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Chapter 5: Extrusion of metals – HINTS

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Exercise 5.1 Look around your house and find one or more examples of extruded metal parts or products. Alternatively, look for products that have not been made by extrusion, but – perhaps with some small changes – might have been. Hint: the main characteristic is a prismatic shape (though not necessarily long thin parts, as they may have been sliced from a single extrusion).

Hint 5.1: extruded aluminium parts will be easy to find, from the tiny iPod Nano to (quite likely) parts of buses, trams or trains. Of course, the latter are not as easy to study in detail! When in need of inspiration, run an Internet search (search terms "aluminium extrusion" or "extruded parts/components"), but be sure to lay your hands on actual samples and do not be content with pictures only.

Exercise 5.2 Billets come in different diameters, usually measured in inches ("). What is the press force range for a 4", 6" or 10" billet, if the pressure on the billet must be 25-100 MPa?

Hint 5.2: the answer is straightforward if you simply observe the units.

Exercise 5.3 In extrusion of relatively hard alloys, the press force often becomes the limiting factor. Explain why it then helps to use shorter billets. What is the consequence in terms of production scrap and hence, profile costs?

Hint 5.3: recall that although recycling of production scrap is possible and indeed, common (though never with 100% efficiency), it does incur a cost penalty.

Exercise 5.4 Billets are sometimes pre-heated with a 'temperature taper' such that the end near the die is hotter than the other end, near the ram. Explain why. Hint: friction and plastic deformation create heat!

Hint 5.4: consider where exactly the heat is created, and where it is dissipated to. As a second hint, consider that for reasons that will become apparent in Section 5.4, the temperature at which most alloys can be extruded well (i.e. in the zone immediately against the die, where the deformation takes place) actually has an upper limit.

Exercise 5.5 If the profile circumscribed diameter is small relative to the billet diameter, do we expect the production scrap fraction to be at the low end or the high end of this 10-20% range?

Hint 5.5: problems? Making a detailed sketch will help!

Exercise 5.6 Formability increases with temperature, and necessary pressures decrease. Both are advantageous. What disadvantages could there be to increasing the billet temperature?

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Hint 5.6: an increase in cooling time is not the right answer, and neither is an increase in the energy required for the process (both effects are much too small to be significant). The correct answer will be found in Section 5.4.

Exercise 5.7 Given a certain alloy and profile shape, which of the three lines on the extrusion diagram do you think are inherent to extrusion as a manufacturing principle, which to the metal in question, and which to the machine that is being used?

Hint 5.7: one of the three will be a machine limit, the other two relate to the metal in question.

Exercise 5.8 Consider the extrusion of two aluminium alloys, one hard, one soft (same press, same profile). Which has the highest possible exit speed? And which has the highest billet temperature at which you would expect it to be extruded? What assumption do you need to make to answer these questions?

Hint 5.8: the answer should be straightforward, the assumption related to hit cracking behaviour.

Exercise 5.9 Sketch, in a semi-quantitative manner, what happens to the extrusion diagram if the extrusion ratio increases (assume A/B = 2). What happens to the maximum extrusion speed?

Hint 5.9: simply use the equation for the extrusion pressure, and go from (for instance) R = 20 to R = 40.

Exercise 5.10 Suppose we extrude an H-shaped profile measuring 60 by 40 mm with a 3 mm wall thickness. What is the extrusion ratio if we start with a 4" billet? And what if we increase the wall thickness to 6 mm?

Hint 5.10: take into account how R is defined and you will get the answers. Higher wall thickness should give a lower value for R.

Exercise 5.11 What do you think is the extrusion ratio of the sample parts or products you found in Exercise 5.1? Note that billets have standardized diameters (2", 4", etc.).

Hint 5.11: all kinds of possibilities. Recall that the billet diameter should be at least 1.25 times the diameter of the profile's circumscribed circle.

Exercise 5.12 What profiles do you think would be easiest to balance out? And what kinds of profile would be more difficult? Hint: consider symmetry (along one or two axes) and differences in wall thickness over the cross-section.

Hint 5.12: the Hint in the Exercise should tell you all you need to know.

