing for blocking                                                  | 19   |
| Creep testing                                                         | 20   |
| Impact resistance testing                                             | 24   |
  - Includes falling weight and flexed beam tests.                      |      |
| Flexure testing                                                       | 28   |
  - Includes three point loading and cantilever flexural tests.         |      |
| Testing for friction                                                 | 31   |
| Wear and Abrasion testing                                            | 34   |

| Appendix 1 | Example of compression test calculations | 36 |
| Appendix 2 | Example of calculations for IZOD test   | 37 |
| Appendix 3 | List of ISO numbers for industrial tests| 38 |
| Appendix 4 | Example of analysis of creep data       | 39 |
| Appendix 5 | Sources of some polymer materials       | 45 |
| Appendix 6 | Alternative wear and abrasion test      | 46 |

**Note**

Each chapter includes background information, details of industrial testing procedures and suggestions for suitable laboratory tests.
Introduction

This booklet is intended for use by teachers and students involved with post 16 physics and technology courses (A level, GNVQ, etc.) which contain an element of materials testing. It has been assembled by a group of sixth form teachers working in collaboration with the Polymer Industry Education Centre at the University of York and staff at ICI Wilton (Teeside).

The sections in this booklet deal with individual areas of mechanical testing, with specific reference to polymers. Each section is designed to provide introductory background information for the tests involved, outlines of industrial procedures, related theory and suggestions for modified versions of the tests which can be carried out in school/college laboratories. Most of the test procedures make use of equipment which is commonly available in science and technology departments but there are a few instances where simple apparatus will need constructing by the teacher or laboratory technician.

Test samples can often be cut from discarded packaging materials, plastic drinks bottles and carrier bags or objects such as plastic rulers, tape cassette boxes, plastic knitting needles, plastic coathangers, plastic curtain rail, plastic straws and plastic cutlery (see appendix 5).

Both teachers and students are recommended to read "Materials testing" by Jon Cunnington and John Leeks. The booklet is published by BSI (BSI cat. no. pp 7318: 1988, ISBN 0-580-16082-3). It contains many photographs of materials testing in practice, as well as offering suggestions for building a simple tensile test rig. The booklet gives a comprehensive background to materials testing including detail of the British (BS) and international (ISO) standards to which industry works.
BACKGROUND TO MATERIALS TESTING

The British Standards Institute (BSI) was the first national body in the world to organise specified criteria for industrial applications and testing which were generally accepted as the bench-mark of good practice and agreed common standards. Over 80 countries now have similar organisations, the majority of which belong to the International Organisation for Standardisation (ISO). So what essentially started as an attempt to encourage British Companies to work to common specifications has now expanded to the international arena.

All major materials manufacturers carry out a continuous programme of testing, sample analysis and quality control on their products. Samples are subjected to all kinds of mechanical testing machines, but most of these involve applying tensile stress (through loading) to prepared samples of the same dimensions in order to make comparisons of physical properties. The machines can be set to increase the applied force at whatever rate is chosen. The sample is monitored and its strain is measured. The output from the measuring sensors can be fed to a microcomputer for processing or a chart recorder for a hard copy of the results. The three most common forms of applied stress are shown below.

Mechanical testing is also used to assess the suitability of a material to a particular application by relating the type of test to the working environment of the product. Material testing of polymers in industry is carried out under standard conditions of humidity (50%) and temperature (23°C). Polymers have properties of both solids and fluids and are therefore known as viscoelastic materials.

The average school or college laboratory does not have these testing machines, but the basic techniques used by the professional testers can be modified to work with simple lab apparatus. The tests outlined in this booklet are based on those used by the mechanical testing labs at ICI Wilton. These have all been tested in school laboratory conditions.
COMPRESSION TESTING

Background information

Imagine an object (for example a cylinder) of original length 10cm which reduces to 8cm when a load is applied - then we say the object has compressed by 2cm.

If a heavier load was placed on the object and the new length was 7cm, the compression is said to be 3cm.

So compression is the difference between the original length and the new length when an object is being compressed by a load. This has a particular relevance to large concrete structures since the density of the materials themselves place considerable loads on the foundations, piles and pillars.

Industrial procedure

In industry the information required is usually the compression or deflection of an object under a set load. In this case elaborate equipment is not needed and the standard test procedure simply involves measuring the change of dimensions of a specimen which has been subjected to a fixed dead weight loading. If more detailed information is required then a tensile testing machine, with a capability of recording load when the crosshead movement is reversed, can be used.

The most commonly used specimen shape and size for industrial BSI and ISO compression testing of plastics is a cylinder 30mm high and 12mm in diameter as shown below:

In industrial compression testing, crosshead speeds are usually low (about 10mm/min).

Crosshead speed is the rate at which the testing machine exerts its force, i.e. the speed at which the clamps pull or push on the specimen.
Compression Tests in the Laboratory

Theory: Compression Strength

Comp. strength = comp. strength at failure

= \frac{\text{load at failure}}{\text{original cross-sectional area}}

Apparatus

A - Two pieces of fairly thin rigid material (e.g. metal sheet, hardwood, plywood), used to distribute the load evenly over the cross-sectional area of the test-piece B.

B - The test-piece or specimen. If the specimen is too long compared to the width, it will buckle rather than compress. Also this system will be unstable.

C - A ruler or some other instrument to measure the compression. For accurate work or when working with materials which show little compression you may need to use a dial gauge, a micrometer or vernier callipers, etc.

D - The load responsible for compression.

Suitable materials to test

Examples of materials that could be compression tested in a school laboratory include:

(i) foam (sponge)
(ii) plasticine
(iii) polythene
(iv) packaging materials
(v) expanded polystyrene
(vi) balsa wood (for comparison)

Materials may be shaped, cut, turned etc into the required format. If the material is too thin, use several sheets, one on top of the other until the specimen is the required height.

Method

1. Prepare specimens of different materials (selected from the recommended list).

2. Using the apparatus described above gradually increase the load until failure is reached (i.e. the point at which compression begins) for each specimen.

3. Record the load at failure for each test in a table.

4. Use the equation below to calculate the compression strength in each case and record the results in the table. (See appendix 1 for an example of a compression test calculation)

5. Write a short report explaining the comparative nature of your results.
HARDNESS TESTING

Background information

Hardness is a measure of how easy or difficult it is to damage a material (indent or scratch it) during static loading.

If two materials have had the same load applied over the same area, then the one which has the smaller resulting indentation is the harder one.

With polymers, hardness is usually considered as the resistance of the material to reversible indentation.

Industrial procedure

Since hardness of thermoplastics varies with temperature, industrial measurements are usually made at 23°C. The test methods involve measuring the depth of penetration of an indentor under load.

The Ball Indentation Hardness test and the Rockwell Hardness test are the industry standard tests for hardness of polymers. Both use a hardened steel ball to produce the indentation. The Shore Durometer is another alternative and is based on the penetration of a cylindrical profile indentor. The depth or area of indentation is measured and the smaller the depth or area the harder the material.

Hardness is normally denoted by hardness numbers on scales which relate to individual machines (e.g. Rockwell hardness number).
Hardness Tests in the Laboratory

Apparatus

An example of a simple stable arrangement that could be used in a school/college laboratory is shown above and the individual components are itemised below:

A - Specimen under test. The specimen should be fairly thin (less than 5 mm thick is preferable).

B - A block of wood with a hole drilled into it. The size of the hole should be matched to component D and the specimen under test is placed in the bottom of this hole.

C - A centre-punch. This has a small cross-section in contact with the specimen over which the load will be concentrated.

D - A centre piece made of wood. The flat top portion can be made out of a round piece of plywood and is used as the base on which to rest the load. The bottom half of the piece can be made from hardwood dowel with a diameter such that it is a close fit when placed in the hole in wood block B. It also has a stopped hole drilled into one end to house the centre punch in a stable vertical position when assembled. (The two parts are glued together to make the single component D.)

E - Pieces of foam or some other material which compresses easily. The foam is used to ensure that the base which supports the loads remains horizontal, i.e. that the arrangement is stable.

F - The load.

G - Stop-watch. (The load must be applied for a specified time.)

Suitable Materials to test

As the load is concentrated over a very small area, results can be obtained with a wide range of materials, e.g.

(i) plastics (polythene, acetate, polystyrene, PVC, etc.)
(ii) soft metals (copper, lead, aluminium, etc.)

There is likely to be a problem with obtaining materials of the same thickness. It is possible to build up thin layers (one on top of the other) to get a sample of the required thickness.

