ME 340-1 Lab 4 Report
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Introduction

In this lab, we seek to understand another manufacturing process: sand casting. Sand casting involves pouring molten metal into a mold composed of densely-packed sand and binders to form a part with high precision and sophisticated geometric features. Here, we make a small anvil from a tin-antimony-copper alloy.

Experimental Method

List the materials and equipment used in the lab and provide a review of the laboratory procedure. (10 points)

Materials:

Sand Casting:
- Metal flask (cope and drag side)
- Match plate
- Wooden platform
- Parting compound
- Sand-scoop
- Riddle (sifter)
- Green casting sand
- Rammer
- Bench scraper
- Sprue block
- Riser block
- Paint brush

Melting and Solidification:
- Tin (92) – Antimony (7.75) – Copper (0.25) alloy ('Lead-Free Pewter')
- Electrical resistance melting furnace
- Graphite crucible
- Steel forging tongs
- Digital thermocouple
- Stop watch
- Safety glasses
- Heat-protection gloves

There are two components of the lab: one concerned with the melting and freezing of the pewter alloy over time and another concerned with the sand casting of a small pewter part.

The melting and freezing component consisted of taking intermittent temperature measurements at given increments (30s) as a sample was melted and resolidified.

The casting component consisted of the preparation of a sand casting mold, the pouring of the pewter, and the post-processing of the riser and sprue. First, the drag was packed tightly with greensand over the pattern. Then, the cope was packed over the pattern with the sprue and riser blocks maintaining flow paths. These are removed after packing, and connecting channels are manually scraped with a brush. Lastly, the cope and drag are matched without the pattern and molten pewter is poured into the cavity. After a short cooling time, the riser and sprue fill is bent off, leaving the final casting.

Results

1. From Part II: Melting and Solidification, make a plot of the data recorded for each of the melting and freezing cycles. Also give a brief qualitative description of what you observed in terms of what we have discussed in class. (15 points)
2. Provide a picture and a brief description of your resulting anvil from Part I: Sand casting. (10 points)

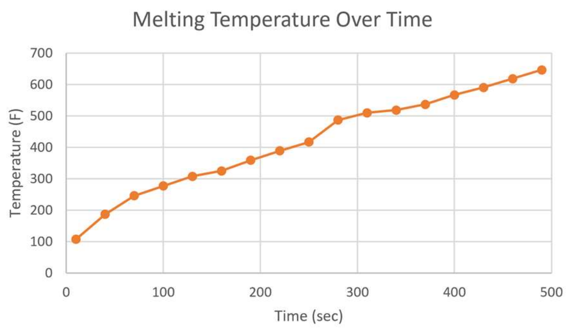

Figure 1a: Melting temperature over time

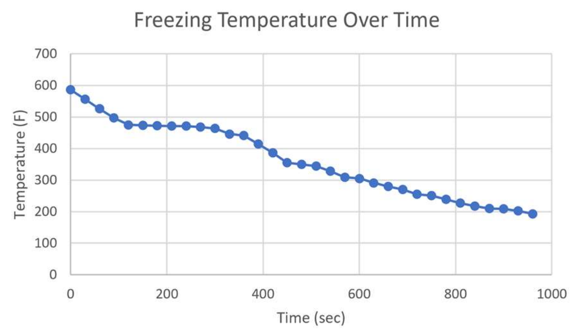

Figure 1b: Freezing temperature over time

Figures 1a and 1b above show the melting and freezing temperatures versus time, respectively, of approximately 380.2g of the provided metal alloy. The raw temperature readings are included below in Appendix A.

Starting with melting process in Figure 1a, the solid alloy was first placed inside the graphite crucible and then heated to approximately 625F. In Figure 1a, the melting temperature over time generally demonstrates the warming of the solid block, then the melting from solid to liquid, and finally the warming of the liquid. The exact phase transitions are not as clear in this figure because the process happened so quickly.

