ACTIVITY BRIEF

Impact testing

The science at work

Impact testing is of enormous importance. A collision between two objects can often result in damage to one or both of them. The damage might be a scratch, crack, fracture or break. Scientists need to know about how materials and products behave under impact and the magnitude of forces they can resist.

Your brief

You need to write a report on designing and testing an impact-testing machine. This includes assessing the machine's effectiveness compared with recognised industrial standards.

Task 1 Getting started

Complete *Study Sheet: Impact testers*. This will give you the necessary background for the remainder on the activity.

It's probably a good idea to work with one or two other people. You are not going to be assessed on the study sheet, but you do need to be sure you have a good understanding of the principles behind impact testing before you start to design your own tester.

Now complete *Study Sheet: Impact resistance of plastic film*. This will give you an example of a standard procedure that is nationally recognised. For copyright reasons, the full procedure cannot be reproduced but the outline may be sufficient to get you thinking.

Task 2 Designing and testing a machine

You have a number of decisions to make before go start to design your tester.

- What material will you test? What type and size of test specimen will you use? It's probably best to use something that is not too strong. What types of materials are tested on Instron's smallest pendulum and weight drop impact testers?
- There are two types of impact tester: pendulum and drop weight (you will learn about these in *Study Sheet: Impact testers*). Which type will you base your design on?
- You will need to get an idea of the strength of the material, in other words, how hard is it to fracture or break? Some trials will be needed in which you can vary (a) the mass of the pendulum hammer or the drop weight, (b) the height of the drop.
- What data will you collect? How will you process these data? Can you calculate the impact energies and the impact velocities?
- Results you obtain will be for the size and shape of test specimens you use. How might you compare these to data obtained from other laboratories?

You will probably make a prototype, carry out some tests and then modify it. Make sure you record all the data you collect and reasons for any changes to the apparatus that you make.

Task 3 Writing your report

Here is a checklist for your report. Make sure you include:

1 your initial plan, together with necessary health and safety precautions

2 a description of your method, supported by a diagram, and a risk assessment

3 details of improvements you made to your initial design following trials with the prototype (give reasons for the changes you made)

4 sample results, together with any calculations you carry out

5 an assessment of its effectiveness compared with the recognised industrial standards.

Your report should be logical and well-structured with correct scientific terminology used throughout.

STUDY SHEET

Impact testers

Impact testing

When two objects collide, damage is often done to one or other of them. How well something resists damage is called its **impact resistance**. An impact test measures how much energy is absorbed when an object fractures or breaks under a high speed collision.

It's an important property. The safety of many consumer products depends on their resistance to breaking. But impact resistance is difficult to quantify.

Questions

1 Describe briefly what you would expect to happen if a snooker ball was dropped from about one metre above a thin sheet of:

   a glass

   b polythene

   c metal

   d ceramic (e.g. a ceramic tile)

   e plywood

   f Perspex.

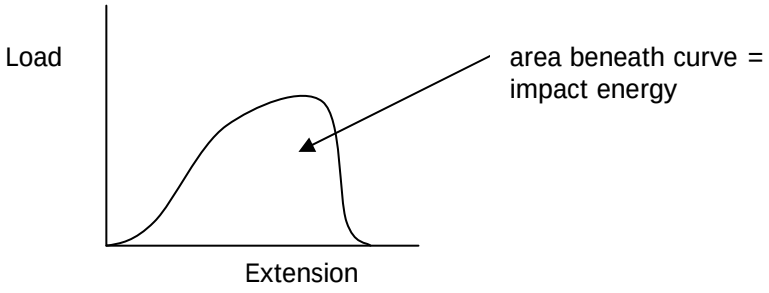
2 Usually it's not good when glass breaks. For a few uses, however, it's important that it does. Give an example of such a use.

3 Thinking about your answer to question 1, say what factors might affect how a material behaves under impact.

4 Impact resistance is difficult to quantify. Thinking of the examples you gave above, explain what this statement means.

