Middle East Technical University

Department of Metallurgical and Material Engineering

Mete215 – Materials Processing Laboratory

Experiment 6: Solidification of Materials

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ABSTRACT

Conventional sand casting was done by the use of Al-Si alloy and silica-clay-water mixture mold. The alloy was melted in an induction furnace and after pouring the molten metal to the created molds the process of cooling was observed statistically with the use of thermocouples that took data. The volume and Surface area were calculated for three different samples and by using chvorinov's equation the constant value of the equation was calculated and found to be between roughly 400-800. The graphs of temperature vs time were drawn and examined. The effect of casting modulus to the solidification time was observed.

INTRODUCTION

Casting is a melt process where the material is first heated enough that it melts and gains the ability to flow with either gravity or external force. The molten material is than poured into a mold to achieve a desired shape. Next comes the solidification of the material, where after the molten material is cooled inside the mold, an object with a desired shape is formed (Francis, 2016) . There consists many types of casting which are mainly categorized by the type of mold the molten is being poured into or in some cases the way the molten material is being poured (Francis, 2016). In the experiment that is going to be discussed in this report, conventional sand casting was used. It is called as sand casting as the molten material is poured into a mold that is composed of sand which is generally silica based. This sand can be mixed with sand with clay and moistened with water (Thomas, n.d).

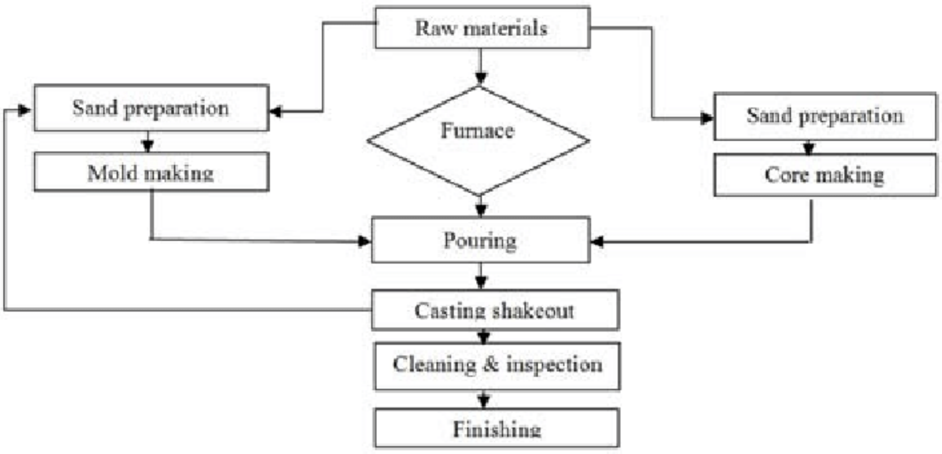

Figure 1. Flow chart of sand casting (Sumaiya Shahria, 2017)

Figure 1 depicts the general process of sand casting. It can be seen that there are basically three steps, mold making, melting and pouring. The composition of the mold has been mentioned but there are a few things to note. Firstly, the sand is generally silica based because silica is a material that is abundant on earth, making a cheap material. It is also resistant to temperature which is very important as molten material is going to be poured on it. Secondly, clay and water are added to sand to increase the strength and plasticity while also making it easier to give shape.

The material is melted in a furnace and there exist many types of furnaces. To give some examples, the oven at our homes can be considered as an electrical furnace where the heating of the material is done indirectly. This results in a relatively slow way of heating.

Another type of furnace is an induction furnace. This furnace allows the heating of the metal to be very fast as the material is directly heated.

Another important concept is the solidification time of the material. For two or more casting processes With measurable volume and surface area, chvorinov's equation can be used;

$$(1)\ t_s = \beta\,(V/A)^2$$

by taking its natural logarithm we get;

$$(2)\ \mathrm{Ln}\ t_s = \ln \beta + 2\ln (V/A)$$

If the plot of ln t_s vs ln(V/A) is plotted a linear line with the slope of 2 and an intersection point of ln β is expected.

EXPERIMENTAL

Materials that were used;

- Silica sand
- Water
- Clay
- Al-Si alloy

Equipment that were used in the experiment;

- Flask
- Rammer
- Riddle
- 3 different patterns
- Steel board
- Muller machine
- Induction surface
- Thermocouple

Procedure

In the beginning, the muller machine was already mixing the clay-sand-water mixture which was put beforehand. From the machine enough amount of the mixture was gotten. This mixture was put on top of the drag-half of the flask. Then, a force was applied to the sand mixture with a rammer as to prevent cavities from occurring. After, it was turned over and dry sand was poured on top of the rammed mixture. The sand allows for easier separation. Next, cope half of the flask was put over the drag half. Afterwards a cylinder was put to the mold to act as a riser. Now, we manually combined the separation of cylinder and the pattern. When the molds became ready, thermocouples were put inside to record the change in temperature with time. Then, in the induction furnace the Al-Si allow was allowed to melt. This molten metal was then poured into the molds where in this time the data of temperature and time were started getting recorded.