After the material had melted completely, the crucible was removed from the furnace and air-cooled to approximately 200F. Figure 1b shows the freezing temperatures over time as the molten liquid metal cools, then solidifies from liquid to solid, and then cools as a solid. Because the cooling process took much longer than the heating process, the time scale in Fig. 1b is almost twice as large as the time scale in Fig. 1a. Further analysis is continued in “Discussion” below.

Fig 2a: The anvil still in the mold, partially submerged in sand.

Fig 2b: Top view

Fig 2c: Bottom view

The finished anvil is shown above in Figures 2a-c. In Figure 2a, the anvil is shown still in the mold. The sand is still packed densely around the bottom half of the anvil.

In Figures 2b-c, the anvil is removed from the mold and cleaned. The sprue has been removed but the riser is clearly shown. The top view (Fig. 2b) highlights a "dimple" in the center. This likely occurred when the molten material cooled on the surface and contracted in the middle, leaving a crater. Since that area is both geometrically large and far from the riser, it cooled slower than the surrounding areas and was unable to fill in with remaining molten material from the riser. The dimple is not present on the bottom of the anvil (Fig. 2c).

Discussion

1. Describe the features of the two curves from Part I. Why are there knees in the curve and what do they indicate? What does the slope of the curve tell you? Do the curves look exactly the same? Why or why not? Can you resolve the positions of the knees in the curve in terms of the binary phase diagrams? Why or why not? (10 pts).

    1. Because the time scale for Fig. 1b is much larger than Fig. 1a, analysis is much easier performed on Fig. 1b. Around 180 seconds, the student measuring temperature noticed metal beginning to solidify along the edges of the crucible. Consistent with this observation is the "plateau" that occurs between 150-300 seconds at 470-475F; evidently, this is the approximate melting point of the alloy. (Of course, because this is an alloy, the plateau is not perfectly flat).

        As time progresses in Figure 1b (Figure 1a), two "knees" on the diagram occur at approximately 470F, indicating the momentary halting of temperature decrease (increase) until the material has solidified (melted) completely, and the subsequent resumption of cooling (heating) of the solid (liquid) afterwards.

The slope of the *solid* warming process in Fig. 1a corresponds to the specific heat of the solid, C_s. Once the solid has melted completely, the slope of the *liquid* warming process should correspond to the specific heat of the liquid, C_l.

In theory, the liquidus on the phase diagram corresponds to the temperature at which freezing begins T_{start}, and the solidus corresponds to the temperature at which freezing is complete T_{end}. For the given composition (Tin-92W%, Antimony-7.75W%, Copper-.25W%), the liquidus and solidus are ~250C (482F) and ~240C (464F), respectively. Indeed, the observations (the "knees" on Fig. 1b) corroborate this to within ten degrees: $T_{start} = 475\text{F}$ and $T_{end} = 470\text{F}$!

2. Estimate how much energy is required to heat the solid material from room temperature (70 °F) to the pouring temperature (625°F). (10 pts).
   Note 1: For this problem, disregard the energy needed to heat the furnace.
   Note 2: Assume the volume needed is twice of the casting volume.
   Note 3: Please convert everything to the SI units.

Material	Heat of Fusion	Specific Heat	Density
Sn	14.4 cal/g	0.054 cal/g-K	7.287 g/cc
Sb	38.5 cal/g	0.050 cal/g-K	6.684 g/cc
Cu	49.0 cal/g	0.092 cal/g-K	8.96 g/cc

3. Estimate the molten metal velocity at the bottom of the sprue during filling. (5 pts).

4. Estimate the molten metal velocity in the middle of the riser during filling. (5 pts).

2. Q = mCΔT

   T = 21.1 C and 329.4 C   ΔT = 329.4 – 21.1 = 308.3 C or K

   V = 2*30.9 cm^3 (from #5)

   m = 61.8[0.92(7.287) + .0775(6.684) + 0.0025(8.96)] = 447.7 g

   C = 0.92(0.054) + .0775(0.050) + 0.0025(0.092) = 0.0538

   Q = mCΔT = 447.7(0.0538)(308.3) = <u>7426 Cal = 31.1 kJ</u>

3. v = $\sqrt{2gh}$
   = $\sqrt{2(9.8)(0.051)}$ = <u>1.00 m/s</u>

4. Flow in = flow out
   $v_1A_1 = v_2A_2$
   v_1 at 1 inch down (halfway full riser) = $\sqrt{2gh} = \sqrt{2(9.8)(0.0254)}$ = 0.706 m/s
   A1 = π($.25^2$) = 0.196 in2
   A2 = π($.375^2$) = 0.442 in2
   Solve for v_2 = <u>0.313 m/s</u>