Toughness not hardness

Impact testing is about resisting impact. This is often called a material's **toughness**. It's the amount of energy a material can absorb before fracturing or breaking and has the unit joules per metre cubed ($J\ m^{-3}$). If you plot *load* against *deflection*, this energy is given by the area beneath the curve:



Questions

5 The terms 'stress' and 'strain' are also used. Match them to the terms 'load' and 'extension'.

6 State the units used to measure (a) load, (b) extension.

7 Describe the difference in shape of a load/extension graph for ductile material compared to a brittle material.

How a material behaves on impact also says something about its ductility and brittleness, but these are not measured. Nor does it provide data on hardness.

Impact testers

There are two types of impact testers used in industry: pendulum and drop weight.

Pendulum impact testers

These were the first types of impact testers used. The UK company Instron manufacture testers. Its Dynatup® BLI Series is used mainly for low energy testing of plastic specimens. Its specifications state:

- Impact energy variable up to 21.7 J
- Impact velocity of 3.3 m s^{-1}

The Dynatup® POE2000 Series is used mainly for low energy testing of plastic, ceramic, and composite specimens. Its specifications state:

- Impact energy variable up to 50 J
- Impact velocity of 3.5 m s^{-1}

http://www.instron.co.uk/wa/products/impact/pendulum_compare.aspx?ref=http

The Pendulum Impact Tester IT 30 ASTM is made by the French company Société DELTALAB (http://www.deltalab.fr/uk/index.php). You find information about it by navigating:

Home > Mechanical Engineering > Solid Mechanics > Testing machines

It has a pendulum hammer (mass 21.3 kg) that is 775 mm from the rotation axis. Anti-friction bearings limit loss by friction to 0.75% of maximum energy. The test angle of fall is 140^{o}.

Test specimens are 10 x 10 x 55 mm. The point of impact is ± 8.25 mm above the centre of the test sample.

During the fall from its raised position the pendulum's potential energy decreases, changing into kinetic energy. The kinetic energy is at its greatest just before impact. This is the impact energy. The energy absorbed by the test specimen during failure (i.e. fracturing or breaking) is worked out from the height of the pendulum after impact.

Questions

8 Explain why the magnitude of the impact energy depends on the mass of the pendulum hammer and the height at which it is released.

9 Estimate the mass of the pendulum hammer in Instron's (a) Dynatup® BLI Series, (b) Dynatup® POE2000 Series.

10 The specifications for the Pendulum Impact Tester IT 30 ASTM state that the impact energy is 300 J. Estimate the impact velocity.

11 Explain how to calculate the energy absorbed by a test sample when it fractures or breaks in a pendulum impact test.

Drop weight impact testers

A mass is dropped vertically on to a test specimen. A tube or rails are used to guide the falling mass. Since the mass either stops dead on the specimen or breaks it, the test was essentially pass/fail.

However, the energy absorbed by a specimen when it breaks can be estimated:

- the mass is dropped from increasing heights until the specimen fractures or breaks
- further tests are carried out on other samples to get more accurate value. This can involve anything up to 100 test samples.

Both the mass and the drop height can be varied. The impact energy is the kinetic energy of the mass at impact. The energy absorbed by the test specimen is the impact energy required to just fracture or break the specimen.

Instron manufactures a number of drop weight impact testers.
http://www.instron.co.uk/wa/products/impact/dropweight_compare.aspx

The MiniTower is a bench-top instrument used for low energy applications such as packaging films and thin or brittle plastics.

- mass variable up to 4.2 kg
- impact energy variable up to 18.1 J
- impact velocity up to 3.0 m s^{-1}

Model 8200 (see left) stands on the floor. It's used for low energy applications such as thin or brittle plastics, composites and ceramics, and low energy metals.

- mass variable up to 13.6 kg
- impact energy variable up to 132.8 J
- impact velocity up to 4.4 m s^{-1}

The 9200 Series are used to test, for example, ductile and brittle plastics, composites and ceramics, and low energy metals.

It's computer-controlled with:

- mass variable, but values not given in the specifications
- impact energy variable up to 1600 J
- impact velocity up to 20.0 m s^{-1}

The 8100 Series (see right) are used for high energy applications such as low and high energy metals.