Method

1. Set up the apparatus as shown above with a test specimen in place.
2. Position a load for a fixed length of time to produce an indentation in the surface of the material.
3. Use a spherometer to measure accurately the depth of the indentation.
4. Repeat the test for a range of materials using the same load and fixed time, recording your results in a table to show comparisons of hardness.
5. Write a short report explaining the comparative nature of your results.
TEAR TESTING

Background information

It is sometimes difficult to get into certain types of sweet/biscuit packages. The contents keep longer if they are enclosed in an airtight packages, designed to keep out moist atmosphere. A very strong film material to do just this has been developed. Its strength makes it difficult to initiate a tear in it. This is why the manufacturer puts a little nick into the end of the packet where it is sealed. Problems arise when the machine doesn’t make the nick properly!

Tear strength is a vital property for packaging film. In applications such as carrier bags, the tear strength has to be high, whereas in break seals, it has to be low. In either case, the tear strength must be monitored in order to control quality. Tear strength is another mechanical property associated with material failure and is normally quoted in terms of force per unit thickness - N/mm. Unlike tensile strength, in which stress is applied uniformly throughout the material, during tear testing the stress is deliberately concentrated at one point. The localized stress produces failure at some weak spot and failure then progresses steadily through the material. Just as bulk failure can be induced by different types of stress, so too can tear. The most common stresses involved in tear are tension and shear.

The Tear Initiation force is usually greater than the force required to propagate the tear through the material. Because tear initiation is sensitive to minute surface imperfections, each specimen behaves slightly differently. To get a reasonable average value it is necessary to test many individual specimens. Tear Propagation is much more reproducible, requiring only three to five specimens.

To the scientist, the important measure is Tear Energy (the energy required to produce unit area of new surface) but most tear tests are arbitrary and measure the Tear Force.

Industrial procedure - Tensile tear tests

(a) Tests devised to measure tear forces with a tensile action differ mainly in the design of test pieces. These are all designed so that the force is concentrated at one point. Reproducibility is improved by introducing a deliberate flaw in the form of a nick with a sharp blade at the point of stress concentration. Current practice prefers a 90° corner on an angled dumbbell. Crescent and angled dumbbell tear tests are designed for use on conventional tensile testing machines with a variety of test conditions.

(b) The Delft test, which is used for rubbers only, has much to recommend it. Firstly the test piece is small and a special die cutter is not essential. Tear is initiated in the form of a slit at right angles to the direction of pull, so that the forces are balanced with two simultaneous tears taking place. The tear force is twice that of the single tear tensile tests.
Tensile tear testing in the Laboratory

Mechanical testing labs use specially prepared samples, which are not available in schools. These samples also need quite large forces to carry out the tests, so there isn’t any point in trying to obtain them. However, modified versions of tear tests can be carried out in the school laboratory.

**Apparatus**

Cut a 2mm nick in a piece of plastic sheeting (about 10cm x 2cm). Now clamp the piece of sheeting between 2 small pieces of wood so that it hangs vertically from a retort stand with the nick in the middle of one side.

A second pair of wooden blocks can be clamped on the bottom end with a model makers G-crimp. The weight of these must be known because they form part of the load. The sample can be loaded by adding a mass hanger to the cramp, or by attaching a spring balance to it.

(This apparatus is also used for other tests described later in this section)

**Suitable Materials to test**

Packets used for sweets, crisps, biscuits etc. could provide a suitable source of materials for this test.

**Method**

(a) **Testing plastic sheeting**

1. Set up the apparatus as above.
2. Gradually increase the load and observe how the nick behaves.
3. Repeat the test using various nick lengths with the same material and record your observations. Does the initial length of the nick make any difference?
4. If the plastic is transparent, stress concentrations in the area around the nick can be examined through ‘crossed’ Polaroids. Your tutor will advise you on this procedure.
5. Write a short report drawing conclusions from your results.

(b) **Testing rubber sheeting**

You can carry out a simple version of the Delft test using the same procedure as for the plastic sheet in (a). This time you cut a slit in the centre of the specimen (a piece of balloon material would be suitable) rather than an edge, as shown below.

Note: Keep the slit at least 5mm from the edge of your specimen.
Industrial procedure - Shear tear test

Shear tear tests follow the more conventional finger and thumb tests. Some run on tensile test machines whilst others have measuring instruments specially designed for the test.

In the “trouser test”, a slit is cut in a rectangular specimen (typically 50mm x 180mm) to give two “legs”. A shearing action is produced by placing one leg in each clamp of a tensile testing machine and pulling. The tearing force is then measured as the crosshead moves at the selected speed.

![Diagram of Trouser and Three Leg Test](image)

The tear seldom runs as a straight continuation of the slit on a two leg specimen. It tends to veer off at an angle because the in-line pull on one leg is out-of-line with the other fixed leg and this causes the applied load to become angled. One way to overcome this is to use a test piece with three legs as shown in the diagram above.

Shear tear testing in the Laboratory

Mechanical testing laboratories use their tensile testing machines to carry out shear tear tests on specially shaped samples. You can cut pieces of plastic sheet to carry out the “Trouser test” and “Three legged test” in a similar manner to the tensile tests described previously.

Apparatus

As used in the tensile tear test

Method

1. Cut 6 specimens of the same material (50mm x 180mm) as illustrated for “Trouser test” and “Three leg test”.
2. Clamp one leg (two for three leg test) of a specimen between the upper pair of wood blocks in the apparatus used previously and clamp the lower pair of wood blocks to the other leg in a similar manner as before to accommodate a load.
3. Gradually increase the load until failure occurs - this gives the specimen tear force
4. Repeat the test 4 or 5 times for the same material and record your results in a table.
5. From your results calculate an average value of tear force for the material.

Theory

Tear strength is normally quoted in terms of: force per unit thickness - N/mm

\[ \text{Tear strength} = \frac{\text{Tear force}}{\text{Material thickness}} \]

6. Measure the thickness of the specimen with a micrometer or vernier callipers. Use this measurement and your average value of tear force in the equation given above to calculate the tear strength of the material under test. Record your result.
7. Repeat the procedures above for a range of materials and record your results in a table.
8. Write a short report drawing conclusions from your results.
Tear initiation

In both the trouser test and three leg test remember that tear is initiated by the slit and the force measured is related to tear propagation. To measure initiation it is necessary to present a flawless surface to the concentrated tear force. One simple method of doing this is to cut a clean hole at the bottom of the slit in a trouser test piece, using a small circular die cutter, and then carry out the tests as before.

Industrial procedure - Elmendorf test

In the Elmendorf test, a rectangular specimen (typically 75mm x 40mm) with a 20mm slit has one leg secured in a fixed clamp and the other located in a clamp which is connected to a weighted pendulum. When the pendulum is released, the specimen is subjected to a high speed tearing action (7,000 to 40,000mm/minute). The test measures energy instead of force because the angle through which the pendulum moves can be related to the amount of energy used in tearing the specimen. Tear energy can then be related to film thickness and length of tear.

It may be possible to design a suitable version of the Elmendorf test to carry out in the school/college laboratory. Discuss the possibilities with your tutor.
PUNCTURE TESTING

Background information
Many years ago crisps used to come in paper bags, but they very quickly went soggy. The manufacturers also realised that crisps could not only be kept crisp, but would also keep longer if the bags were airtight - to keep out oxygen and moisture.

To be airtight, the film from which the bags are made needs to be very strong to avoid being punctured. Now crisps have sharp edges, but the salt crystals are even sharper! In other words, the contents are more likely to puncture the bags, than their surroundings, or even rough handling!

Industrial procedure
Industrial puncture testing makes use of either a tensile testing machine in compression mode or a drop weight impact machine. Material test scientists usually measure the energy to burst a film, or alternatively they measure the length of tear for a specific drop energy.
Puncture testing in the Laboratory

**Apparatus**

Firmly fix a centre punch to a push-pull forcemeter (electrical insulation tape will do).

The film should be clamped on a simple frame (something like the rings used to hold embroidery are good)

**Suitable Materials to test**

Packets used for sweets, crisps, biscuits etc., plastic carrier bags and film wrappings (cling film) could provide suitable sources of materials for this test.

**Method**

Puncture testing can be done in two ways:

(a) 1. Using the apparatus described above, push the force meter, with centre punch attached, into the film (thus applying a load over a known surface area) and measure the force needed to puncture the film.

2. Repeat the test about 4 times with the same material and record your results in a table.

3. Calculate the average puncture force from your results.

4. Repeat the procedure with different thicknesses and materials to get a comparison of puncture forces.

(b) 1. Set up the film as above, but this time drop the punch from, say 5cm above the film.

2. Does the film break? If not, increase the height from which you drop the punch a further 5cm and repeat until the film punctures.

A cylindrical tube can be used to guide the centre punch during its fall and maintain its vertical alignment. Transparent tubes can be marked with 5cm divisions, otherwise slots can be cut into the tube wall at 5cm intervals, to accurately locate the height of the punch prior to drop. A length of thread can be attached to the punch to lower it down the tube to the required height.