5. Estimate the volumetric flow rate for casting i.e., in filling the mold. Calculate the mold fill time for the casting. Assume that the molten metal poured into the mold is 150% of the final casting volume. The cross-section area of the gate can be approximated as 25 mm^2. How does your calculated value compare with that measured in the laboratory? Explain any differences. (10 pts).

(1) The volume of the anvil is **30.9cm³**.

(2) The height of the sprue can be estimated as **1.2inch** depth with **0.5inch** diameter, while the riser is **5/8inch** diameter with the same height. (If you do not have your own measurement, please use this as a reference)

5. Let T_{MF} denote the filling time, then

$$T_{MF} = \frac{V}{Q}$$

Laboratory-measured value:

V = 1.5(30.9cm^3) = 46.35 cm^3 over 8.1s

Q = 46.35/8.1 = <u>5.72 cm^3/s</u>

Theoretical value (at 2in below surface)

From (3): v at sprue bottom = 1.00 m/s

Q = vA = 1000mm/s(25mm^2) = <u>2.50 cm^3/s</u>

As expected, the laboratory measurement is larger than the theoretical one. This is attributable to a slow/interrupted pour, non-laminar flow, backpressures in the mold cavity, and frictional losses.

6. Suggest a method for decreasing the fill time of the mold. (5 pts).

6. Injecting the molten alloy (with a press), instead of using gravity to pour it, would decrease the fill time considerably. Do note that at a threshold pressure, the greensand mold would be unsuitable for injection, since it would be destroyed during casting.

7. Describe the surface finish of your casting. Explain any surface blemishes. (5 pts)

7. The finished surface is relatively smooth but matte, reflecting the coarseness of the greensand that comprised the mold. There are no significant defects other than the shrinkage cavity previously discussed. This shrinkage cavity is unfortunately inevitable given the design of the mold (thick center) and pour temperature. Despite that, the finishing quality is quite good for our sand casting, and flashing was minimal.

Conclusion

Conclusions: Provide a few statements of what the main takeaways were. (10 pts)

Please provide any detailed calculations, data intepretation and other information. Photos are also appreciated.

Through this lab, we gained hands-on experience with sand casting. Through the construction of the mold, pouring of the molten metal, and post-processing/finishing, we are better able to understand the intricacies of sand casting.

Additional analysis explored some material properties of the provided metal alloy. For instance, on the melting and freezing plots (Figs. 1a-b), the slopes and knees corroborate outside data, such as the specific heat and liquidus/solidus on the phase diagram.

Ultimately, we leave with a greater appreciation and increased knowledge of this manufacturing method.

Appendix A: Melting & Freezing Temperature Measurements

Melting		Freezing	
Time (s)	Temp (F)	Time (s)	Temp (F)
10	107	0	586
40	187	30	556
70	246	60	526
100	277	90	497
130	308	120	475
160	325	150	473
190	359	180	472
220	389	210	471
250	417	240	471
280	487	270	468
310	510	300	464
340	519	330	446
370	537	360	441
400	567	390	414
430	591	420	386
460	619	450	355
490	647	480	350
		510	344
		540	328
		570	309
		600	305
		630	291
		660	280
		690	270
		720	255
		750	251
		780	239
		810	227
		840	217
		870	210
		900	209
		930	202
		960	193

Other recorded information:

- Temp at pouring: 600F
- Pour duration = 8 seconds
- .75x2 = riser
- .5x2 = sprue
- Area of exit bit of sprue .0123”
- Gate = 1/8 x 1/4