- mass variable up to 454 kg
- impact energy variable up to 27 800 J
- impact velocity up to 7.0 m s^{-1}

Questions

12 Explain how the impact energy and impact velocity are calculated for a drop weight impact tester.

13 For the MiniTower and Model 8200, compare the maximum impact energy quoted with that calculated from the other data.

14 Estimate the height of the mass above the sample in the MiniTower when a 4.2 kg mass produces the maximum impact energy the instrument can achieve.

15 A mass for the 9200 Series is not given in the instrument's specification. Estimate its value from the data provided.

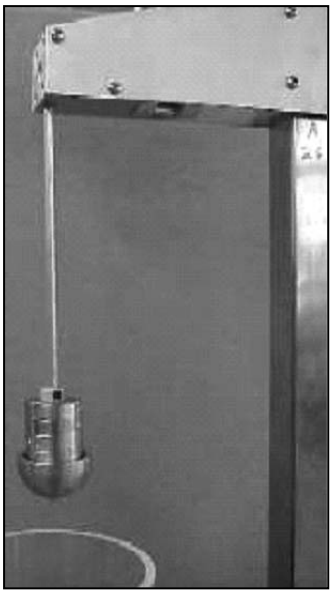
Instrumented impact testing

It has been said that impact testing is where tensile testing was 50 years ago. However, modern impact testers are becoming increasingly sophisticated. In modern instruments, the load is increased steadily rather than added in increments. Also any deformation to the sample is observed and recorded.

Instrumented drop weight and pendulum testing is considered to be the best general impact testing method presently available.

STUDY SHEET

Impact resistance of plastic film



Free-falling dart impact is a traditional way to evaluate the impact strength or toughness of a plastic film. It uses a single dart configuration, a single drop height and a variable mass dart.

http://www.ptli.com/testlopedia/tests/Drop_Dart_D1709.asp

Outline procedure

Depending upon the expected impact strength of the test sample, either Method A or Method B is chosen:

Method A: 38 mm diameter dart dropped from 0.66 m

Method B: 51 mm diameter dart dropped from 1.5 m

A number of test samples are tested to determine a suitable dropping height for the dart.

The test specimen is clamped in a pneumatic ring at the base of the drop tower. The dart is clamped at the dropping height and then released to drop onto the centre of the test specimen. The drop weight and the test result (pass/fail) are recorded.

Data are analysed using the 'Bruceton Staircase' method. A series of 20 to 25 impacts are conducted. If a test specimen passes, the drop weight is increased by one unit. If a test specimen fails, the drop weight is decreased by one unit. From these tests the **impact failure mass** (g) – the point at which 50% of the test specimens will fail under the impact – is calculated.

Test specimens

- Dimensions: 230 mm x 230 mm.
- A minimum of 30 specimens are required for the test

Equipment

- Atlas / Dynisco CS-126 Drop Impact Tester
- Appropriate masses and darts

Questions

1 What safety precautions are taken?

2 What is a pneumatic ring and why is it used?

3 Explain how the impact failure mass is calculated.

4 What determines the precision of the impact failure mass?

5 The method says to give the result as an impact failure mass (g). How could you calculate the impact energy when a sample just fails?

Teacher notes

This activity links to **OCR A2 Unit 11 Materials for a purpose**.

One assessment requirement for the unit is that students must produce:

a report on your design and testing of an impact testing machine and an assessment of its effectiveness compared with the recognised industrial standards

with the highest marks gained if they show that have

- *produced a report on their design and testing of an impact testing machine, including unaided plan and safety precautions, a description and diagram of their method, improvements from initial prototype, sample results, and an assessment of its effectiveness compared with the recognised industrial standards; their report is logical and well-structured and uses correct scientific terminology throughout.*

There is some difficulty in meeting the requirement to compare their results 'with the recognised industrial standards'. There are standards for testing (i.e. exactly how procedure should be carried out), but no standard values quoted in the literature (unlike tensile strength, hardness etc).

