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Chapter 3: Casting of metals – HINTS

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Exercise 3.1 Look around your house and find one or more examples of cast parts or products. How important do you think form freedom, strength and cost were in choosing casting for these products?

Hint 3.1: a quick scan through the chapter should already give some ideas for applications. In addition, a simple image search on the Internet (e.g. with search term “aluminium castings” or even just “cast iron”) will provide suggestions – but be sure to lay your hands on actual parts.

Exercise 3.2 Look up the compositions of several zinc and magnesium casting alloys (at least two of each). Also, find a typical composition of brass. What are the key alloying elements? How do the melting temperatures of all of these alloys compare to those of the pure metals?

Hint 3.2: the CES EduPack (level 3) or www.matweb.com will help you here.

Exercise 3.3 Do you think that '18/8' stainless steel (AISI 304) can be cast as well as cast iron? In fact, do you think it can be shape cast at all, for practical purposes?

Hint 3.3: the melting temperature of this steel type should give you some idea of its castability, in comparison to e.g. grey cast iron.

Exercise 3.4 Are high viscosities beneficial (i.e. do they postpone the transition to turbulence to longer flow lengths and/or higher filing speeds) or detrimental for mould filling?

Hint 3.4: check the formula for the Reynolds number!

Exercise 3.5 Beneath its white plastic shell, the Apple G4 iMac had a hemispherical support frame (Figure 3.3), weighing 2 kg and cast in Zamac, a common zinc alloy. With part thicknesses as low as 3 mm, the filling time had to be less than 0.2 s to prevent cold running. Do you think this involved laminar or turbulent filling? Explain!

Hint 3.5: consider the size of the part, and assume it is filled through a single gate. This will give you an estimation of the flow length.

Exercise 3.6 Look closely at the products you selected for Exercise 3.1. Can you see where the gate (or gates) was placed to fill the moulds? Can you also spot any air vents? And which metals and alloys have been used in these castings, and how can you tell?

Hint 3.6: gates are usually placed on the side of the product, somewhere on the parting plane; vent holes (if any – they are usually very hard to spot!) are usually placed somewhere opposite of the gate. As for the metals in question, these are most likely cast iron (heavy, usually dark-coloured), aluminium (light, light-coloured), brass (heavy, yellowish in colour) or 'Zamac' i.e. zinc (a bit like aluminium: use scales and submersion in a metered beaker to determine the part's density and identify the metal used). The alloy in question follows from the application: for instance, aluminium parts that must have some toughness are usually made of alloy EN-AC-42000 a.k.a. AlSi7Mg (heat treated), while parts for which toughness is not an issue are usually made of alloy EN-AC-46000 a.k.a. AlSi9Cu3 (not heat treated).

Exercise 3.7 How can we deal with the contraction between $T_{solidus}$ and RT, in the design or casting of products? How can we deal with shrinkage?

Hint 3.7: for the contraction, the answer lies in the precise mould (or die) dimensioning. For dealing with shrinkage, read on!

Exercise 3.8: Why do different alloys have different shrinkage? Hint: consider the possible differences in crystal structures, and also consider what happens to certain alloying elements before and after solidification.

Hint 3.8: tough question – which is why the question itself already gives a Hint. In addition, note that the solubility of elements in alloys is much higher in the liquid state than in the solid state. So, during solidification, elements can be 'expelled' to form their own phases.

Exercise 3.9 For each alloy in Table 3.1, determine the amount of heat that must be dissipated to cool 1 kg of this metal from the bottom of its solidification range ($T_{solidus}$) down to RT. Compare your answers to the latent heat of solidification of the various metals. Which is bigger, and by what factor?

Hint 3.9: simply observe the units properly and finding the answer should present no difficulty.

Exercise 3.10 In practice we can de-mould when the casting is cool enough that it will have sufficient hot strength. Assuming this occurs at a temperature of 0.5 $T_{solidus}$ (in Kelvin), revise the analysis made in the previous exercise.

Hint 3.10: recall that 0K equals -273°C. The latent heat should become more significant now.

Exercise 3.11 Glass is very different from metals, but can nevertheless be cast quite well. What do you think would be the shrinkage for glass? And which property of molten glass allows a skilled glass-blower to mould and shape the material on the end of a hollow rod in the open air, whereas this is impossible for metals?

Hint 3.11: recall that shrinkage occurs when, from the unordered liquid state, the atoms pack themselves into the ordered solid state. So, the question is: does glass crystallize? See also the section on press-blow moulding of glass in Chapter 13.

Exercise 3.12 On skateboards, the wheels are mounted onto the board by means of a 'truck', which consists of a 'hanger' and a 'base plate'. Both are usually aluminium castings (Figure 3.5). Using Chvorinov's Rule, estimate the solidification times of these parts by modelling them as simple geometrical shapes. Which takes longest?

Hint 3.12: simply model the hanger as a cylinder, and the base plate as a thick rectangular plate. Then, putting in realistic dimensions will give you the V and A of both parts. Next, assuming e.g. sand casting as a method, you can find the Chvorinov constant in Table 3.2 to arrive at the solidification times.

