Practical 1P7  
Fabrication and Tensile Testing

What you should learn from this practical

Science
Some of the most important mechanical properties of a material can be determined by means of a simple tensile test. This practical introduces tensile testing of metals and plastics and demonstrates the meaning of often-used mechanical property specifications, giving a comparison of actual values for a variety of real materials.

Practical skills
The first part of the practical involves the preparation of metal tensile specimens by machining, giving valuable practical experience of some workshop technology.

Overview of practical
After instruction from the Students' Workshop technician, students will each fabricate some metal tensile specimens (choosing from steel, copper and 70/30 brass).¹

¹ The tensile testing experiments use two steel and one each of the copper and brass specimens, but it is not necessary to make all of these yourselves, as the teaching lab has stocks of test specimens (besides, it would take far too long). This part of the practical is so you can gain some experience of how simple metal components and specimens can be made.
**Safety note:** You **must not** use any equipment in the students' workshop without first attending the safety talk there. You must not use any equipment in the students' workshop without supervision from the workshop Technician or a Junior demonstrator. You must be especially careful of your own, and others', safety in the workshop.

This will occupy the first day of the practical. At the end of the day, the specimens should be handed to the Practical Class Technician (PCT), so that (s)he can heat treat them for 2 hours at 500°C in a sand bath to relieve residual stresses on the morning of the second day. On the second day the specimens are tested to failure in a Hounsfield Tensometer. A slightly more sophisticated testing machine, an Instron, is used to tensile test strip specimens of various plastics which are supplied ready for testing, also on the second day.

**Experimental Details**

1) **Testing of metals**
Mechanical testing of metals is carried out on a Hounsfield Tensometer. Use Tensometer No. 14 chucks, with the 20 kN load cell and maximum strain magnification, Before starting the testing set the Hounsfield Reduction in Area and Elongation gauges for each sample. Test one sample of each material to failure. The results obtained from the tensometer are put out in the form of a load-extension plot on the laser printer at the end of the test. To convert this into an engineering stress-strain plot, use the following relationships:
Engineering stress,  \( \sigma = \frac{\text{applied load}}{A} \)
where \( A \) is the original cross-sectional area,

Engineering strain,  \( \varepsilon = \frac{\text{extension}}{\text{original length}} \)

There are two important mechanical properties that can be calculated from the plot obtained:

Yield point = point at which plastic deformation begins, i.e. end of linear region of plot.

(Engineering) Ultimate tensile strength,  \( \text{UTS} = \frac{\text{maximum load}}{A} \)

Also measure and compare the % reduction in area and % elongation values for each sample.

Take second sample of mild steel. Start the test as before, but stop when a small amount of plastic deformation has taken place. Unload the sample, then reload to produce further plastic deformation. Remove the sample and place it in boiling water for 15 minutes, then reload the specimen and test to failure. How do these results differ from the previous steel sample?

Caution: use tongs for handling the sample in boiling water and avoid scalding yourself.
<table>
<thead>
<tr>
<th>Material</th>
<th>Young's Modulus (Nm⁻²)</th>
<th>Yield Stress (Nm⁻²)</th>
<th>U.T.S. (Nm⁻²)</th>
<th>% elongation</th>
<th>% reduction in area</th>
</tr>
</thead>
<tbody>
<tr>
<td>70/30 brass</td>
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<tr>
<td>Copper</td>
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<tr>
<td>Mild steel</td>
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<tr>
<td>Mild steel (water treated)</td>
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</tbody>
</table>

The Young's modulus is the ratio for $\sigma/\varepsilon$ for the initial elastic region of the plot. However the value obtained by measurement from the Hounsfield plot will be much too small (why?) To obtain an accurate value of Young's modulus it is necessary to attach an accurate extensometer to a specimen itself and load the specimen within the elastic range.

**Caution:** Extra-long gauge length specimens for use with an extensometer are supplied – these must not be loaded to more than about one half of the yield stress as determined from the shorter gauge length specimens. (The long gauge length specimens are to be re-used and the extensometer cannot tolerate large strains). **Do not use the extensometer**, which is very delicate and expensive, except under the direct supervision of the PCT.