3. Repeat the test for different thicknesses and materials and record your results in a table.

4. How could you modify this test to check out the effect salt crystals would have on the film?

**Theory**

\[ \text{drop energy} = \text{weight} \times \text{drop height} \]

\[ = mgh \]

where:

- \( m \) = mass
- \( g \) = acceleration due to gravity
- \( h \) = drop distance

5. Now use your results in the equation above to calculate the drop energy at failure for each of the specimens tested.

6. Produce a short report explaining the comparative nature of your results.
Background information

There are many ways of joining materials together. For example, they can be joined mechanically by means of bolts, screws, rivets, etc. Each of these items can have a range of mechanical tests carried out on it, and comparisons can be made between items of different size, material and design. Many of the tests in this book could be applied to, say 4 mm bolts made of steel, brass and plastic (e.g. the bolts used to secure car number plates). However, there are occasions where two surfaces need to be continuously joined, for example, the steel plates which make up a ship’s hull must be continuously joined to stop the water getting in! Similarly the waste pipes from kitchen sinks are often “solvent welded” to provide a continuous leak-proof joint.

The term “welding” implies that the molecular structure of the two surfaces to be joined is disrupted by some process, such as applying heat, and is then allowed to settle back into a stable state where there is no discountable junction between the two parts which have been joined. This, of course, can only be done if both the surfaces to be joined are the same material. If the materials are different we need to fill the joint with some kind of gap filling material. Such a material will need to:

- be strong itself
- stick well to the materials to be joined.

We can carry out mechanical tests on a sample of the adhesive itself to check out its bulk properties, but just how well it sticks to another material is also vitally important. This property is called adhesion.

More and more modern polymeric products consist of assemblies of several components (known as substrates). Accordingly, measurements of adhesion between any two components are necessary. As was the case with the previous tests, the first task is to identify the types of stresses associated with adhesive failure. In some cases tensile stresses are present but shear stresses are more common.

In both tension and shear the forces are uniformly distributed across the complete adhesive layer or interface between the two components. The easiest way to overcome adhesion is by cleavage or peel.
**Industrial procedure**

Cleavage and peel feature as types of failure in many products. If both substrate's are flexible, specimens can be constructed from strips of uniform width by separating the substrate's from part of the joint and locating the free ends in the clamps of a tensile testing machine. As the clamps are separated at a preset speed, the peel force is recorded.

Both cleavage and peel mechanisms have much in common with tear; stress is concentrated at one point and failure occurs progressively across the material. Failure during adhesion tests is a complex subject. Industrial procedures consider five sites of failure with a simple assembly:

- **V** Failure within substrate S\(_1\)
- **W** Failure at the substrate S\(_1\)/adhesive A interface
- **X** Failure within adhesive A
- **Y** Failure at the adhesive A/substrate S\(_2\) interface
- **Z** Failure within substrate S\(_2\)

Failure within one layer can be termed **Cohesive failure** whereas failure at an interface is termed **Adhesive failure**.
Adhesion Tensile testing in the Laboratory

Apparatus

Stick two prepared surfaces together, and once the adhesion has set/cured carry out a simple loading test.

- Top block clamped to a retort stand
- Lower block drilled and fitted with a cup hook so that a mass hanger and slotted masses, or a spring balance can be used to exert a tensile force.

Suitable Materials to test

Prepare specimens of a single polymer material having the same surface area on one face. Square and rectangular section plastic strip is available from model supplies shops. Select a range of adhesives to use with the test (discuss with your tutor).

Method

1. Using the apparatus shown above, gradually increase the load on the mass hanger until the adhesive fails.
2. Repeat the test for different adhesives, using the same surface area, and record your results in a table.
3. If no failure occurs when all the weights have been added you will need to consider the surface area over which you spread the adhesive!

Theory

The force at failure can be related to the area of the joint as follows:

\[
\text{Tensile adhesive strength} = \frac{\text{Maximum load}}{\text{Area of joint}}
\]

4. Use your results to calculate the tensile adhesive strength for each specimen tested.
5. Produce a report explaining your results.

Adhesion Cleavage Tests in the Laboratory

Apparatus

- Flexible layer
- Lower strip drilled to accept mass hanger

Suitable Materials to test

Stick together two flexible strips of wood or plastic (top and bottom substrate's) of the same surface area. Clamp the top substrate and secure a mass hanger to the bottom one in a similar way to the tensile test.

Method

1. Using the apparatus shown above, gradually increase the load on the mass hanger and observe the effect.
2. Record your observations. Do you get a precise fracture load? Or does the adhesive fail gradually.
3. Repeat the test with a range of adhesives using the same surface area.
4. Present a short report discussing the results of your tests.
Industrial procedure - Peel tests

Two versions of the peel test are used in materials labs. In products where one substrate is rigid, tests can be done with either a 90° or 180° peel angle.

In the 180° peel test, the joint is subjected to additional stress due to bending of the flexible substrate. This may result in misleading peel strength values, particularly with pressure sensitive adhesives. Furthermore, 180° peel is seldom the mode of failure in real products. Efforts are usually made to adapt peel tests to give data for low angle peel.

Adhesion Peel tests in the Laboratory Method

Apparatus

Flexible top substrate
Adhesive layer
Rigid bottom substrate

Clamp
Mass hanger

1. Using the apparatus shown, gradually increase the load on the mass hanger and observe the effect.
2. Record your observations. Do you get a precise fracture load? Or does the adhesive fail gradually.
3. Repeat the test with a range of adhesives using the same surface area.

Theory

Peel strength is quoted as force per unit WIDTH with units of N/mm or kN/m, giving:

\[ \text{Peel adhesive strength} = \frac{\text{Maximum load}}{\text{Width of joint}} \]

4. From your recorded observations calculate a peel adhesive strength for each specimen tested.
5. Produce a short report explaining the comparative nature of your results.
Industrial procedure - Shear tests

There are two methods used for adhesive shear testing. Simple overlap joints are the first obvious method of generating shear strength data but close observation of the test shows that the forces pulling the substrate's would need to be slightly out of plane to give true shear failure. This can be overcome by using an offset joint but a double lap joint is preferable.

Adhesion Shear testing in the Laboratory

Apparatus

The top piece of material is clamped, and the lower ones can be drilled to take a bar for a mass hanger or spring balance.

Suitable Materials to test

Make up a range of test specimens as illustrated above. In each case use three strips of the same polymer but vary the surface areas for the same adhesive.

Method

1. Set up each specimen in turn, as shown in the apparatus diagram, and gradually increase the load until the adhesive fails.

2. Record your observations, the surface area of adhesive and load value.

3. Does the adhesive fail suddenly or gradually? Does the adhesive become elastic before failure?

4. Repeat the tests for a range of appropriate and inappropriate adhesives.

5. Produce a report explaining your results.
Industrial procedure - Napkin Ring tests

Where a purer form of shear is required (for design purposes) the second method, known as the "Napkin Ring Test", may be used. This uses a twisting action in a hollow cylinder assembly.

For this test a machine is used which can twist the test piece and measure the twisting force, or torque.

Adhesion "Napkin Ring Test" in the Laboratory

The "Napkin Ring Test" can also be easily simulated in school.

Apparatus

1. Set up the apparatus shown, with each end of the supporting rod clamped in a retort stand.

2. Gradually increase both loads simultaneously until the adhesive fails.

3. Does the adhesive fail suddenly or gradually? Does the adhesive become elastic before failure?

4. Record your observations and the load value at point of failure.

Theory

Applied torque = Load x diameter of ring = F x d (for each ring)

Suitable Materials to test

Specimens need to be made up as illustrated above with a hole through the centre so they can freely rotate on the supporting rod. A small hole should also be drilled in the side of each ring to use as anchorage points for the load strings.

Method

1. Set up the apparatus shown, with each end of the supporting rod clamped in a retort stand.

2. Gradually increase both loads simultaneously until the adhesive fails.

3. Does the adhesive fail suddenly or gradually? Does the adhesive become elastic before failure?

4. Record your observations and the load value at point of failure.

4. Use the equation above to calculate the applied torque at the point of failure for each specimen tested.

5. Produce a report explaining your results.
**Adhesion Sticky Tape test in the Laboratory**

This is the basic test used by professionals to test the “stickiness” of adhesive tapes.

**Apparatus**

![Diagram of Adhesion Sticky Tape test](image)

The length of adhesive tape is mounted on a horizontal surface with the “sticky side” uppermost. Some form of plastic channel/groove extrusion (e.g. curtain rail or sliding door guides) or folded cardboard could be used for the sloping groove to guide the ball bearing.

**Method**

1. Set up the apparatus as in the diagram above.
2. Place the ball at a marked point on the slope, then release.
3. Measure how far it travels along the horizontal surface of the tape. The shorter the travel, the stickier the tape.
4. Produce a short report outlining your conclusions from the test results.

