MIT 2.810 Manufacturing Processes and Systems
Homework 6 Solutions
Casting

October 15, 2015

Problem 1. Casting defects.

(a) Figure 1 shows various defects and discontinuities in cast products. Review each one and offer solutions to avoid them.

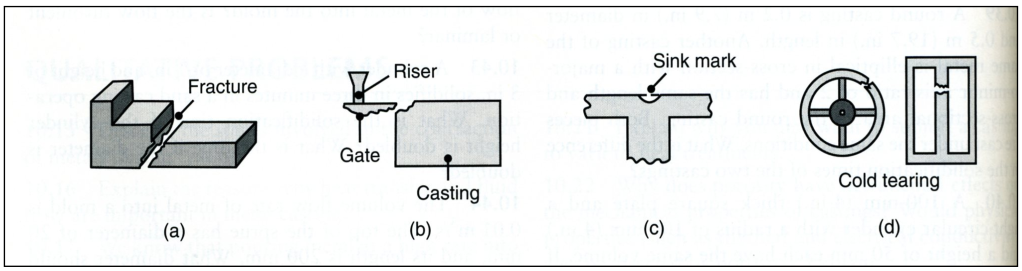


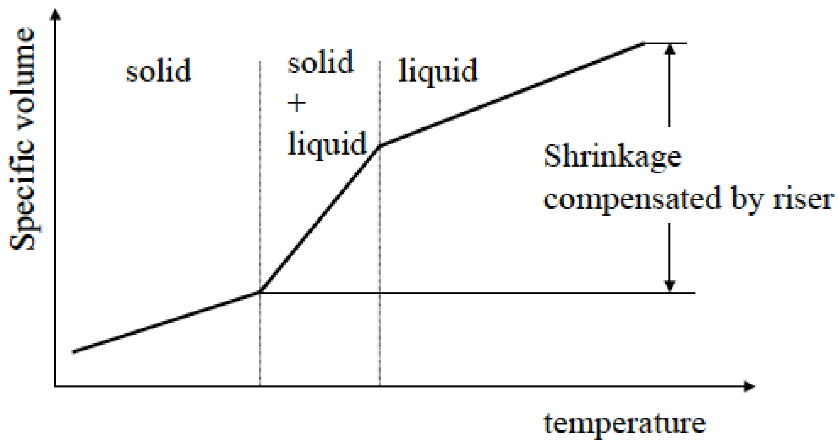
Figure 1: Casting defects

(b) Sketch a graph of specific volume versus temperature for a metal that shrinks as it cools from the liquid state to room temperature. On the graph, mark the area where shrinkage is compensated for by risers.

Answer:

(a) Most defects and discontinuities occur because the thinner sections of the casting solidify faster. As a result, the thick sections will contract more than the thin sections will allow. This could lead to residual tension stresses, fracture, shrinkage, voids and porosity. The fracture in (a) is caused by high concentration of stresses at the corner. To avoid such fractures, you should add fillets to inside corners.The purpose of the riser in (b) is to serve as a reservoir of molten metal to supply the casting with additional metal while it is experiencing shrinkage during solidification. Here, the runner seems to be too narrow, so it solidifies early, prevents the riser from performing its function and leads to fracture. This could be remedied by using a thicker runner. To prevent the sink mark in (c) due to shrinkage, you could add a chill or redesign the part to reduce the thickness at the intersection. Cold tearing as in (d) happens in areas susceptible to tensile stresses during cooling if the part is constrained from shrinking freely.