Exercise 3.13 In two-shift production, we typically have around 3,000 hours per year of effective production time. What then is the maximum time to produce one part (i.e. the 'cycle time') if we want to produce 60,000 skateboard trucks per year? Will the solidification time you estimated in Exercise 3.12 allow this volume?

Hint 3.13: the exercise is simple enough, but make sure to make an assumption for the mould (or die) that is used. Will this be a single or multi-cavity mould, i.e. will it produce a single part for each cycle, or more than one?

Exercise 3.14 Estimate the solidification time for a brass church bell measuring 20 cm across and 30 cm high, with a 15 mm wall thickness (model as a hollow cylinder, open at one end). Do this for a worst case scenario (i.e. zero internal surface area) as well as for a best case scenario.

Hint 3.14: your answers should differ by a factor of about three.

Exercise 3.15 For a thin, flat plate with thickness d, the thermal modulus can be approximated by d/2. Explain why.

Hint 3.15: this should be straightforward if it is noted that $l, b >> d$.

Exercise 3.16 Estimate the solidification times for your various sample products (see Exercise 3.1).

Hint 3.16: of course, this depends on the product. Note once more that for thin-walled parts and products, Chvorinov's Rule will underestimate the solidification time.

Exercise 3.17 Which of the alloys in Table 3.1 is probably the most susceptible to porosity formation? Why?

Hint 3.17: the first key word here is 'shrinkage'; provided that solidification shrinkage is dealt with (e.g. by using feeders), the second key word is 'gas porosity'. NB: the exact answer will require searching beyond the chapter's text!

Exercise 3.18 Again, consider the G4 iMac frame. This casting has an average wall thickness of 3 mm, but has local sections measuring up to 15 mm thick (see Figure 3.3). How do the cooling times of these thicker sections compare to those of the thinner wall?

Hint 3.18: it is advisable here to assume a linear relationship between local thickness and solidification time.

Exercise 3.19 Consider a cast iron manhole cover with ribs for increased stiffness. Suppose that during casting we get a certain temperature difference ΔT between the thicker and thinner sections of this product. How large does ΔT need to be to cause permanent deformation (typically at a strain of order 0.1%)? Is this difference likely to occur during casting?

Hint 3.19: basically, the question is whether the thermal strains $\varepsilon_{thermal}$ = *CLTE ΔT* can cause permanent deformation (i.e. strains beyond 0.1%). Also, consider the mould material that is most likely used for a product like this.

Exercise 3.20   Look closely at the parts you selected (see Exercise 3.1). Do you think that porosity and/or internal stresses or distortion are present? Explain. Hint: measure your products carefully and estimate the thermal moduli of the various sections. Another Hint: cut right through the thickest section and see if you can see any porosity – polishing the section and using a microscope will help, but in cast aluminium, you can often see porosity with the naked eye.

Hint 3.20: many options possible, but notably in aluminium and magnesium die castings you should expect porosity in all thicker sections, if any.

Exercise 3.21   Estimate the number of grains across the thinnest section of the casting you identified in Exercise 3.1. Hint: what about the cooling rate?

Hint 3.21: recall that faster cooling will give smaller grains.

Exercise 3.22   Which element(s) can be used to ensure that the carbon in cast iron emerges as nodules ('nodular cast iron') instead of as flakes ('lamellar cast iron')? Look it up! And what is the key difference in material properties and hence, applications?

Hint 3.22: a quick Internet search will do (make sure to add 'composition' to your search term).

Exercise 3.23   Look up a cast alloy composition in detail. What are the impurities? What elements are deliberately added, and why?

Hint 3.23: again, run an Internet search. In general, the various aluminium alloys (e.g. AlSi7Mg or AlSi9Cu3) provide instructive results.

Exercise 3.24   Do you think inoculants will affect the cycle time?

Hint 3.24: consider carefully which process steps dominate the cycle time, and look at the amount of inoculant that is typically added. To what steps, if any, would this make a difference?

Exercise 3.25   Which method(s) would you choose if you want maximum design freedom? Think of the size of the casting and its material, but also of the ability to create undercuts, deliver fine detailing and sharp radii, or allow for changes in section thickness.

Hint 3.25: attentive reading is the key here. You should expect to get different answers when it comes to shape, size and surface detail!

Exercise 3.26   Which method(s) would you choose for castings that are highly loaded and therefore require high strength and good ductility? And which one(s) would you choose in order to realize narrow tolerances?

Hint 3.26: here, the main key word is oxide formation. Which methods minimize this problem? Another key phrase is cooling speed: methods that allow fast cooling will produce fine-grained material, which is stronger than coarse-grained material.

Exercise 3.27 Which method wins when it comes to investments, that is, which is best for small production volumes? And which offers the lowest part price, provided that production volumes are sufficiently large to amortize the mould or die costs?

Hint 3.27: again, attentive reading will show you that there are different answers, this time for investments and part price.

Exercise 3.28 Look back at one of the product examples you located (see Exercise 3.1). Consider which metal and which method were involved, and then draw up three design guidelines for this combination. How are these rules reflected in your product?

Hint 3.28: by this time you should already have some ideas. If all else fails, run a quick Internet search (e.g. with search term “casting of metals design guidelines”), but be sure to interpret the search results carefully to see if they are informative and make sense.