Exercise 5.13 In extrusion of 'easy' aluminium alloys, we can typically make slots in profiles with an H/B ratio of up to 3 if the bottom is flat, and up to 4 if the bottom is round (see Figure 5.5). How might these ratios change if we use 'hard' aluminium alloys, or if we reduce the extrusion speed?

Hint 5.13: recall that harder alloys increase the forces on the die, all else being equal, and that lower extrusion speeds reduce these forces, again all else being equal.

Exercise 5.14 Imagine you would want to extrude the numerals zero to nine. How many numerals have no cavities (i.e. are 'solids')? How many have one? How many have more than one?

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Hint 5.14: this should be easy, but to make sure, consider that in the font type used here, the answers for lowercase letters, not numerals, would be 18 (with no cavities), 8 (with one cavity) and 0 (with more than one cavity).

Exercise 5.15 Hollow aluminium profiles offer excellent bending stiffness per unit weight. Can the weld seams become critical spots with respect to bending strength? And what about torsion? Analyse the loading, and conclude where you would <u>not</u> want to place these seams.

Hint 5.15: whatever the situation, you want to keep the weld seams away from areas with high shear stress.

Exercise 5.16 In dies for solids, slot ratios are limited (see Exercise 5.13). But could we not increase this limit if we were to use a die for hollows? Where would we then place the legs?

Hint 5.16: the answer is 'yes', the explanation is up to you to give!

Exercise 5.17 Look up the strength of the alloys with designation 6060, 6005 and 6082, all in the T6 ('precipitation hardened') temper. Also, look up the percentages of Mg, Si and manganese (Mn) in these three alloys. Sketch a graph of strength against the total content of alloying elements, and explain the trend you see.

Hint 5.17: the data are all in the CES EduPack, and can also be found on the Internet (search term: "composition aluminium 6060" etc.).

Exercise 5.18 Which of these three alloys can be extruded at the highest speed, given a certain press and profile? Explain. Hint: alloying elements also contribute to the strength when they are distributed homogeneously at temperature, by solid solution hardening.

Hint 5.18: basically, this is a question of which alloy has the lowest strength under extrusion conditions.

Exercise 5.19 Which of these three alloys gives the most form freedom, given a certain press and a certain minimum allowable extrusion speed? Explain, using the theory covered in Sections 5.2-5.4.

Hint 5.18: same answer as the previous exercise.

Exercise 5.20 Now give three rules for designing successful profiles, using alloys from the 6000-series. Explain on the basis of the preceding theory and/or practical considerations. Hint: do not forget to look beyond the issues raised by Exercises 5.17-5.19!

Hint 5.20: many possibilities! Recall the design rules must refer to *design*, not to manufacture. For instance: "apply a temperature taper on the billet" is *not* a design rule, whereas "ensure that fragile parts of the profile make no contact with the stretching table" *is* a design rule (a practical one, as it happens).

Exercise 5.21 How can you make a snap-fit joint between two profiles? And a hinge? And how would you integrate a screw hole into a profile, both parallel to the direction of extrusion and perpendicular to it? Be creative!

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Hint 5.21: in need of inspiration, feel free to search the Internet. However, never simply copy what you find, but consider carefully what you see!

Exercise 5.22 Recall that as a rule-of-thumb, 50% of the price of parts made of aluminium profiles is taken up by the price of the aluminium. Think of parts where this ratio is lower and where it is higher. Explain!

Hint 5.22: consider which additional operations would be needed to turn a certain profile into ready-to-assemble parts, and what the cost (machine costs, labour costs, amortized investments) of these operations would be.

Exercise 5.23 A 'performance index' for minimising product weight for a given stiffness in bending is $\sqrt{E}/\rho$. Compare the values of this index for aluminium and magnesium. On this criterion, how much lighter can a magnesium product be, in theory, if bending stiffness is the design driver? How do both of these materials compare on this criterion with low carbon steel?

Answer 5.23: you will need to look up the stiffness and density of the three metals.

Side note: lightweight design now would appear to be an issue of material choice. It certainly is, but other factors are equally influential: for instance, proper specification is important (i.e. not over-dimensioning, with respect to stiffness, or any other design requirement), as is the issue of minimising bending and torsion in favour of pure tension and compression. Remember that while steel may be inefficient in bending and torsion as compared to the light metals, it is equally effective for tension/compression – and typically at less than half the cost!

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