**Some variations**

Think how you could modify the test to investigate the following:

1. Does the tape lose its stickiness in use? (over a few minutes or a few days, etc.)
2. The stickiness of different types of tape. (manufacturers/widths/colours, etc.)
3. The stickiness on different sizes of ball bearing.
4. The stickiness effect on different materials e.g. wood/ceramic/glass etc.
BLOCKING

Background information
Have you ever had problems opening a polyethylene food bag from a roll? The sides tend to stick together. This happens as the material is rolled, and the process is called blocking. The manufacturers try to prevent the problem by minimising the tension when rolling and adding anti-blocking agents to the polymer.

Industrial procedure
Industrial tests for blocking make use of a tensile testing machine which has been adapted to measure the line force needed to separate two layers of film.

Measuring Shear Blocking Force in the Laboratory
This simple test investigates the effectiveness of manufacturers anti-blocking processes by measuring the shear blocking force of a food bag.

Apparatus
1. Obtain a food bag from a roll and cut off the closed end:

2. Obtain 3 metal strips (e.g. meccano) - two of them need to be the length of the cut down bag, and one about 5cm longer.

3. Clamp the two shorter pieces to one edge of the bag, using modellers’ G-cramps or nuts and bolts, as shown in the diagram. (Card strips could be used as an alternative and stapled in position.)

4. Carefully slide the longer metal strip between the two sides of the bag at a midway position across its width so that it projects from the bag at both ends. (Make sure you only pull the film apart just enough to slide the strip through.)

5. Now place the ends of the longer strip on firm supports and allow the clamped on strips to hang down, as shown in the diagram.

Method
1. Gradually load the clamped strips until the whole bag starts to slide down as the two films peel apart.

2. The load at this point is now equal to the shear blocking force.

3. How could you measure the tensile (direct pull) blocking force?

HINT:
You could start by cutting the closed end from a food bag as before, then use some double sided sticky tape to hold it down to the bench. Discuss the possibilities with your tutor.

4. Present a report explaining your results.
CREEP TESTING

Background Information

Under load, components may change shape over a period of time and this is known as Creep. For example, a poorly designed large storage tank may retain its shape well when first filled with a liquid but it could gradually distort over a period of months and may even rupture. An every day occurrence is more noticeable in the way plastic carrier bags and dustbin liners stretch when they contain heavy items. Clearly, manufacturers and designers require advance knowledge of the amount of deformation that will be experienced by their products in long-term service. Vital information on creep properties is required for the design of such products as bridge bearings, gears, valves, storage vessels, pipes, break fluid reservoirs and suspension systems.

The term Creep is used to describe the increasing amount of deformation of materials under a constant stress over a fixed period of time. For materials under tensile stress, this property is quantified by categorising three types of deformation as follows:

1. Elastic Behaviour. In this case, a strip of material is stretched by a fixed amount immediately on application of a load and returns to its original length and shape immediately after the load is removed. The creep strain is therefore proportional to the applied stress.

2. Linear Viscoelastic Behaviour. In this case, the material deforms immediately on application of a load, but it extends further with increasing time under load. When the load is removed, the sample reverts to its original dimensions. The recovery is rapid at first but then slows down towards the final stages. Thus, with a linear viscoelastic material, the observed creep strain is not only proportional to the applied stress or load, but is also a function of the time of application of the load.

3. Non-Linear Viscoelastic Behaviour. Unlike the previous two processes, creep in a non-linear solid is not directly proportional to stress. Instead, the amount of creep is not only a function of time of application of the load, but also of the stress level applied for that time. After removal of the load, recovery is not complete. Non-linear viscoelastic creep behaviour needs to be described in three dimensions and is, therefore, a very complex mechanical property. Unfortunately for those involved with the plastics industry, all thermoplastics exhibit non-linear viscoelastic behaviour.

Stress-strain-time data can be presented in different ways according to the selection of information for particular requirements as follows:

creep curves of strain versus log time
isochronous stress (i.e. stress at constant time) versus strain curves
isometric stress (i.e. stress at constant strain) versus log time curves

<table>
<thead>
<tr>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creep stress = creep force</td>
</tr>
<tr>
<td>original cross sectional area</td>
</tr>
<tr>
<td>Creep strain = increase in length</td>
</tr>
<tr>
<td>original length</td>
</tr>
</tbody>
</table>
**Industrial procedure**

Creep tests in industry may be done over a period of several years so the test rigs must be simple in design and relatively inexpensive compared to other testing machines. Even so, a typical cost for a creep test rig could be about £10,000. The most widely used test methods for creep involve either suspended dead weight loading or lever loading.

The test samples are loaded and changes in length are noted at specified intervals of time for a constant load over an extended time period. Measurements to an accuracy of 0.1% are normally sufficient so conventional dial gauges and micrometers are adequate.

Greater accuracy is achieved in industry by the use of a Moire fringe extensometer. This is based on the optical patterns created when two fine grids are moved relative to one another.

As with other tests, temperature and humidity conditions are carefully controlled over the full test period (hours/days/weeks/years).
Creep Tests Under Constant Stress in the Laboratory

Apparatus

Possible test arrangements include:

(i) suspending the specimen vertically with a load at its lower end.

(ii) placing the specimen horizontally, clamped at one end with a thread or wire attached to the other end which runs over a pulley to a vertically suspended load.

There should be some means of protecting the floor from the falling weight if the specimen breaks (for example placing a bin below filled with paper/foam/sand/wood chips/carpet).

Suitable Materials to test

Strips of material can be cut from polythene sheet, heavy duty plastic bags and bin liners, carrier bags, plastic document wallets etc. Ideally test specimens should be dumbbell shape but narrow rectangular shapes (100mm long x 10mm wide) will be adequate.

Method

1. Measure the original width and thickness of the test specimen and hence calculate the cross sectional area.

2. Measure the original length of the test piece either by the use of index marks on the specimen or the distance between the clamps.

3. Set up the specimen under load as shown in the diagram. Remember that the lower clamp and mass hanger are part of the load.

4. Measure the changes in length of the specimen under load at regular time intervals for an extended period of time (as allowed by local circumstances) and record your results in a table. Measurements can be made using a micrometer, vernier callipers or dial gauge and relate to the separation of index marks on the specimen or clamp separation. Position sensors (available from Phillip Harris) connected to a computer could also be used.

5. Ideally the stress should not vary by more than 1% over the time period of the test so large deformations should be avoided. Calculate stress and strain values as shown earlier.

6. After a series of length measurements have been made at one specific load, plot a graph of creep strain against time, as in Graph - A below. If the frequency of readings decreases with increasing time, it is better to plot strain against log time and the curve shape changes as shown in Graph - B.

7. What conclusions can you draw from the graphical data?
Examples of other possible curves and derived graphs

Isometric stress - constant strain

Isochronous stress - constant time.
IMPACT RESISTANCE TESTING

Background information

The ability of a polymer to cope with a single high speed stress is known as Impact Resistance and the minimum stress level required to cause catastrophic failure (destruction) is the Impact Strength of the polymer. At sufficiently low temperatures, all polymers behave in a brittle manner when exposed to impact. However, a polymer which normally fails in a ductile manner under test (by first exhibiting yield and then drawing or necking) can be transformed into a brittle material by speeding up the rate of application of stress.

Impact is a complex stress phenomenon controlled by many variables and there is no single, universally accepted test. In mechanical testing, particularly destructive testing (testing to fracture of the material), tests must be selected which approximate most to the service conditions of the finished product. Impact testing can only be used to indicate toughness if all the critical parameters are matched between the test specimens and finished articles.

Impact tests divide into three main categories as follows:

- Falling weight impact test
- Flexed beam impact test
- Tensile impact test

In this section we deal mainly with the first two of these tests since the third (Tensile impact) requires specialist industrial equipment.

Industrial procedure - Falling Weight tests

Falling weight impact tests are closer to service impact conditions than flexed beam tests and finished products are often used as the test specimens. There are many variations of this test with some equipment consisting of a clamping system to locate the specimen and a falling weight (often known as a TUP) guided in a tube or on rails. The simplest tests are the GO/NO GO type where a specified weight is dropped from a fixed height. The test specimen either passes or breaks and fails. The Staircase method and Probit method are examples of this.

Until recently, drop weight impact tests were associated with catastrophic failure (i.e. test to destruction) but now the preferred methods assess the deformation that occurs during catastrophic failure. This is accomplished by fitting force transducers and accelerometers to the falling weight. Data is collected immediately before, during and after impact with the aid of microcomputers which record and display the stress/strain behaviour over very brief time scales. The data recorded by the computer allows a more sophisticated determination of break energy, yield point, yield energy and embrittlement temperature. The Instrumented Fracture test is an example of this type.
Falling Weight Impact Test in the Laboratory

**Apparatus**

- **A** - Test-piece or specimen.
- **B** - G-cramp or some other means of securing sample to a surface/bench.
- **C** - A piece of strong material (one that is stronger than the material being tested) on which the falling weights land. This ensures that the impact force acts over the same surface area of the specimen each time the procedure is repeated.
- **D** - The weight being dropped.
- **E** - Some means of protecting the floor from the falling weight if the specimen breaks (for example a bin containing paper/ foam/sand/carpet).
- **F** - A tube to guide the falling weight. The falling weight must not touch the sides of the tube. If the weight is dropped through a small height, h, a guide may not be required.

