Practical 2P2

Dislocations and Plasticity

What you should learn from this practical

Science

This practical ties in with the lecture courses on dislocations and microplasticity. It will help you understand:

- how crystal type and crystal structure control the ease with which dislocation motion can be activated in a material;
- how the likelihood of twinning as a deformation mode is affected by the number and activity of slip systems;
- how the dislocation core structure affects such things as the likelihood of cross-slip;

Practical skills

You will need to use optical microscopes at high resolution, and to be able to photograph or draw what you see accurately. You will learn how to prepare good damage-free surfaces of a wide range of materials, and how to etch surfaces to show grain structures. You will learn how to operate a hardness tester.

Overview of practical

You will prepare well–polished surfaces of metals of each of the most common crystal structures (copper – cubic close packed; zinc – hexagonal close packed; iron – cubic body centred), and deform them at low and high strain rates at low temperature and at room temperature. You will examine the resulting deformation patterns, and relate these to the crystal structure and dislocation characteristics of each material.

Experimental details

In each group, divide the polishing of metal surfaces between you. All specimens should be examined, discussed and photographed by all members of the group.

Metals:

Preparation

The metal samples must have parallel ends, or the hardness testing and punch testing will be very difficult. To achieve this, grind one side, then the other, with the smaller diameter copper and steel specimens mounted in the holders.

Each sample should now be polished on one surface to give a surface as strain - free as possible. The experiments will not work if the polishing is not good enough. This can be done simply by careful diamond polishing. Holders are provided for keeping the samples level; using these will make the polishing much quicker and more certain. Make sure you check the state of the surfaces frequently using the microscopes. Polishing should take no more than a few minutes for each stage. The Demonstrators will explain polishing procedures to you.

Etching

The etchants used contain acids and must be used with due care in a fume cupboard.

Polished specimens should be very lightly etched to show grain boundaries. Use 2% Nital for the iron, and $FeCl_3$ for the copper.
If the etching produces a rough surface, re-polish using 1μm and 1/4 μm pastes and then re-etch more carefully.

Deformation

Low strain rate deformation is done using a hardness tester, at a load of 2kg. The Demonstrators will show you how to use it. Make a mark on the edge of the specimen so you know where the indent is to be found.

High strain deformation is done using a punch and hammer. Make this test a couple of mm away from the room – temperature indentation (close enough to identify it as the room temperature test, far enough away that the deformation zones do not overlap). Be careful not to scrape the punch over the metal surface.

Liquid nitrogen temperature deformation

Wear safety glasses and exercise care when handling liquid nitrogen and cold specimens. On no account hold or touch cold specimens directly. Two people will be needed – one to manipulate the specimen and one to do the testing.

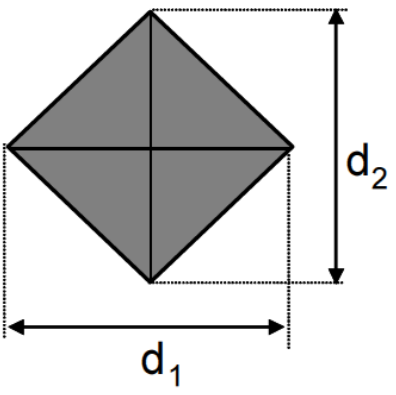
Wrap each specimen round with wire, leaving the top and bottom surfaces free, and with a 30 – 40 cm long tail for handling. Put each specimen in the nitrogen flask and wait until the violent bubbling stops. Withdraw each specimen in turn, and use tongs to place it on the platen of the hardness tester, so that an unused area of specimen is under the indenter. Make an indentation and replace the specimen in the liquid nitrogen.

Now take each specimen out in turn, and use tongs to place on a solid base, and make a punch indentation in an unused area.

Observation

The surface should be examined in the optical microscope. Measure the sizes of the room temperature and liquid nitrogen temperature indentations, and calculate the hardness of each material at the two temperatures.

If there is a problem with any of the indents (large scratch, punch slipped, punch hit too hard etc.) then repeat the test. The test does not take long compared to the sample preparation and microscopy.



Hardness is defined as the pressure on the contact area of the indentation impression: For the 'Vickers' diamond pyramid profile the Vickers Hardness Number (HV or VHN) is given by:

$$\mathrm{HV} = \frac{1.8544\ \mathrm{P}}{\mathrm{d_1 d_2}}$$

with P the applied load (in kgf) and d_i the indent diagonals (in mm). This gives the Vickers hardness in its usual (non-SI) units of kgf/mm^2.

Convert the hardness numbers to yield stresses, σ_y in MPa, (remembering to convert kgf to N) and using the result that for most metals, $H \approx 3\sigma_y$.

Now look at the deformation patterns around each type of indentations. Strains and strain rates will be highest close to the indentations, decreasing with distance from the indentations into undeformed material. Identify slip lines (where slip planes have met surface, and thus where the emergence of dislocations has given visible slip steps), deformation twins (where twins meet the surface, they produce surface tilts) and any cracks; the relative numbers of these, and indeed whether they are present at all for a given deformation condition, will be different for the different materials.

Take photographs of characteristic deformation patterns in each case. For each metal/temperature/strain rate combination, determine what the mode of deformation are, and why. Metals might respond to an applied loading by slip, twinning or fracture. What factors will determine which will happen – in terms of the crystal structure and dislocation structure of the materials? Think about how each material behaves individually, and also how behaviour varies across the range of materials and test conditions used.

Some points to think about and explain:

- How does hardness and therefore yield stress vary with material and temperature?
- What slip or twinning systems exist?
- If twins are seen, when were they formed? and what can their shape and thickness tell you?
- Do you see one set of slip line in each grain or many? Why?
- How do temperature and strain rate affect what you see?
- Why do some metals twin when deformed and not others?
- Why do some metals have wavy slip lines and not others?
- What role does stacking fault energy play?
- Does behaviour change with temperature and strain rate? In which materials? Why?
- What would you expect to happen if you increased the test temperature (to say, 400°C)?

What should be in the write up

Structure of write up

Structure the report as it is normally done in a scientific paper:

Background and aims, Experimental method, Results, Discussion, Conclusions. (Some of these sections might be as short as a few sentences.)

You should focus on the results of the experiments you did, and on explaining why these arise from the structure of the materials tested.
Label and annotate figures and micrographs clearly do not just rely on the figure caption. Each figure should have a scale bar and an explanatory caption.
Make sure your text refers to what is seen in the figures you use.
Try to answer the points in the bullet points above, and to explain what happens over the range of metals and conditions studied.

Marking considerations

Write concisely! (2,000 words + figures should be adequate)
Quality of sample preparation and micrographs presented.
Coherence of argument for what is seen in each case.
An assessment of measurement errors.
A good concise summing–up, comparing the behaviour of the materials studied.

Not wanted in write – up

More than the **brief** necessary details of the experimental procedure.
More than the **brief** necessary details of what slip, twinning, etc. are.