Practical 2P6

Extrusion

Safety considerations

You will be working with indium metal which is toxic. Always wear gloves when handling the indium. When casting the indium metal wear eye protection and thermally insulating gloves.

The tensometer devices are designed to be used in tension, but are capable of being driven into compression which can be hazardous. Always ensure you are driving them into tension, and that the cage converting tension to compression at the sample is moving freely causing extrusion to occur. Keep long hair and fingers clear of the experiment during the extrusion process.

When extruding the play-dough, again ensure that the extrusion is proceeding freely and that excess pressure is not building up in the mortar gun. Aim the extruded materials onto the lab bench.

What you should learn from this practical

Extrusion is a process used widely in industry. The forces involved are large and the metal flow patterns are complex, much more so than in a simple tension test of a single crystal. This practical is related to the macroplasticity lecture course and should provide some insight into industrial metal working. You may find it useful to read a little about the extrusion process, so three simple text books are listed at the end of this sheet, but do not copy from these books when writing your report.

Extrusion involves forcing metal (or another material) through a die. It is an efficient, high deformation metal forming process for manufacturing products with a variety of shapes. Good metal quality, dimensional accuracy and surface finish can be achieved at high production speeds with relatively low die costs. Extrusions are widely used for everyday items such as window frames and toothpaste tubes; a recent 'high-tech' application is the Lotus Elise sports car, the chassis of which is built up from extrusions glued together with epoxy resin.

Practical skills

You will learn to handle liquid metal in small quantities, cast at the right temperature and the importance of cleanliness; modelling in play dough (not as easy to do well as you might think!); operation of the tensile testing machines.

Overview of the practical

The practical is in two parts. The first part uses a soft metal to obtain extrusion pressure vs ram travel curves illustrating the various features of the process and which are then analysed to determine the various parameters involved in the process. In the second part, coloured play-dough is used to simulate a rigid-plastic metal, which allows the material flow during extrusion to be analysed.

An elementary analysis of extrusion, assuming some friction between the billet and container wall, gives an expression for the extrusion pressure

$$P = \sigma_y \ln R \cdot \left(1 + \frac{4\mu L}{D}\right)$$

where σ_y is the yield stress of the metal, R is the extrusion ratio, μ is the coefficient of friction, and L and D are the length and diameter of the billet respectively.

Redundant work is taken into account by multiplying by a factor β, and die friction can be added to give a semi-empirical expression of the form:

$$P = \left(\alpha\sigma_y + \beta\sigma_y \ln R\right)\left(1 + \frac{4\mu L}{D}\right)$$

where α and β are dimensionless constants.

Experimental details

Divide up the tasks so that each of you has a go at exercising every skill. Although your numerical data will be the same, your analysis, the drawing of graphs etc must be done on an individual basis. Part I is concerned with the forces involved in the extrusion process and in analysing and evaluating various parameters. In Part II, the flow of material is observed and analysed.

Part I

You will cast from liquid indium a set of billets. The indium is melting in a glass boiling tube and cast into the mold provided. The trimming of the billets will be done by the laboratory demonstrators.

Fit the small extrusion apparatus to the Tensometer and record extrusion load vs ram travel curves for each of the dies using the laptop. Always ensure that the Tensometer is being operated to apply tension to the cage by turning the handle clockwise, and that the extrusion is occurring freely.

Solid soap may be used as a lubricant. Extrapolate the main part of the extrusion graph to zero billet length and measure the load P (using Excel's Trendline and the displayed equation will be very helpful). Plot the corresponding pressure, p, against lnR and use this graph to evaluate the dimensionless constants α and β. Tabulate P, p, R and ln R for reference.

Data

Yield stress of indium: 2-5 MPa (use data derived from your extrusion curves).

Container diameter: 10 mm.

Die identifier	2	4	8	16	32
Orifice diameter (mm)	7.07	5.00	3.54	2.50	1.77

Part II

This part of the experiment uses play-dough and a mortar gun to examine the plastic flow involved in extrusion. The first step involves making dough with a suitable consistency for extrusion. The following recipe can be used. You will need to make this twice (using 2 different food colourings):

- 200g plain flour
- 80g table salt
- 100ml warm water
- 6ml food colouring
- 25ml vegetable oil

1. Mix the flour and salt in a large bowl. In a separate bowl mix together the water, a few drops of food colouring and the oil.

2. Pour the coloured water into the flour mix and bring together with a spoon.

3. Dust a work surface with a little flour and turn out the dough. Knead together for a few minutes to form a smooth, pliable dough. If you want a more intense colour you can work in a few extra drops of food colouring.

Create a small billet to test that the play dough is the correct consistency to extrude smoothly. If not, either water or salt can be added to adjust the consistency.

(a) Make a composite billet from at least 12 layers of alternating colours. Extrude this billet through the large die marked '4', stopping the extrusion process after the ram has travelled about half the possible distance. Carefully remove the extrusion from the press and section with the cutting wire. Examine and photograph (or sketch) the resulting flow patterns labelling the features of interest and explaining why they are there.

(b) Make a composite billet that has a cylindrical layer about 3 mm thick of different colour to the core. Extrude through the die marked '8' until the extrusion pressure rises markedly near the end of the process. Carefully remove the extrusion from the press, section, examine and make a labelled sketch as before.

N.B.(i) It is important to keep the extrusion press clean throughout the experiment, and to clean off all play-dough at the end of the experiment.

(ii) The play-dough sections can be photographed using the digital camera.

Work schedule

Day 1: Make play-dough billets. Extrude and record results.

Day 2: Extrude indium billets and record results.

Day 3: Finish any experimental work and work on data analysis.

Analyse data, write-up.

What should be in the report

Experimental method (refer to sheet but add any special details), presentation of results, discussion, conclusions. It should contain drawings, graphs and (copies of) the Tensometer charts, and brief descriptions of the extrusion process and what can be learnt from the play-dough experiment.

Make sure you show your calculations in algebraic form as well as in a table of computed values.

Questions you should try to answer

- Why has indium been used?
- What is the yield stress of the indium billets used by you?
- Why does the extrusion curve have its characteristic shape?
- What is happening at each stage during the extrusion process?
- Discuss the elementary analysis. Can you obtain the first expression?

- What assumptions have been made in evaluating α and β; can you improve on the method used and how does it affect your values?
- Is it possible to evaluate μ? Value?
- How well does play dough represent the ideal plastic solid and what relevance does the latter have in the real world of industrial extrusion?
- What are the two play dough composite billets designed to show?

Background reading

1. G E Dieter **Mechanical Metallurgy** McGraw-Hill (1976)
2. W A Backofen **Deformation Processing** Addison-Wesley
3. G W Rowe **Principles of Industrial Metalworking Processes** Edward Arnold (1977)