**Suitable Materials to test**

About 18 identical moulded specimens are required, i.e. same material, same width, etc. It is best to use long, thin specimens (e.g. 100mm long x 10mm wide x 4mm thick) except with very weak materials. Flat style plastic trouser and coathangers (found in clothing stores), handle sections of plastic cutlery and plastic rulers can be suitable sources of material.

**Method**

1. The apparatus is set up as illustrated above. The weight is dropped from the same height each time.
2. (a) If the specimen breaks after the weight is dropped from the specified height, then a lighter weight should be dropped when the procedure is repeated with another specimen.
   (b) If the specimen does not break and shows no signs of damage - then leave the specimen in place and repeat the procedure with a much heavier weight.
   (c) If the specimen does not break but shows visible signs of damage (cracks/indentation) then it should be replaced and a heavier weight used when the procedure is repeated.

This procedure is used to find the minimum weight which results in fracture. Increases and decreases of weight could be at intervals of 5N. Record your observations.

3. After all 18 specimens have been used the results will show values of several weights which caused the specimen to fracture during impact. Calculate an average value of all weights used to include in the formula below to determine the impact energy for the material under test.

**Theory:**

In this test the energy needed to break a sample is found, where:

\[ \text{Impact Energy} = \text{force} \times \text{distance} \]

In the case of a falling weight the force acting on it is gravity

\[ \text{i.e. force} = \text{weight} = \text{mass} \times \text{gravitational field strength} \ g \]

\[ \therefore \text{Impact energy} = \text{mgh} \] (Nm)

where :

- \( m \) = mass
- \( g \) = gravitational field strength
- \( h \) = height through which mass fell

4. Produce a report discussing the results of your tests.
**Industrial procedure - IZOD and CHARPY tests**

The cantilever beam (IZOD) and three point loaded beam (CHARPY) tests are used for Flexed Beam impact testing in industry.

The IZOD test uses bars of rectangular cross section for the test specimens (typically 80mm x 10mm x 4mm). The bars are clamped vertically with one half extending above the clamp (usually a vice). A blow from a weighted pendulum is made at a point 22mm above the clamp, applying a bending stress to break the specimen. The energy used to fracture the specimen (impact energy) is calculated from knowing the height at which the pendulum was released and the height to which it continues to swing after impact.

The test bars are usually cut with a 45° notch at their mid point to a depth of 20% of the bar thickness. The bar is positioned with the notch on line with the jaws of the clamping device. This overcomes irregularities in values caused by flaws and imperfections in the material and ensures that specimens of a particular polymer will fail at about the same impact energy level.

The CHARPY impact test also uses rectangular bar specimens, with or without notches. The smallest bar measures 50mm x 6mm x 10mm and the largest 125mm x 13mm x 13mm. The specimen is placed un-clamped in a horizontal position on the impact tester with the front face (with notch) resting against two radiused supports. For the smallest size test specimen the supports are 40mm apart. The bar is then struck by a weighted radiused pendulum head on the back face. Impact energy is then measured as before.

**Flexed Beam Impact Test in the Laboratory**

This is a modified version of the IZOD cantilever beam test

**Apparatus**

![Diagram of IZOD test apparatus](image)

A - The specimen.  
B - Vice or some other device for clamping the specimen vertically.  
C - A pendulum made from thin metal rod with a mass attached.

A more stable pendulum using a hammer pivoted on a fixed vertical support could be used:

![Diagram of modified pendulum](image)

Specimens can have a notch machined into them. This ensures fracture at lower impact energies and helps with reproducibility of results. If a notched specimen is used the impact must occur above the notch.
Suitable Materials to test

Specimens need to be long but fairly thin (typically 80mm x 10mm x 4mm). Around a dozen equal sized specimens of each material to be tested are required for quantitative work. Flat style plastic trouser and coathangers (found in clothing stores), handle sections of plastic cutlery, tape cassette boxes and plastic rulers can be suitable sources of material.

Method

(a) Comparative

1. The pendulum is attached directly above the point where the specimen is to be clamped.

2. Clamp the specimen vertically so that one half extends above the jaws.

3. Raise the weighted pendulum through some height, h and release it.

To compare how different materials respond to impact - use the same pendulum raised through the same height on each specimen of a different material and compare the damage.

(b) Finding Impact Energies

1. Using the same apparatus as above, raise the pendulum through some height, \( h_1 \) (measured in metres) and release it.

2. After the pendulum has impacted with the specimen the height, \( h_2 \) through which the pendulum continues to swing must be measured using a ruler.

3. A preliminary test should be done to find the approximate pendulum mass and height of drop needed for fracture.

4. (a) If the specimen breaks when the pendulum impacts with it then a smaller mass for the pendulum should be used from the same height when the procedure is repeated with another specimen of the same material.

(b) If the specimen does not break but shows signs of damage - then replace with a new specimen of the same material and repeat the procedure with a slightly larger mass from the same height.

(c) If the specimen does not break and shows no signs of damage - then leave the specimen in place and repeat the procedure with a heavier mass pendulum from the same height.

5. After all the specimens of a single material have been used, you should have height \( (h_1 \text{ and } h_2) \) and mass values for several pendula which resulted in the samples breaking during impact.

Theory

In this test some of the gravitational potential energy of the pendulum was transformed into the impact energy.

The formula for the gravitational potential energy of the pendulum is

\[
\text{mass} \times g \times \text{height}
\]

To find the impact energy you need to find the maximum gravitational potential energy (i.e. at point of release \( h_1 \)) of the pendulum before impact and resultant potential energy after impact (i.e. at height to which it swings after fracture \( h_2 \)).

Impact energy is the difference in these two gravitational potential energies.

Impact strength is the impact energy per cross sectional area at the point of fracture.

\[
\text{Impact strength} = \frac{\text{impact energy}}{\text{cross-section area}}
\]

6. Use the values of mass and corresponding heights \( (h_1 \text{ and } h_2) \) to calculate an impact energy figure for the material under test (example calculations for an IZOD test are given in appendix 2 to help you with this).

7. Present a report of your findings.
FLEXURE

Background Information

In everyday use, products made from polymer materials are probably more commonly subjected to flexing than either pure tension or pure compression. Flexural testing of polymer materials therefore gives important information about their performance in everyday use. For practical application of a material, flexural yield stress sets the upper limit of its usefulness. This is the stress at which a material begins to experience permanent deformation.

Any single flexing test you devise will represent a particular combination of tension, compression and shear. The tensile component is the most important. Although the ratio stress/strain is called the Flexural Modulus, it is in fact a tensile modulus (i.e. it is closely related to the Young Modulus obtained from tensile testing). Flexural Strength is the strength related to a surface stress at failure/fracture associated with bending beams.

Interpretation of data is further complicated by the fact that the structure of a polymer sample is virtually always heterogeneous. The molecules at the surface of an injection moulding are oriented in the flow direction, whilst those inside are either unoriented or aligned at right angles to the flow direction. In the case of fibre-filled polymers, the effects of molecular orientation are over-ridden by the orientation of the fibres themselves.

Industrial Procedure

Industry uses standard three point loading tests to investigate flexure, the test piece is a bar of rectangular cross section with a length at least twenty times its thickness. The bar is placed on two supports near its ends, the distance between the supports being about sixteen times the thickness. The test load is applied at the mid-point. To avoid localized stresses, the supports and load nose are rounded.

The test usually takes the form of applying static loads and measuring the corresponding deformation at the mid-point. Deflection is small and measured with precision instruments. Also deflection changes with time so a fixed time interval is allow after adding the load before measuring the deflection. In industry this process can be carried out on specially modified tensile test machines. This involves attaching an appropriate frame with two rounded supports to the fixed head, and a rounded nose attached to the moving crosshead.

An alternative method is the cantilever flexural test where the test piece is a bar of rectangular cross-section securely clamped at one end in a horizontal position. Loads are applied to the free end to produce measurable deflections. Since deflection is a function of time, the measurements are taken at a fixed time after the specimen has been loaded.

One of the limitations of this method is the difficulty in measuring the small deflections at the point of application of the load. To overcome this, some comparative tests incorporate lever systems to amplify the deflection.
Three Point Loading test in the Laboratory

Apparatus

A - Rectangular bar test specimen typically 100mm x 10mm x 4mm.

B - Retort stand with round bars clamped to act as supports for the test specimen. Clamp to the bench for stability/safety.