Compare the value of Young's modulus obtained by using the extensometer with the apparent value determined from the Hounsfield plot.
2) Testing of Polymers

Strip specimens of various plastics are supplied and these should be tested using the Instron machine; the Junior Demonstrator will show you how to operate it. Suitable conditions are: cross head speed 0.5mm/min and chart speed 50mm/min. The polystyrene and butadiene toughened polystyrene specimens should be taken to fracture but the other specimens should merely be taken past yielding as fracture may take an excessively long time. Note the appearance of the polystyrene and butadiene-toughened polystyrene just before fracture.

It will be seen that for small strain, the load-extension relationship is not precisely linear. These are the results expected in this type of test for a viscoelastic material, i.e. a material in which the recoverable strain increases with time after a fixed load is applied. The fundamental viscoelastic properties cannot be evaluated from this test but from the maximum slope of the load-extension curve an apparent elastic modulus (stress/strain ratio) can be derived which gives a useful indication of the practical stiffness of the material in relation to other plastics or other types of material. The elastic modulus of a material is normally obtained by measuring the strain on the specimen with an extensometer since the displacement as measured by the travel of the Instron chart is partly made up of elastic displacement in the grips, machine cross-head etc. as well as in the specimen gauge length. However since polymers have a relatively low stiffness, the elastic deflection in the machine is relatively small although not necessarily negligible and the Instron chart trace will in this case give the apparent modulus with moderate accuracy (error in worst case -25%). Compare the apparent moduli of the plastics with one another.
and with the Young's modulus of a typical metal (assume specimen gauge length 110mm, measure specimen cross-section with a micrometer).

Calculate also the fracture stress of fractured specimens and the approximate yield stress of others, and make a comparison with the metal yield stresses.

Some notes on the plastics used are given in the Appendix.

**What should be in the report**
The report on this practical should contain only a brief description of the experiment and the experimental method. The main part of the write-up should be the discussion of your results.

Your report should not exceed 3-4 pages of text. In addition, you should include copies of all your group's Hounsfield and Instron load-extension curves, your calculated stress-strain curves and a completed version of the table of data given in this script.

Your write-up should not contain detailed descriptions of the equipment used in the practical, the experimental procedures or the machining processes used to make your specimens.

**Questions to answer:**
As well as the specific measurements and calculations mentioned in the “experimental details” section, you should, in your discussion of the results, try to answer the following:
• Why do the stress-strain curves have the forms they have?
• In what ways do the two steels behave differently? What is happening microstructurally?
• Why does calculating Young's modulus directly from the Hounsfield tensometer graph underestimate the real value?
• Why do you expect calculating Young's modulus from the data you got using the extensometer to give a more accurate value?
• How do the appearances of the polymer specimens differ from each other after testing? How is this related to their structures?
Appendix

**Polycarbonate**

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 \\
\text{O} & \quad \text{O} \\
\text{C} & \quad \text{C} \\
\text{O} & \quad \text{O} \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
\]

Although of low crystallinity it has unusually high impact resistance for a plastic and is used, for example, for crash helmets.

**Polystyrene**: composition \((\text{CH}_2\text{CHC}_6\text{H}_5)_n\)

An amorphous polymer, i.e. the long chain molecules are not arranged in a regular manner. Below a fairly well defined temperature, the "glass transition" temperature, the molecules of an amorphous polymer are unable to make large scale movements relative to one another. The glass transition temperature of polystyrene is about 100°C.

**Butadiene-toughened polystyrene**

The toughness of polystyrene can be improved by the addition of particles of rubber, such as the synthetic rubber, polybutadiene. The rubber particles are present as a fine dispersion within a matrix of polystyrene.

**High density polyethylene**: composition \((\text{CH}_2)_n\)

In this material the long chain molecules are, in local regions, lined up in regular patterns. Such polymers are called crystalline, although they contain a much higher degree of disorder than low molecular weight crystalline materials. Many crystalline polymers can be "drawn" at temperatures well
below their melting temperature. "Drawing" is a response to a tensile stress in which the molecules become oriented parallel to the tensile axis and produce a large tensile strain in doing: so. Stiffness and strength are much enhanced by drawing.

**Low density polyethylene**: composition $(\text{CH}_2)_n$

In low density polyethylene, a relatively large proportion of molecules contain branches instead of being single chains. The branches hinder close-packing of the chains: the material is less crystalline and less stiff than high density polyethylene.

**Polypropylene**: composition $(\text{CH}_2\text{CH}($CH$_3$)$)_n$

Properties are similar to high density polyethylene.