One solution might be to find somewhere that has one of these testers. A university department, for example, might carry out a test on the same material students are studying. This would provide 'standard values' for impact energy against which students might compare their own data.

Further, there are various reasons why students will find it difficult to mimic closely industrial systems. For example, they are not likely to be able to:

- make a pendulum impact tester with friction limited to 0.75% of maximum energy
- use falling masses with fixed shape and variable mass.

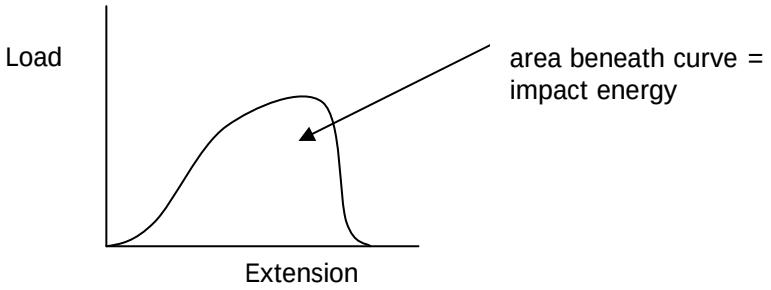
There is further confusion in the specification caused by the statement:

Modern methods of measuring the hardness of a material measure its ability to withstand indentation. Industrial testing machines include Vickers, Brinell, and Rockwell. To help you to understand what these tests involve, you need to, individually or in a group, devise and test your own impact-testing machine.

Impact testing is not about hardness. It's about the energy required to fracture or break an item.

Study Sheet: Impact testers is a reasonably accurate description of how impact testers work.

Impact testing can measure a material's **toughness**. It's the amount of energy a material can absorb before fracturing or breaking and has the unit joules per metre cubed ($J\ m^{-3}$). It's given by the area beneath a load/extension curve.



However, students will not be able to do this. They might, however, consider how they can give the impact strength as a value independent of sample thickness.

The most accessible machine to make is probably a free-fall drop weight method to investigate plastic sheet. Having completed *Study Sheet: Impact resistance of plastic film*, students may be encouraged to think along these lines. They could modify the procedure and test materials such as tissue paper (dry and wet), paper, cardboard, thin rigid plastic sheet such as Perspex etc. It would be best to avoid materials that might shatter into pieces with sharp edges (e.g. glass). If they are used, suitable safety precautions are essential.

Impact resistance of plastic film

Answers

1 What safety precautions are taken?

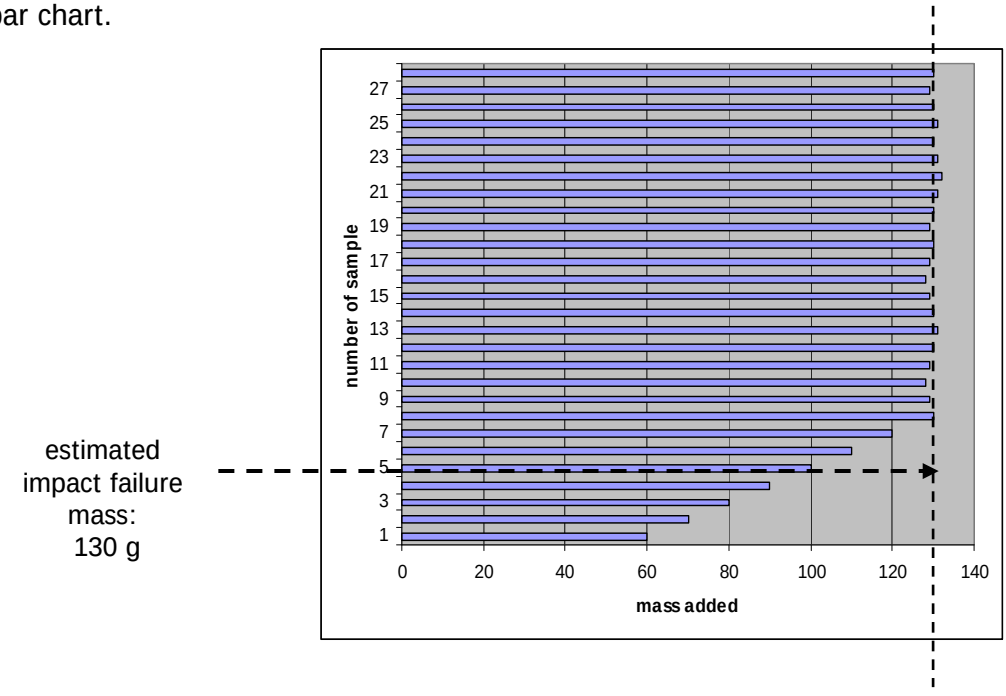
Cylinder to prevent mass from falling off the apparatus

