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Chapter 6: Forging of metals – HINTS

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Exercise 6.1 Look around your house and locate one or more forged products. Hint: don't forget to inspect your bike, or to explore a toolbox.

Hint 6.1: (all kinds of possibilities).

Exercise 6.2 Using the data in Table 6.1, draw the true compressive stress-strain curves of these four metals (on a log-log scale).

Hint 6.2: straightforward if you have understood Figure 6.4.

Exercise 6.3 Use the data for K and n to estimate a compressive yield stress for each alloy (assuming the yield stress is defined as the stress at which the plastic strain is equal to 0.2%).

Hint 6.3: don't forget that there will be elastic strain on top of the plastic strain of 0.002; you will therefore need to look up the modulus E for each alloy, noting that the total strain ε at the required stress is $\sigma/E + 0.002$. A graphical approach is best – but use linear scales, and limit the strain axis to at most 1%, to show the elastic and plastic strains clearly.

Exercise 6.4: Choose a metal from Table 6.1. What are the forces required to upset a billet of this metal by 25% and 50% (neglecting the influence of friction)?

Hint 6.4: the answers depend, of course, on the diameter of the billet. To give one example, for a 10-cm diameter stainless steel billet, upsetting by 25% requires a force of some 6,500 kN (650 tons!). Note that this gives the stress for uniaxial loading – in practice it is an under-estimate, as friction increases the compressive stress needed to produce yielding.

Exercise 6.5 Which metals were used for your sample products (see Exercise 6.1)? Which parts of these products require close tolerances to function? For instance, for a typical spanner that would be the distance between the two beaks, as well as how parallel they are.

Hint 6.5: all kinds of possibilities, but note that few people will own forgings made of other materials than steels (common) or aluminium (less common, and usually limited to sports and/or premium products).

Exercise 6.6 Determine the 'cold', 'warm' and 'hot' temperature ranges, in degrees Celsius, for high carbon steel and compare with those for one or two metals with a lower T_m (such as Al, Mg or Zn).

Hint 6.6: when your database presents a range for the melting temperature, you can assume the lower limit to be the $T_{solidus}$, which is what you need for this exercise. if this temperature is sufficiently low, you can expect the cold forging temperature to be low also – even be below 0°C.

Exercise 6.7   An aluminium forging process is conducted at 385°C. To improve productivity, we wish to increase the strain-rate by a factor of 10, but cannot increase the forging load (i.e. applied stress). By how much should the operating temperature be raised to achieve this? For hot deformation of aluminium in this regime, the activation energy Q = 156 kJ/mol. (Hint: for the same yield stress, the value of Z will remain unchanged).

Hint 6.7: write down expressions for Z_1 and Z_2, and equate them (as indicated in the hint in the question). Solve this equation for T_2, noting that the ratio of the strain-rates is known.

Exercise 6.8   Compare the range of hot yield stress for 6000 series aluminium alloy in Figure 6.5 with the data for 6082-T6 in Chapter 4. By roughly what factor is the material strength reduced?

Hint 6.8: the factor is probably larger than you expected.

Exercise 6.9   Hot forging can in principle be done with dies that are 'cold' or 'hot' (i.e. heated to the same temperature as the billet). Both have benefits and drawbacks. Given that the dies are made of tool steel, which options are applicable to forging of aluminium? And which for forging of steel?

Hint 6.9: note that the strength of typical plain carbon or low alloy steels, in a QT condition suitable for tooling, begins to drop significantly at temperatures above 500°C (i.e. the temperature at which they would previously have been tempered). More heat resistant high alloy tool steels retain their strength to somewhat higher temperatures, perhaps 600°C or so. It is not viable to use a steel for dies close to or above the temperature at which it transforms from ferritic to austenitic (750-850°C).

Exercise 6.10   Observe your sample products (see Exercise 6.1). Can you see where any flash has been removed?

Hint 6.10: flash, if present, is always located at the parting plane.

Exercise 6.11   Look up the compositions of low, medium and high carbon steels. What are the values for the carbon content (C) that designate the boundaries between these three groups of steel? Do low alloy and high alloy steels also contain carbon?

Hint 6.11: any decent materials database will give you this information.

Exercise 6.12   What will the ultimate strength be if tempering is too short: too high or too low? And what if the austenitising step is too short? So, how important is the factor of time in this respect?

Hint 6.12: consider the effects of temperature history on microstructure, and thus key properties (not just ultimate strength, but also fracture toughness and ductility).

Exercise 6.13   Does the QT treatment also affect the Young's Modulus of the steel? Explain your reasoning.

Hint 6.13: consider the physical origin of Young's Modulus, and whether heat treatment can affect it.

Exercise 6.14   Which are likely to be processed hot with this method: small or large workpieces?

Hint 6.14: simple exercise, simple answer.

Exercise 6.15   Which of the following attributes of the part affect die lifespan: metal type, complexity (i.e. requiring more or less deformation), small radii and fine detailing, narrow tolerances? So, how do these attributes affect part cost?

Hint 6.15: the short answer is 'all' – but be sure to ponder on the 'why'. Regarding the effect on part cost, recall that cost is partially made up by the depreciation of the forging dies over the production run.

Exercise 6.16   Draw up three design rules for cold closed-die drop forging of low alloy steel parts. How do these rules change if we would have hot forging? And how do they change if instead of steel we would have aluminium?

Hint 6.16: going through the text you will easily find several design rules. In general, form freedom, part size and look & feel that can be obtained for low alloy steel are considerably more constrained than those for e.g. sand casting of cast iron. Also, recall the peculiar effect that upsetting-type forging steps have on the tolerances in the direction of upsetting, which also 'hides' a design rule.

Exercise 6.17   Identify a sample part from those you found in Exercise 6.1 that has been manufactured using closed-die drop forging, identify the location of the parting plane. What kind of secondary machining has been used, and why? Hint: apart from flash removal, also consider tolerances.

Hint 6.17: (all kinds of possibilities).

Exercise 6.18   Take a close look at some coins. Why is there no parting line in the middle? Do you think the ring around the edge can be made out of one piece?

Hint 6.18: the answer is – perhaps surprisingly – that the retaining ring is indeed made out of one piece. As to how this works, a further hint is that the ring is always made of a much stronger material than the blank that becomes the coin, so the plastic deformation of the blank only causes elastic deformation of the ring. If that is the case, how could you eject the coin from the ring?