Practical 2P3

Extrusion

This practical will run remotely due to COVID restrictions. The teaching assistants, after a brief introduction, will run the experiments and share the raw data they acquired with the students to be used for the lab report. The lab report should comply with Acta Materialia journal style[1], bearing in mind there is a 3000-word limit and a maximum of 10 figures. Use your lab notebook as instructed.

Safety considerations [For information only]

The experimentalists will be working with indium metal which is toxic. Always wear gloves when handling indium. The tensometer device is designed to be used in tension but is capable of being driven into compression which can be hazardous. Always ensure you are driving it into tension, and that the cage converting tension to compression is moving freely, causing extrusion to occur. Keep long hair and fingers clear of the experiment during the extrusion process.

When extruding the playdough, 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

[1] https://www.elsevier.com/journals/acta-materialia/1359-6454/guide-for-authors

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 references are listed at the end of this sheet, but do not copy from these sources when writing your report.

Extrusion involves forcing metal (or another material) through a die. It is an efficient, large 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.

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 playdough 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

Although your numerical data will be the same, your analysis, plotting 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

A set of indium billets are cast from liquid indium. The indium is melted in a glass boiling tube and cast into a mold. After casting, some trimming might be necessary to remove excess material from the edges.

We fit the small extrusion apparatus in 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. Soap shavings are 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.

Die dimensions

Yield stress of indium: 2-5 MPa (use data derived from your extrusion curves – this is provided as a guide estimate).

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 playdough 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. The experimentalists 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. Note that the correct orientation of the die is with the flat side facing the dough.

(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.

What should be in the report

The report that you submit should be in the style of an Acta Materialia journal article[2] with a maximum of 3000 words and 10 figures. It should contain drawings, graphs and photographs with annotations as needed with brief descriptions of the extrusion process and what can be learnt from the play-dough experiment. Present error analysis for your quantitative analyses.

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

Points you should discuss in your report:

- 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 and derive 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 playdough represent the ideal plastic solid and what relevance does the latter have in the real world of industrial extrusion?

[2] See this link for details: https://www.elsevier.com/journals/acta-materialia/1359-6454/guide-for-authors

- What are the two playdough composite billets designed to show?

Background reading

1. G E Dieter **Mechanical Metallurgy** McGraw-Hill (1976)
2. W A Backofen **Deformation Processing** Addison-Wesley (1972)
3. Pradip, K. Saha. *Aluminum Extrusion Technology*, A S M International, 2000. ProQuest Ebook Central, https://ebookcentral.proquest.com/lib/oxford/detail.action?docID=3002441.