2 What is a pneumatic ring and why is it used?

It's a rubber ring that can hold the plastic sheet securely so that it doesn't slip.

3 Explain how the impact failure mass is calculated.

See bar chart.



You will see that the mass has been increased in 10 unit increments until the sample breaks (sample number 8). After that, the mass is reduced by 1 unit at a time until the sample fails (sample number 10). At this point the mass in increased by 1 unit increments until the sample breaks (sample number 13).

And so the test procedure continues.

4 What determines the precision of the impact failure mass?

The smallness of the 'units' of mass added or taken away.

5 The method says to give the result as an impact failure mass (g). How could you calculate the impact energy when a sample just fails?

By calculating the change if PE of the dart.

Impact testers

Answers

1 Describe briefly what you would expect to happen if snooker ball was dropped from about 1 metre above a thin sheet of:

a glass breaks; may shatter into lots of sharp-edged pieces or it may break into just a few large pieces; the glass does not seem to stretch at all before it breaks

b polythene stretches, probably will not break or tear unless it is quite thin

c metal likely to have little effect; may dent the metal and the sheet may stretch a little under the impact; it will not fracture or break

d ceramic (e.g. a ceramic tile) breaks; probably get just a few pieces though it may shatter into many pieces; the tile does not seem to stretch at all before it breaks

e plywood might bend a little if it is thin enough, but unlikely to break

f Perspex. might stretch a little and possibly break if it is thin enough

2 Usually it's not good when glass breaks. For a few uses, however, it's important that it does. Give an example of such a use.

e.g. glass you break in emergency to get to a safety device

3 Thinking about your answer to question 1, say what factors might affect how a material behaves under impact.

The type of material, its thickness, the mass of the object dropped on it, the height from which the object is dropped, any weak points in the materials (e.g. a scratch).

4 Impact resistance is difficult to quantify. Thinking of the examples you gave above, explain what this statement means.

Being able to measure a value for impact resistance along with appropriate units.

5 The terms 'stress' and 'strain' are also used. Match them to the terms 'load' and 'extension'.

Stress corresponds to load (stress is load/cross-sectional area; strain corresponds to extension (strain = extension/ original length).

6 State the units used to measure (a) load, (b) extension.

(a) N m^{-2}, (b) m

7 Describe the difference in shape of a load/extension graph for ductile material compared to a brittle material.

Extension will be significantly smaller for a brittle material than a ductile material; the load required to break the material does not depend on ductility/brittleness

8 Explain why the magnitude of the impact energy depends on the mass of the pendulum hammer and the height at which it is released.

PE of pendulum hammer = mgh, where m = mass (kg), g = gravititational field strength (9.8 N kg^{-1}), h = height above ground (m)

As it falls from height $h_{initial}$ to h_{final},

decrease in PE = $mgh_{initial} - mgh_{final} = mg(h_{initial} - h_{final})$

This PE is converted into kinetic energy (KE = ½ mv^2) which, in this case, is the impact energy.