C - Mass hanger for applied loads (W)

D - Rectangular carrier frame made from two flat side strips (similar to meccano) with horizontal round bars joining across the top and bottom. The top cross-bar rests on the top surface of the test specimen and the bottom cross-bar provides a location for the mass hanger

Suitable Materials to test

Flat style plastic trouser and coathangers (found in clothing stores), tape cassette boxes and plastic rulers can be suitable sources of material.

Method

1. Set up the apparatus as in the diagram with the retort stand supports positioned according to the thickness (t) of the test specimen (L=16 x t).

2. Position the carrier and mass hanger on the test specimen at the mid-point between the two supports.

3. Add a load and measure the deflection (y) at the mid-point after a fixed time (e.g. 60 secs).

4. Increase the load and repeat the procedure until failure occurs. Record your results.

5. From the information given below calculate the Fibre Stress and the Strain for each deflection measurement made.

Theory

The critical stress value to which the material is subjected is the tensile stress along the bottom face - referred to as the Fibre Stress. The formula relating fibre stress to applied load is:

\[ \sigma = \frac{3WL}{2bt^2} \]

Where: 
- \( W \) = load (force) applied at mid-point
- \( L \) = distance between supports
- \( b \) = bar width
- \( t \) = bar thickness

(make sure all dimensions are in the same units)

At the point of failure, \( \sigma \) becomes the ultimate flexural stress (also called flexural strength or cross breaking strength).

The Strain is given by:

\[ \text{Strain} = \frac{6yt}{L^2} \]

where:
- \( L \) = distance between supports
- \( t \) = thickness of bar
- \( y \) = deflection at the mid-point.

6. Use your figures to plot a graph of fibre stress against strain.

Theory

Provided that the deflection at the mid-point is small (i.e. in the region where the stress/strain plot is linear), Flexural Modulus (\( E_f \)) can be calculated using the expression:-

\[ E_f = \frac{WL^3}{4bt^3y} \]

where:
- \( W \) = load (force) applied at mid-point
- \( L \) = distance between supports
- \( b \) = bar width
- \( t \) = bar thickness
- \( y \) = deflection at mid-point

7. What conclusions can you draw from your graph?
Method for Flexural yield stress

The previous procedure may be modified to produce a value for flexural yield stress. After adding each extra load and noting the new deflection, the whole load should be removed and the deflection measured. When the load is removed, it will be necessary to allow a time (for example 60 seconds) for the specimen to recover its shape before taking the measurement. Before yield stress is reached, the deflection will return to zero.

Cantilever Flexural test in the Laboratory

Apparatus

A - G cramp or similar to secure test specimen to a bench top.
B - Small wood blocks to evenly distribute the clamp pressure over the surface of the specimen
C - Test specimen - a bar of rectangular cross-section (typically 100mm x 10mm x 4mm). Avoid soft or thin section test pieces in which the weight of the specimen is sufficient to give a measurable deflection.
D - Mass hanger to apply the load.

Suitable Materials to test

Flat style plastic trouser and coathangers (found in clothing stores), tape cassette boxes and plastic rulers can be suitable sources of material.

Method

1. Set up the apparatus as in the diagram with some means of protecting the floor from the falling weight if the specimen breaks (for example a bin with paper/foam/sand/carpet).
2. Hang a load from the free end of the bar and measure vertical deflection (y) at that point after a fixed time (e.g. 60 secs). Accurate measurements can be made with a micrometer, dial gauge, vernier callipers or travelling microscope. Less satisfactorily, a millimetre scale could be used.
3. Repeat the procedure gradually increasing the load each time, and record your results in a table.
4. From the information given below calculate the Flexural Stress and the Strain for each deflection measurement made.
5. Use your figures to plot a graph of flexural stress against strain.
6. What conclusions can you draw from your graph?
TESTING FOR FRICTION

**Background information**

When a body is moved across a surface, a resistance force is experienced between the two surfaces. This resistance force is termed **friction**. The heat caused by friction is just one reason why it is important to test the frictional properties of materials.

For example, in compact disc players and self loading tape cassette players the materials for the gear wheels which actually drive the tray (taking the CD or tape cassette into the player) need to have low frictional properties, largely because you can't regularly give them a good dose of oil. However, in the case of a pop bottle you want high frictional forces between your hands, the bottle and the cap if you are going to be able to open it easily.

All of this means that specific frictional properties are required for different purposes and as a consequence, manufacturers need to test materials to see if they match up to product and customer requirements. For most traditional materials and surfaces, friction increases in direct proportion to the weight of the body, i.e.

\[ \frac{\text{friction}}{\text{weight}} = \text{constant} \]

This constant is known as the **Coefficient of Friction** ($\mu$). With traditional materials (metal, wood, ceramics, etc.) the coefficient of friction is independent of:

- area of contact
- relative speeds of movement of the two surfaces.

For traditional materials the only exception to the foregoing laws is that the resistance force experienced when starting a body from rest (static friction-$\mu_s$) is usually significantly higher than the frictional force recorded when the surfaces are moving at uniform speed (dynamic friction - $\mu_d$).

Unfortunately, polymers do not obey the classical laws of friction. With these materials the measured coefficient of friction is not constant but varies with speed (velocity) and load (pressure). As with other properties, F/W also varies with humidity and temperature. Thus, in contrast to most traditional materials, the frictional properties of polymers cannot be defined adequately from the results of a single test.

Why do polymers behave in this way? It is reasonable to assume that friction will be directly proportional to the area of contact between the two bodies. However, under a microscope the contacting surfaces of all materials do not appear smooth but consist of a series of peaks and troughs as shown below.

![Microngraph of contacting surfaces](image)

The true contact area is quite small. Increasing the load causes the peaks to deform and increase the true contact area and hence increases frictional force.
In traditional materials, where the deformation mechanism approximates to classical elasticity, the true contact area is directly proportional to the applied load. In this case, the frictional force is also directly proportional to the applied load and $F/W$ remains constant over a range of applied loads. However, polymers are viscoelastic materials and exhibit non-linear stress/deformation relationships. So, for polymers, we should not expect the true contact area to vary directly with applied load and the ratio $F/W$ will not necessarily be a constant for all values of applied load. Since deformation also varies with rate of application of strain, $F/W$ also varies with relative speed of movement of two bodies.

Thus, for friction testing of polymers and elastomers, it is essential that the following features of the test should be clearly defined:

- applied load
- relative surface velocities

Industrial mechanical testing also considers temperature, humidity and surface conditions. In school/college laboratories we may be able to control surface conditions to some extent but we do not have the facilities (i.e. a sealed chamber) to investigate the effects of temperature and humidity in too much detail.

Industrial procedure

This is how the professionals test materials for friction:

(a) Dynamic Friction

Friction tests may be between two surfaces of the same material or between different materials. Several different designs of test are in common use. One of the simplest is to move a flat surface of one material under a block or sled of the other. The sled is connected to a spring balance to measure the frictional force.

For film testing, the film may be clamped to the moving bed or wrapped round a metal block to act as a sled. In the latter case, it is advisable to have an underlay of medium density foam between the film and the metal block to ensure uniform surface contact with the moving bed.

(b) Static Friction

This can be measured from the angle of inclination required to start a body (the sled) moving on a surface. The test body of known weight is placed on a horizontal surface. The angle of inclination of the surface is then gradually raised until the body starts to slide.
Static Friction test in the Laboratory

Method

1. Record the weight of the test specimen.
2. Set up the apparatus as in the diagram with the test specimen resting on the movable surface in the horizontal position.
3. Gradually increase the angle of inclination of the movable surface until the test specimen just starts to slide. At this point measure the angle of inclination with a protractor or other angular scale.
4. Repeat the procedure three times with the same test specimen. Record your results and calculate an average value for the angle of inclination.
5. Repeat the test with different materials.
6. Use the information below to calculate the coefficient of friction ($\mu$) for each specimen.
7. Produce a report explaining your results.

Theory

At the point where the test piece begins to slide, the frictional force, $F$, is equal to the component of weight in the plane of the friction surface. In calculating the coefficient of friction, the load which has to be used is the force acting at 90° to the friction surface (Normal force, $N$). For horizontal surface tests, the weight of the sled is the effective normal force. On inclined surfaces, the normal load is related to the weight and the angle of inclination.

$$W = \text{weight of test specimen}$$
$$\theta = \text{angle of inclination at point of slipping}$$
$$N = \text{force normal to inclined surface}$$
$$= W \cos \theta$$
$$F = \text{frictional force in the plane of inclination}$$
$$= W \sin \theta$$

Calculation

coefficient of static friction ($\mu$)

$$\mu = \frac{F}{N}$$
$$= \frac{W \sin \theta}{W \cos \theta}$$
$$= \frac{\sin \theta}{\cos \theta}$$
$$= \tan \theta$$

Associated maths

For any right angled triangle:

$$\sin \theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$
$$\cos \theta = \frac{\text{Adjacent}}{\text{Hypotenuse}}$$
$$\tan \theta = \frac{\text{Adjacent}}{\text{Opposite}}$$

.$$. \tan \theta = \frac{\sin \theta}{\cos \theta}$$. 