RESULTS

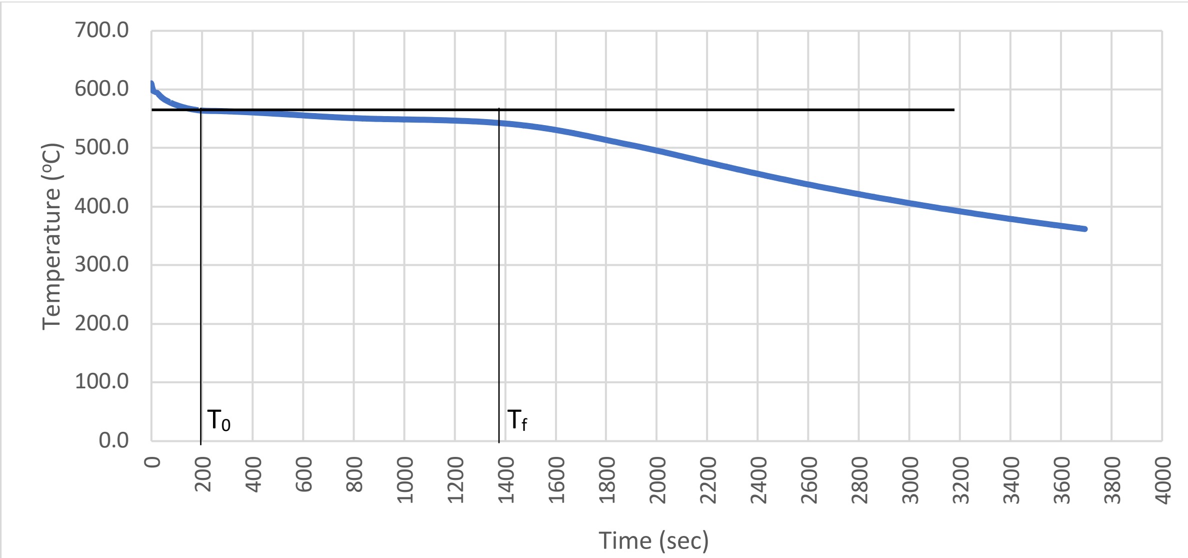

Figure 2. The change in temperature over time for red-black

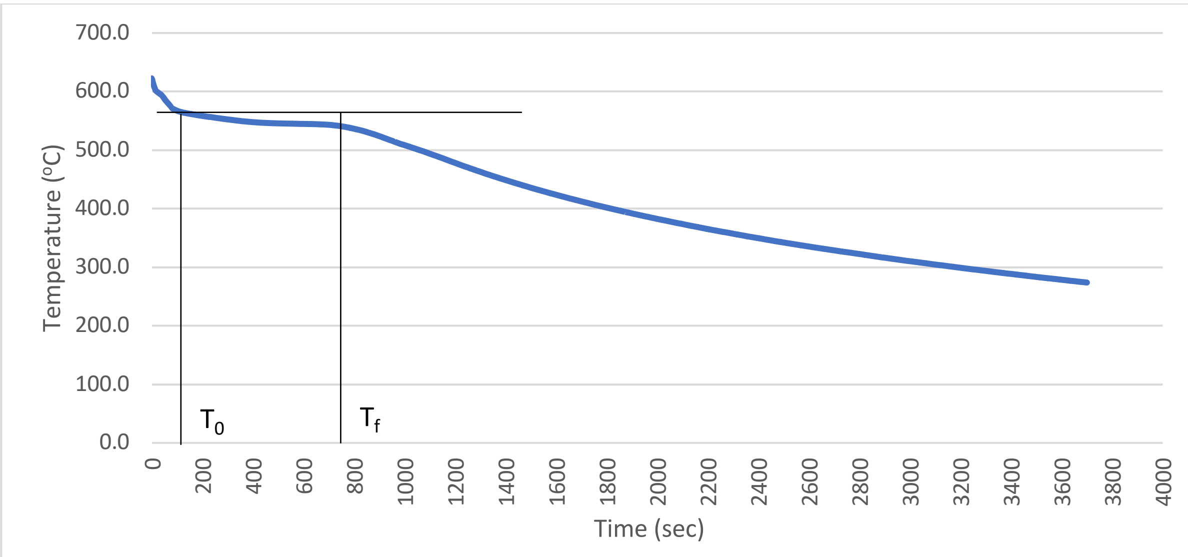

Figure 3. The change in temperature over time for red-brown

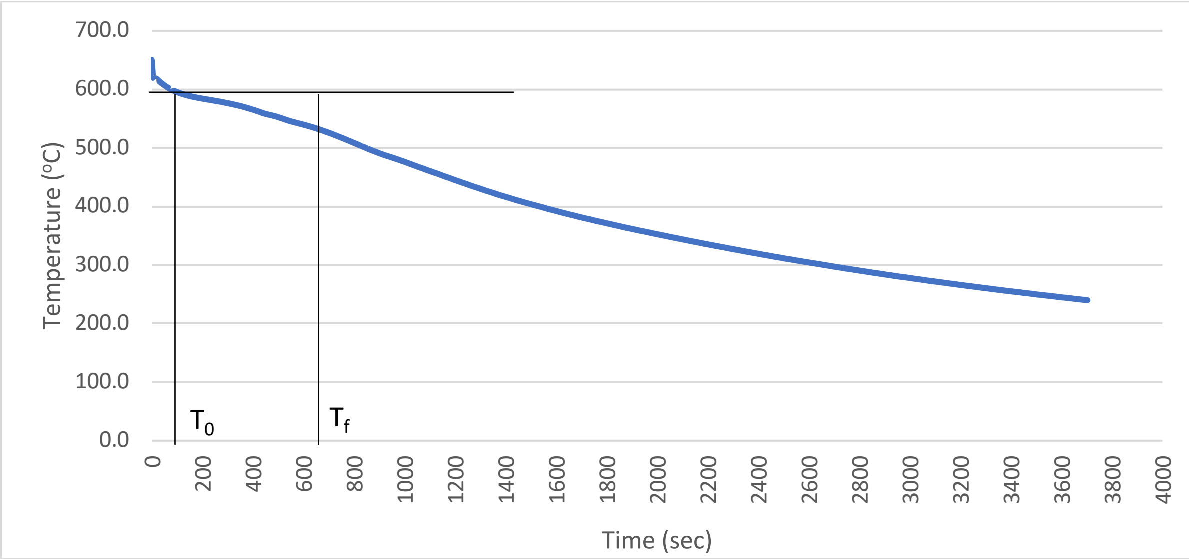

Figure 4. The change in temperature over time for red-red

Figure 2 till 4 is the temperature vs time graphs for red-black, red-brown and red-red samples. In the graphs the approximate places where the solidification started and ended are shown with the labels T_0 for the beginning and T_f for the end. Table 1 shows these values as well as some other properties of the samples.

Samples	Volume(cm^3)	Surface Area(cm^2)	Casting Modulus (V/A)	T_0	T_f
Red-Black	1174.23	697.69	1.68	200	1400
Red-Brown	778.90	791.40	0.98	100	780
Red-Red	435.17	418.50	1.04	100	640

Table 1. The properties of the three samples

One thing to note here is that the values of T_0 and T_f are found roughly and $T_f - T_0$ gives T_s which is the solidification time.

It was mentioned that $t_s = \beta\,(V/A)^2$ is defined as the Chvorinov equation with β being the Chvorinov constant. The values for each of the samples are:

