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Cite as: AIP Conference Proceedings **2283**, 020028 (2020); https://doi.org/10.1063/5.0025429
Published Online: 29 October 2020

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Solidification Behaviour of Squeeze Cast Aluminium Composites

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Abstract. The effect of die temperature on the solidification behaviour of aluminium mixed ceramic cast samples are studied. The samples are prepared by squeeze casting method. The die temperatures are assigned in this work from 220 - 280°C and the preparation of aluminium in liquid state of temperature is 850°C, respectively. The application of pressure during this process is 70 MPa. It was observed that the solidification time varies from 29 seconds at 220ºC and 37 seconds at 280ºC. Increasing the die temperature resulted in decreasing the cooling rate. The experimental and theoretical solidification time was almost equal and close in their values.

INTRODUCTION

There are many manufacturing processes for conventional casting which has its own pros and cons. The main obstacle during the process of casting is formation of defects in the cast product. Casting defects are formed due to the presence of air or any other substance existing in the die. The defects which could be removed by the innovative processing approach of squeeze casting method [1, 2]. Liquid state processing of metal matrix composite is most economically feasible as compared with other state of processing. The particle settlement in liquid state process is tedious as compared with mixing of different powder [3]. Hence liquid state processing is cost effective and also most of the manufacturer would prefer to choose liquid state processing. In liquid state processing the solidification of samples would decide the mechanical properties. Though there has been wide of range solidification study on composite, the solidification time is difficult to predict.

The majorities of studies have taken the parameters to study the effect of solidification of composites with and without application of pressure. Samuel et al. [4] reported a study to determine the effect of processing temperatures on the metal matrix composites with increasing the ceramic particles. The particles are pushed away from the base metal and few are settled in intercellular area. The non-uniform ceramic particle distribution in the matrix would also affect the properties of metal matrix composites. This results in the distribution of SiC being reliant on the solidification rate of the molten metal [5]. Rajan et al. [6] studied the solidification time of an aluminium matrix composite, using steel, graphite and sand dies. They reported that the cooling rate increased on adding SiCp, and reached a maximum, and then decreased with increasing SiCp content, it causes the transfer of heat inside melt is reduced. The results show that the amount of SiC particles would decides the cooling rate of the base metal. A similar kind of study was reported by Hanumanth and Irons [7].

Proceedings of International Conference on Recent Trends in Mechanical and Materials Engineering
AIP Conf. Proc. 2283, 020028-1–020028-6; https://doi.org/10.1063/5.0025429
Published by AIP Publishing. 978-0-7354-4013-5/$30.00

This paper reports the influence of die pre heat recommended temperature for sample preparation, as well as the required solidification time for the aluminium alloy composite. The solidification curves are analyzed with respect to the various processing temperatures.

EXPERIMENTAL WORK

Materials

In this work, aluminium alloy (A356) with ceramic particles (40 micron) have taken for preparation of test sample. The aluminium alloy possess very good strength, machinability hardness, fatigue strength, ductility and fluidity. The crystal lattice of SiC has structured with silicon atoms and tetrahedralcarbon in it. This leads to strong and hard characteristics. Further it has high thermal conductivity attached with low thermal expansion and thermal shock resistant. It can withstand high temperature has made the material very useful in preparation of composites. Table 1 shows the Composition of A356 alloy . Table 2 shows the thermo physical properties of A356 aluminium alloy and Sic The specimen preparation is listed in Table 3. The temperature is recorded with the help of K-type thermocouple, and from the values, the cooling curves were plotted. The values are measured by 1.5 mm diameter of the thermocouple. Data acquisition system is incorporated to record the temperature values at one-second intervals. 180 seconds has taken for recording the temperature values. The size of the die into a cylindrical shape of 150mm height and of 50mm diameter

TABLE 1. Composition of A356.

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
6.5-7.5	0.2	0.2	0.1	0.25-0.45	0.1	0.2	Balance

TABLE 2. Thermo physical properties of A356 aluminium alloy and SiC [9].