9 Estimate the mass of the pendulum hammer in Instron's (a) Dynatup® BLI Series, (b) Dynatup® POE2000 Series.

(a) about 4 kg, (b) about 8.2 kg

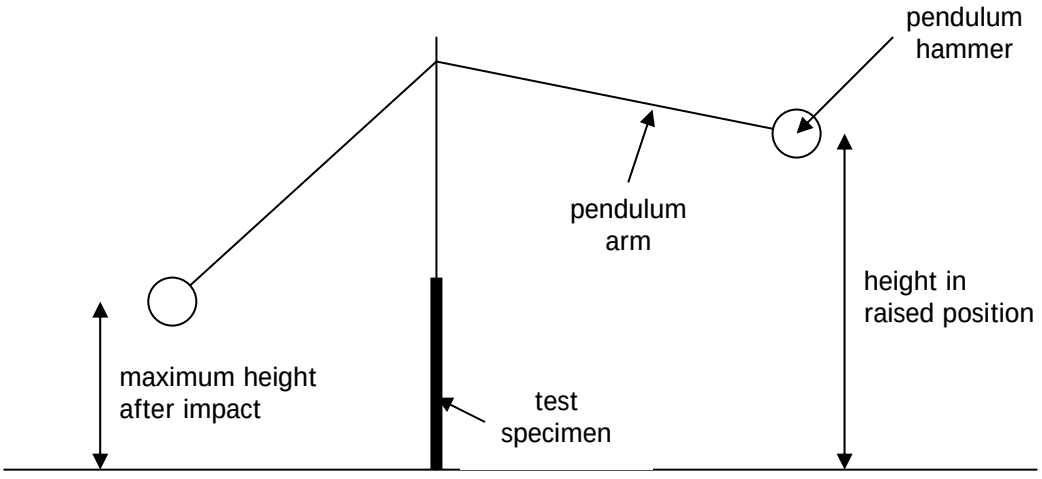
10 The specifications for the Pendulum Impact Tester IT 30 ASTM state that the impact energy is 300 J. Estimate the impact velocity.

Using KE = ½ mv^2, the impact velocity works out to be about 5.3 m s^{-1}.

11 Explain how to calculate the energy absorbed by a test sample when it fractures or breaks in a pendulum impact test.

If the test sample was not in the tester, the pendulum would swing almost the same height on the other side of the tester ('almost' because there will be some loss through friction – hence the comment in the Pendulum Impact Tester IT 30 ASTM description that 'Anti-friction bearings limit loss by friction to 0.75% of maximum energy').

However, the test specimen absorbs energy when it breaks and so the pendulum does not rise as high as if the specimen were not present. The difference in the potential energy of the pendulum hammer in its raised position and its potential energy at the maximum height after impact = the energy absorbed by the specimen (ignoring losses due to friction).



12 Explain how the impact energy and impact velocity are calculated for a drop weight impact tester.

The idea is the same as for a pendulum impact tester. PE of mass = mgh, where m = mass (kg), g = gravititational field strength (9.8 N kg^{-1}), h = height above ground (m)

As it falls from height $h_{initial}$ to h_{final}, the decrease in PE = $mgh_{initial} - mgh_{final} = mg(h_{initial} - h_{final})$. $h_{initial} - h_{final}$ is the distance between the mass at its highest position and the test specimen directly below it.

This PE is converted into kinetic energy (KE = ½ mv^2) which, in this case, is the impact energy. Once we know the impact energy and the mass, we can calculate the impact velocity.

13 For the MiniTower and Model 8200, compare the maximum impact energy quoted with that calculated from the other data.

Using KE = ½ mv^2, for the MiniTower value quoted = 18.1 J. Calculated from mass and impact velocity the value is 18.9 J; for Model 8200 value quoted = 132.8 J. Calculated from mass and impact velocity the value is 131.6 J

14 Estimate the height of the mass above the sample in the MiniTower when a 4.2 kg mass produces the maximum impact energy the instrument can achieve.

Max impact energy = 18.1 J. Using PE = mgh, h = 18.1 ÷ (4.2 x 9.8) = 0.44 m

15 A mass for the 9200 Series is not given in the instrument's specification. Estimate its value from the data provided.

Using KE = ½ mv^2, v = 20 m s^{-1} and KE = 1600 J. Therefore m = 8 kg