Red-black : 425.17

Red-Brown: 708.04

Red-Red: 499.26

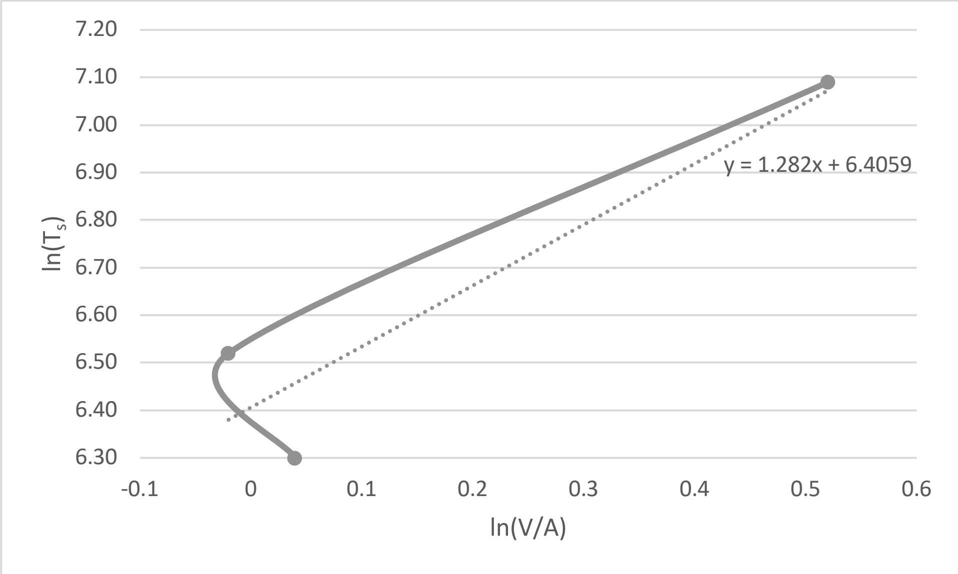

Figure 5. ln(V/A) vs ln(T_s) graph

The figure 5 shows the ln(V/A) vs ln(T_s) graph as well as the best line for this graph and the equation of that line.

DISCUSSION

In figure 1 till 3 the data that the thermocouple got which is the temperature can be seen. In these graphs the initial decrease is the period where aluminum is getting colder but it is still in liquid state. Then, we expect the temperature to stay constant. In this time the phase transformation from liquid to solid is occurring. However, as it can be seen from the graphs there are not any places that stagnation happens. Therefore, the time that the slope of the line changes is taken as T_0 and T_f. T_0 is the time that solidification begins. In our case the temperature for that to happen is supposed to be 577 ^{0}C however due to the impurities inside our metal the exact temperature is not seen. T_f is the time that the solidification ends. From this point on it is expected for the temperature to once again decrease. The values of T_0 and T_f is given in the result part of the report.

The Chvorinov equation is also given and from this equation we can conclude that as V/A (casting modulus) gets bigger the time of solidification increases. In our case the red-black sample has the highest casting modulus while also having the highest solidification time which relates with our expectations. However, Red-brown has a higher solidification time than Red-Red despite having a smaller casting modulus which theoretically is not correct. The reason for this anomaly is that the volume and/or surface area has been calculated wrongly. This can be seen from the fact that surface area has a bigger value than the volume which is physically impossible.

Another thing to note that is in figure 2 and figure 3 the times where the slope changes can be easily distinguished but for figure 4 it is not so easily seen. This may have also resulted in a wrong determination of the solidification time.

From the values we got and by again using Chvorinov equation the constant value β is calculated for our three samples. In theory this constant should be same for all 3 cases but theory does not match reality as they have different values where red-brown sample has an obvious difference from the other two sample's values. This is again due to the fact that the volumes and surface areas may be calculated wrongly as well as the solidification time value is calculated roughly meaning that it may also have caused distortion from reality.

In figure 5 ln(V/A) vs ln(T_s) graph is shown and theoretically this graph should have a slope value of 2 as can be seen from the equation (2). In reality, from the equation of the best line of the graph the slope is determined to be 1.282. This graph is also expected to be linear but once again reality deviated from theory as that is not what is observed in figure 5. The reason is the calculation errors once again.

CONCLUSION

In this experiment sand casting was used to create three different samples. The mold was composed of silica as it is cheap and resistant to temperature, clay and water to strengthen and give some flexibility to the mixture. To this mold Al-Si allow was cast. The alloy was melted in an induction furnace and after it was poured the thermocouple inside the molds took data. It can be said that with the increase in casting modulus the solidification time increases but in our experiment the calculations of surface area and volume was of. This led to getting results that did not match the theory. Therefore, it is important to calculate the values correctly. The used furnace is also important as without direct heating done by the induction furnace it will be hard to melt the metal.

REFERENCES

Francis, L. F. (2016). *Materials Processing, A Unified Approach to Processing of Metals, Ceramics and Polymers* . Minnesota: Academic Press.

Sumaiya Shahria, M. H. (2017). Optimization of Molding Sand Composition for Casting Al Alloy. *International Journal of Mechanical Sciences*, 155-161.

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APPENDIX

$t_s = \beta\,(V/A)^2$, is Chvorinov equation. Calculations to find β for the three samples;

Red-Black: $1200 = \beta\,(1.68)^2 \rightarrow \beta = 425.17$

Red-Brown: $680 = \beta\,(0.98)^2 \rightarrow \beta = 708.04$

Red-Red: $540 = \beta\,(1.04)^2 \rightarrow \beta = 499.26$

	$\ln(V/A)$	$\ln(T_s)$
Red - Black	0.52	7.09
Red - Brown	-0.02	6.52
Red - Red	0.04	6.30

Table 2. The data for figure 5