33
WEAR AND ABRASION

Background information

Many fabrics and solid materials are exposed to wear in everyday use - for example, carpets become worn and tyres on cars and bikes wear. **Wear** is the loss of material under the action of dynamic frictional forces.

There are three types of wear mechanism:

**Adhesive wear** - the physical transfer of material from one surface to another.

**Abrasive wear** - loss of material due to dynamic contact with hard surfaces or abrasive particles.

**Fatigue wear** - loss of material resulting in failure due to dynamic stresses in the vicinity of the interface. This is usually characterised by loss of larger pieces of material than in abrasive wear.

When testing for wear, the first task is to devise an abrasion test which is most suited to the type of wear and service conditions of the material.

### Industrial procedure

There are several standard test methods used in industry as follows:

**The Taber abrader** - This method consists of two 100mm diameter abrasive wheels bearing down on a test specimen in the form of a flat sheet on a rotating turn-table. The abrading wheels are slightly misaligned to produce the necessary abrading action and dead weights are applied to the wheels to vary the abrading pressure. The abrader is run for a set number of cycles and the results are then compared with those of a standard material under identical conditions. Assessment is normally based on loss of weight from the specimen in mg/1000 revolutions.

**The DuPont abrader** - In this method the abrading surface is a flat disc rotating at a set speed. The specimens are in the form of small discs which are pressed against the face of the abrasion disc under a controlled tension. Assessments are then made as before.

**The DIN abrader** - This is the German standards abrasion test and consists of a rotating drum which has an abrasive outer surface and an arm which moves laterally along the length of the drum. This ensures that a fresh abrasive surface is always presented to the specimen. The test specimens are in the form of discs or small blocks which are secured to the arm and then held against the abrasive surface of the drum under a controlled pressure using a lever and weight system. In this case volume loss is measured as thickness loss from the specimen and assessments made as before.

**The National Bureau of Standards (NBS) abrader** - In this method the abrasive surface is the outer surface of a wheel or cylinder. The test specimens are in the form of blocks or discs mounted on an arm and held against the abrading surface by a lever and weight system. Volume loss is again measured as thickness loss from the specimen and assessments made as before.
Abrasion Wear Testing in the Laboratory

This method is based on a simple version of the apparatus used in the National Bureau of Standards (NBS) test and can be made up from kit components such as meccano.

**Apparatus**

A - Dial gauge mounted on the lever arm to measure thickness loss.
B - Pivot
C - Vertical support.
D - Test pieces in the form of blocks or discs held against the abrading surface.
E - The abrasive material is fixed to the outer surface of a wheel or cylinder, for example, emery paper or sandpaper may be wrapped around the wheel.
F - Fixed reference surface for measurements.
G - Lever arm.
H - Applied load (weight)

**Suitable Materials to test**

Prepare three identical test specimens, in the form of discs or rectangular blocks, for each material to be tested. Off-cuts of materials may be available from Technology Departments or materials suppliers.

**Method**

1. Calculate the volume of the test specimens:

   | **For rectangular blocks** |
   | volume = length x breadth x height |

   | **For discs** |
   | volume = \( \pi r^2 \times \text{thickness of disc} \) |

   (where \( r \) is the radius of the disc)

2. Set up the apparatus as in the diagram with a test specimen in place.
3. Set the dial gauge to zero.
4. Rotate the abrasive wheel for a fixed number of rotations and then read the thickness loss of the specimen from the dial gauge (a micrometer or travelling microscope could also be used).
5. Repeat the procedure for the other two specimens of the same material and calculate an average thickness loss from your results.
6. Calculate the volume loss of the specimen using the thickness loss figure.
7. Using the information below calculate the abrasion resistance of the material under test.

   | Abrasion loss = volume loss |
   | Abrasion resistance = \( \frac{1}{\text{abrasion loss}} \) |

   = \( \frac{1}{\text{volume loss}} \)

8. Repeat the test for each of the materials under investigation and record your results in a table for comparison.
9. Produce a report explaining the comparative nature of your results.

**Theory**

Wear is proportional to both sliding velocity, \( V \), and applied load or pressure, \( P \). It is permissible to use the product, \( PV \), as a basis for comparison of different tests.

In wear tests, abrasion should, strictly, be assessed as volume loss, but it is more convenient, and more accurate, to measure weight (mass) loss and convert to volume loss if required. Abrasion resistance is the inverse of abrasion loss.

Because wear is so dependent upon abrasion conditions, it is customary to express abrasion resistance of a sample in relation to that of a standard material abraded under identical conditions.

\[
\text{Abrasion resistance index} = \left( \frac{\text{abrasion loss for material under test}}{\text{abrasion loss for standard material}} \right) \times 100
\]
Appendix - 1

Example of Compression Test Calculation

In a compression strength test on a new epoxide resin, a cylindrical test specimen 9.50 mm high and 9.50 mm diameter was found to fail at an applied compression load of 8.90 kN.

We need to calculate the compression strength at the point of failure.

Step 1 - calculate cross sectional area:

\[
\text{Cross sectional area} = \pi r^2 = \pi \left(\frac{9.50}{2}\right)^2 \times \left(\frac{9.50}{2}\right) \text{ mm}^2 = 70.88 \text{ mm}^2
\]

With a cylindrical test piece, the cross sectional area during test is represented by the circular plane shown by the shaded area in the diagram above. (Note that the cross sectional area is constant over the specimen).

Step 2 - calculate compressive stress:

compressive stress at failure = \( \frac{\text{force at failure}}{\text{cross sectional area}} \)
\[
\frac{8.90 \text{ kN}}{70.88 \text{ mm}^2} = \frac{8900 \text{ N}}{70.88 \text{ mm}^2} = 125.5643 \text{ N mm}^{-2}
\]

\[\therefore \text{ compressive strength} = 126 \text{ N mm}^{-2} \text{ (three significant figures)}
= 126 \text{ MN m}^{-2}
= 126 \text{ MPa}\]
Appendix - 2

Example of Calculations for IZOD Test

Values obtained from a simple IZOD cantilever beam test using specimens of 0.04m² cross-sectional area were as follows:

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Mass in Kg</th>
<th>h₁ in metres</th>
<th>h₂ in metres</th>
<th>Result of test</th>
<th>Initial potential energy (J)</th>
<th>Resultant potential energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.4</td>
<td></td>
<td>no fracture</td>
<td>5.89</td>
<td>1.84</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>0.4</td>
<td>0.125</td>
<td>fracture</td>
<td>7.85</td>
<td>2.94</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.4</td>
<td></td>
<td>no fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>0.4</td>
<td></td>
<td>no fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>0.4</td>
<td>0.15</td>
<td>fracture</td>
<td>7.85</td>
<td>2.94</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
<td>0.4</td>
<td>0.12</td>
<td>fracture</td>
<td>7.85</td>
<td>2.94</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0.4</td>
<td>0.105</td>
<td>fracture</td>
<td>3.92</td>
<td>0.41</td>
</tr>
<tr>
<td>8</td>
<td>0.5</td>
<td>0.4</td>
<td></td>
<td>no fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>0.4</td>
<td></td>
<td>no fracture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.5</td>
<td>0.4</td>
<td>0.115</td>
<td>fracture</td>
<td>5.89</td>
<td>1.69</td>
</tr>
</tbody>
</table>

1. Calculate the initial potential energy of the pendulum prior to fracture and resultant potential energy after fracture for each test specimen that breaks, adding the values to columns 6 and 7 of the table as above.

\[
\text{initial potential energy} = \text{mass x g x initial height of pendulum} \quad (J)
\]

\[
\text{resultant potential energy} = \text{mass x g x height to which pendulum swings after fracture} \quad (J)
\]

2. Calculate an average value for the initial potential energy from the figures in column 6 of the table and an average value for the resultant potential energy from the figures in column 7.

\[
\text{average initial potential energy} = \frac{5.89+7.85+5.89+3.92+5.89}{5} \quad J
\]

\[
= 5.89 \quad J
\]

\[
\text{average resultant potential energy} = \frac{1.84+2.94+1.77+0.41+1.69}{5} \quad J
\]

\[
= 1.73 \quad J
\]

3. Calculate the impact energy from these average figures:

\[
\text{impact energy} = (\text{initial potential energy})-(\text{resultant potential energy})
\]

\[
= 5.89 - 1.73
\]

\[
= 4.76 \quad J
\]

4. Calculate the impact strength as follows:

\[
\text{impact strength} = \frac{\text{impact energy}}{\text{cross section area of fracture}} \quad (J/m^2)
\]

\[
= \frac{4.76}{0.04}
\]

\[
= 119 \quad J/m^2
\]