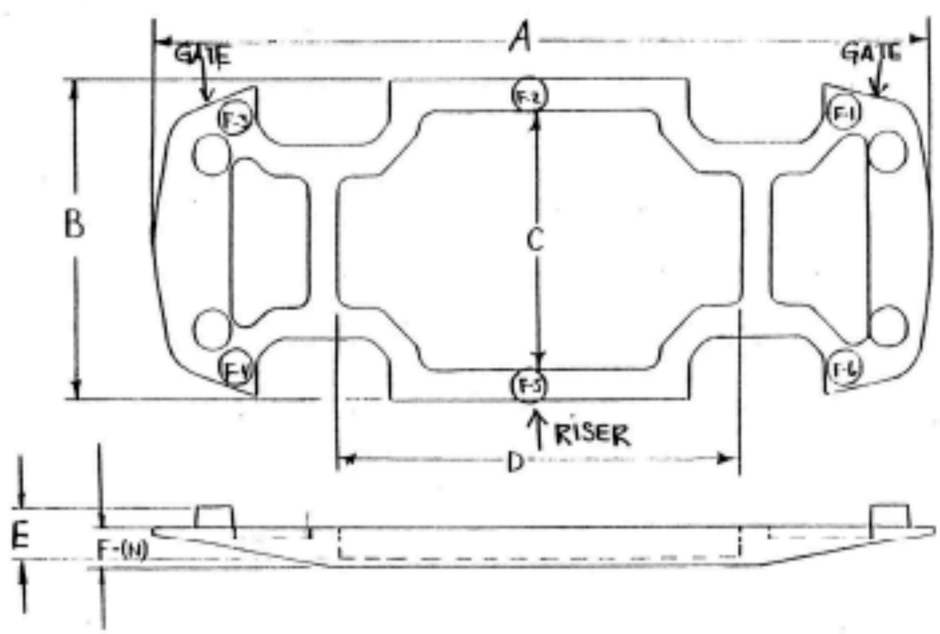
(b) The graph of specific volume vs. temperature for an alloy metal is given below, including compensation for shrinkages:


Specific volume
solid
solid
+
liquid
liquid
Shrinkage
compensated by riser
temperature

Problem 2. Shrinkage.

Figure 2 shows a drawing of a chassis pattern designed and machined by Gerry Wentworth for an earlier class of 2.810. On the drawing you will find dimensions for the machine pattern and for the green sand cast chassis. Please compare these two cases for all of the dimensions (A) through (E) and the thickness measurements designated F-2 and F-5. Can you comment on how these values compare with typical shrinkage values for aluminum of 0.013 in/in. Please explain any deviations in terms of the design and the physical phenomena which might be responsible for the deviation.

2.810 Car Chassis



Legend	Green Sand	No-Bake	Machine Pattern
A	9.935	9.930	10.070
B	3.8300	3.8265	3.8800
C	3.1070	3.0920	3.1320
D	5.1735	5.1600	5.2260
E	.742	.746	.757
F-1	.4940	.4980	.5070
F-2	.5052	.5002	.5075
F-3	.5030	.4980	.5050
F-4	.4940	.4995	.5063
F-5	.5080	.5020	.5100
F-6	.5000	.5020	.5100

Figure 2: Chassis pattern drawing and dimensions of cast parts

Answer:

The observed shrinkages are all within the usual range for aluminum (0.013/1). The cause for deviations lies within the cooling pattern, the mold material, measurement accuracy, and the placement of gates and riser. Generally, green sand molds are less stiff than their no-bake counterparts, which are solidified by using a binding component. However, the data does not show that the dimensions, which are expected to be constrained, experience less shrinkage for the no-bake; in fact, it is the other way around. Note instead that not all of the variations for the green sand mold are easily explained. Some possible comments for the green sand mold are:

- the height E exhibits a considerably higher shrinkage, since the material is allowed to contract freely,
- less shrinkage in the area of the gate and the riser, since these sections solidify last and material is continuously fed into the mold.

Problem 3. Cooling time.

(a) Consider the zinc die casting of a "C" section as shown in Figure 4. Calculate the cooling time for two different sets of dimensions:

1. (1 + 2h = 100mm) x (w = 2.5mm)
2. (1 + 2h = 100mm) x (w = 8mm)

Use the following values:

H_f = 113 kJ/kg (enthalpy of fusion)	T_{inject} = 410 °C
C = 419 J/kgK (heat capacity)	T_{eject} = 240 °C
h = 1.58 kW/m²K (film coefficient)	T_{mold} = 60 °C
α_t = 40.9 mm²/s (thermal diffusivity)	r = 6.6g/cm³ (density)