37
## Appendix - 3

<table>
<thead>
<tr>
<th>TEST</th>
<th>REFERENCE NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard compression test</td>
<td>ISO 604</td>
</tr>
<tr>
<td>Ball indentation hardness test</td>
<td>ISO 2039/1</td>
</tr>
<tr>
<td>Rockwell hardness test</td>
<td>ISO 2039/2</td>
</tr>
<tr>
<td>Shore Durometer test</td>
<td>ISO 868</td>
</tr>
<tr>
<td>Delft tensile test</td>
<td>ISO 816</td>
</tr>
<tr>
<td>Staircase impact test</td>
<td>ISO 6603/1</td>
</tr>
<tr>
<td>Instrumented fracture test</td>
<td>ISO 6603/2</td>
</tr>
<tr>
<td>CHARPY impact test</td>
<td>ISO 180</td>
</tr>
<tr>
<td>Three point loading flexure test</td>
<td>ISO 178</td>
</tr>
<tr>
<td>Taber abrader test</td>
<td>ISO 9352</td>
</tr>
<tr>
<td>Elmendorf tear test</td>
<td>BS 2782/3088</td>
</tr>
</tbody>
</table>
Appendix 4
Example of Analysis of Creep Data

To illustrate how creep data can be analysed a specific material has been chosen. Figure D1 represents the creep data for polyamide 6:6 from a series of tests carried out at 20°C at a low relative humidity.

![Creep data graph](image)

**Fig. D1** Creep data for polyamide (PA 6:6) at 20°C, dry.

At a stress of 40 MN m$^{-2}$ - about half the tensile strength - initially the strain is restricted to less than 1.5%, but within 1 week (604800), the strain has risen to over 3.0% and eventually would lead to rupture. On the other hand, a stress of 5 MN m$^{-2}$ causes less than 1% elongation even after 1 year (31536000 seconds or 3.15 x 10$^7$ seconds).
Now consider the alternative ways of presenting creep data to suit different requirements of interpretation. In the creep strain v log time graph a horizontal line represents a particular strain value - say 1% strain (Fig. D1).

Where this line intersects each creep curve, a time value and corresponding stress value can be read off.

Creep data at 1.0% strain

<table>
<thead>
<tr>
<th>Point on Fig. D1</th>
<th>Creep Stress (MN m(^{-2}))</th>
<th>Creep Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>30</td>
<td>1.0 x 10 = 100</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>4.2 x 10 = 42,000</td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>3.0 x 10 = 300,000</td>
</tr>
<tr>
<td>D</td>
<td>15</td>
<td>1.0 x 10 = 1,000,000</td>
</tr>
<tr>
<td>E</td>
<td>10</td>
<td>4.2 x 10 = 4,200,000</td>
</tr>
<tr>
<td>F</td>
<td>7.5</td>
<td>1.3 x 10 = 13,000,000</td>
</tr>
<tr>
<td>G</td>
<td>5.0</td>
<td>5.2 x 10 = 52,000,000</td>
</tr>
</tbody>
</table>

Fig. D2 Isometric stress/time curve for 1.0% strain
Repeating the procedure for other creep strains (other horizontal lines on our original graph) would lead to a family of ISOMETRIC STRESS/TIME curves (Fig. D3).

Isometric stress/time curves are useful in situations where a particular design limitation of deformation has been set. The curves can then be used to establish the maximum stress which could be tolerated at different service life time.
Creep data can be presented in a third format by going back to the original strain/time graph (fig. D1) and this time drawing a vertical line representing one particular time value.

Creep data from fig. D1 at $10^5$ seconds

<table>
<thead>
<tr>
<th>Point on Fig. D1</th>
<th>Creep Stress (MN m$^3$)</th>
<th>Creep Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>5.0</td>
<td>0.25</td>
</tr>
<tr>
<td>J</td>
<td>7.5</td>
<td>0.35</td>
</tr>
<tr>
<td>K</td>
<td>10</td>
<td>0.44</td>
</tr>
<tr>
<td>L</td>
<td>15</td>
<td>0.66</td>
</tr>
<tr>
<td>M</td>
<td>20</td>
<td>0.85</td>
</tr>
<tr>
<td>N</td>
<td>25</td>
<td>1.12</td>
</tr>
<tr>
<td>P</td>
<td>30</td>
<td>1.38</td>
</tr>
<tr>
<td>R</td>
<td>35</td>
<td>1.72</td>
</tr>
<tr>
<td>S</td>
<td>40</td>
<td>2.12</td>
</tr>
<tr>
<td>T</td>
<td>45</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Repeating this procedure for other time values (vertical lines on the original graph) leads to a family of ISOCHRONOUS STRESS/STRAIN curves, each representing the stress/strain values associated with a particular time value (Fig. D4).

![Fig. D4](image)

Fig. D4 Family of isochronous stress/strain curves for PA 6:6 at 20°C, dry

Isochronous stress/strain curves are useful when establishing deformation under various loads if the service life of the product is known.
Creep data handling exercise

Figure D5 represents tensile creep data for polypropylene at 20°C. From the data you are requested to extract the following specific pieces of information.

1. Creep strain after one year under a stress of 6.0 MPa
2. Creep strain after
   a) one day under a stress of 6.0 MPa
   b) one week under a stress of 6.9 MPa
3. Maximum applied stress to limit the strain to
   a) 1.0% after 50 days
   b) 2.0% after 50 days

In the process you will also produce:
- isochronous stress/strain curves for 1 day and 1 week
- isometric stress/time curves for 1.0% and 2.0% strain
Fig. D5 Creep in tension: 20°C Polypropylene
Appendix 5

Sources of Some Polymer Materials

The following product types may be made from the named polymers:

**High density polyethylene (HDPE)**

Plastic bottles for milk, fruit juices, household cleaners and chemicals. Motor oil containers. Some carrier bags. Most aerosol caps.

**Low density polyethylene (LDPE)**

Jif lemon juice container. Some squeezy containers for sauces and cosmetics. Plastic films - shrink wrap, sacks, freezer bags, carrier bags that are not crinkly. Some aerosol caps. Some plant pots. Ink-tubes in ball-point pens.

**Polyvinyl chloride (PVC)**


**Polystyrene (PS)**

Yoghurt pots, margarine tubs, clear egg cartons, food packaging trays. Ferrero Rocher chocolate boxes. Plastic cutlery and cups. Clear 'plastic' glasses. Ball-point pen cases, cassette boxes, plastic coathangers.

**Expanded polystyrene (EPS)**


**Polypropylene (PP)**


**Polyethylene terephthalate (PET)**


**Adoption of Society of Plastics Industry (SPI) identity marks**

Containers may be marked with identity codes as follows:

(1-PET, 2-HDPE, 3-PVC, 4-LDPE, 5-PP, 6-PS, 7-OTHER)
Appendix 6

Alternative Wear and Abrasion Test

APPARATUS

two cotton reels (old shape)
wooden dowel to fit through cotton reels - approximately 5mm x 150mm
Sellotape
one six volt electric motor
elastic bands (as many as ten may be needed)
two clampstands, bosses and clamps
PVA glue
superglue
sand paper (medium/rough)
slotted masses (100g) and hanger
large sticky labels
access to a hole punch
stop clock
variable low voltage supply
G-clamp
access to a selection of unused plastic carrier bags
Assemble the apparatus as follows:

1. Using PVA glue, stick a piece of sand paper around one cotton reel.
2. Stick two cotton reels together using superglue (CARE!)
3. Wrap Sellotape around the dowel to provide a suitable thickness and minimise friction.
4. Use Sellotape wrapped around the dowel several times at each end of the cotton reels to prevent sideways motion of the cotton reels.
5. Use two clampstands, clamps and bosses to hold the dowel so that the cotton reels are supported in a horizontal position.
6. Using a G clamp secure the motor to the bench.
7. Couple the motor to the cotton reels using an elastic band around the uncovered cotton reel. The motor will need to be used on about 6 volts measured with a voltmeter.

Investigation

1. Measure the thickness of a sample of plastic using the micrometer screw gauge.
2. Cut samples of the plastic bag which are the same width as the sandpaper but about 12cm long (they need to be long enough to be extended over the sandpaper on the cotton reel).
3. Reinforce both ends of the sample with white self adhesive labels and punch a hole in the centre.
4. Suspend masses (about 200g) from the ends of the plastic strip until a suitable tension is achieved.
5. Start a stop clock as you start the motor, stopping the clock when the sample is worn through.
6. Record your results in a table.
7. Repeat using different samples of plastic carrier bags.

SAFETY NOTE

The rotational nature of the wear wheel used in this apparatus allows the possibility of masses being projected into the air if the apparatus is not carefully designed. Eye protection must be worn and a safety screen should be placed between the apparatus and the student.