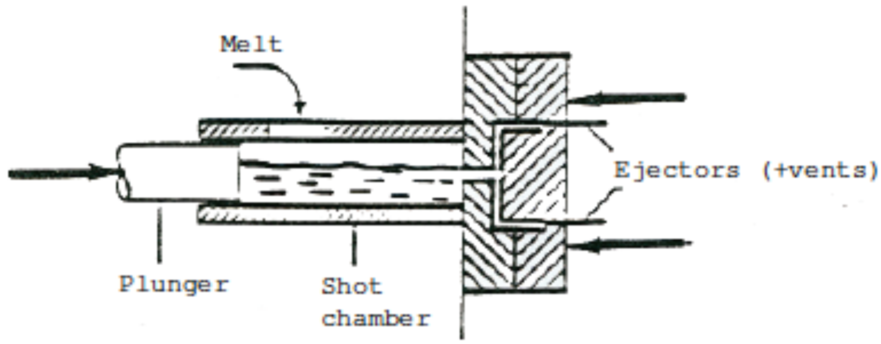


Figure 3: Zinc C-Section die

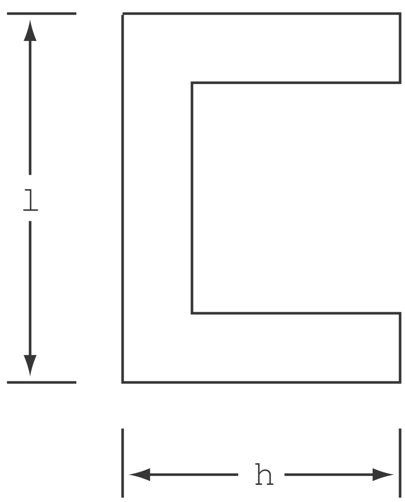


Figure 4: Cast C-Section

(b) Describe how you might go about calculating the cooling time required to cool a sand cast part to below its melt temperature. How would you formulate the problem? What physical quantities would you need to know? What problems might there be in doing this calculation accurately?

Answer:

(a) From the lumped parameter model for die casting,

$$t = \frac{w\rho C}{2h} 1n\left[\frac{T_{inject} + \Delta T_{sp} - T_{mold}}{T_{eject} - T_{mold}}\right]$$

Note the film coefficient can vary for aluminum die casting from about 1 – 14 kW/m^{2}C depending upon the surface condition. Here we use h = 1.58 kW/m^{2o}C.

For w = 2.5,

$$t = \frac{2.5\times10^{-3}[m]\times6.6\times10^{3}[kg/m^{3}]\times0.419[kJ/kg\circ C]}{2\times1.58[kW/m^{2}\circ C]}\ln\left[\frac{410+270-60}{240-60}\right] = 2.7\sec.$$

For w = 8, t = 2.7 * 8/2.5 = 8.6 sec.

Note here we have assumed that "C channel" shapes look like thin sheets. Probably these shapes would not cool as quickly in the corners and on the inside.

We can compare these values with the die casting cooling time approximations given in the Casting lecture slides. For zinc, the estimate is $t \cong 0.42\sec/mm\times W_{\max}$, where W_{max} is the maximum thickness. This gives 1.05 sec for the 2.5 mm part thickness and 3.36 sec for the 8 mm part. Apparently the approximations use a larger value for h, about 4.04 kW/m^{2o}C.

(b) The solution given in the class notes and derived by Flemings is for solidifications only. This resulted in the time estimate t = C(V/A)^2 which is called Chvorinov's Rule. (These values are determined experimentally, and range from C ~2 to 4 min/cm^2.) Recall that during solidification it is assumed that the part is at a constant temperature T_{melt}. In reality, the part is poured at some initial temperature $T_i > T_{melt}$ and it is removed at some temperature $T_r < T_{melt}$. Hence the complete time for cooling would be the time to go from T_i to T_r (ignoring the latent heat of fusion for the moment) and then add to that the solidification time from Chvorinov's Rule (which only accounts for the latent heat of fusion). For a rough estimate of the cooling time, we could use a lumped parameter model like the one shown in class for die casting:

$$mC_p\frac{\delta T}{\delta t} = q$$

Where mC_p is for the metal part and the q is the rate of heat transfer out of the part. To solve this problem we would need to solve for the temperature gradient in the sand, but now with a changing temperature at the wall equal to the current temperature of the cooling part. Here we are ignoring any temperature gradient in the part, any film coefficient and the fact that the mold is actually finite in extent.