Property	Solid	Liquid	SiC
Density (ρ) (kg m^{-3})	2700	2400	3200
Specific heat (C_p) (J $Kg^{-1}K^{-1}$)	1084	963	1300
Thermal conductivity (K) (W m^{-1} k^{-1})	159	121	100
Latent heat (L) (KJ Kg^{-1})	-	389	-
Viscosity (μ) (Kg m^{-1} s^{-1})	-	0.002	-
Liquidus temperature (T_L) (ºC)	-	615	-
Solidus temperature (T_S) (ºC)	-	577	-
Melting point of aluminium (T_M) (ºC)	-	660	-

TABLE 3. Specimen Preparation

Sl No	Melt Temperature (ºC)	Die Temperature (ºC)	Pressure (MPa)
1	850	220, 240, 260, 280	70

Preparation of composites

Graphite crucible has taken for melting and preparing the aluminium alloy. Aluminum alloy is melted above the temperature of 800°C to 850°C. The reinforcement particle has to uniformly be mixed with base alloy. To maintain

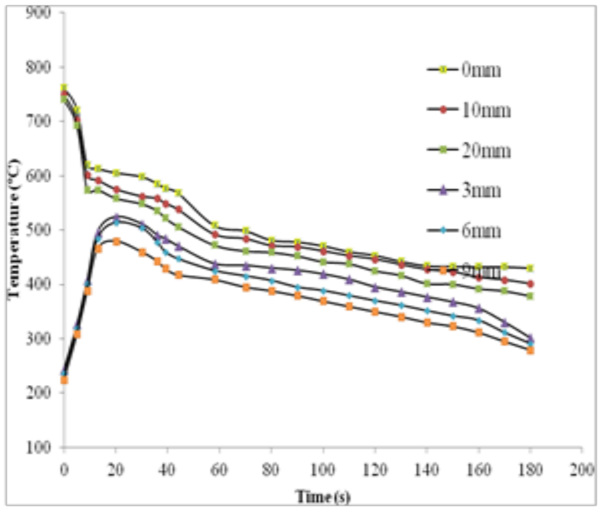

FIGURE 1. Cooling curves for die temperature at 220ºC

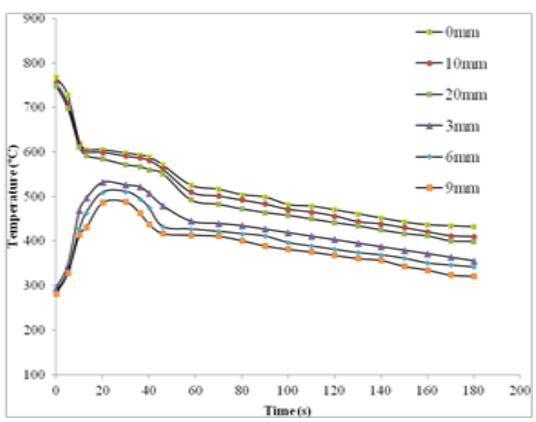

FIGURE 2. Cooling curves for die temperature at 240ºC

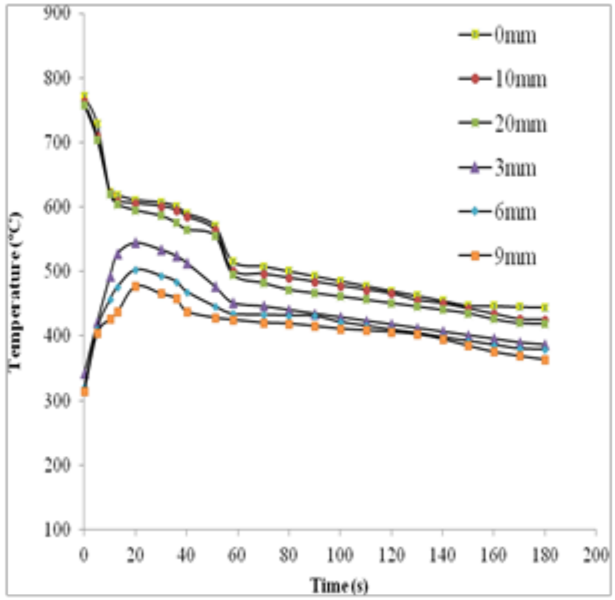

FIGURE 3. Cooling curves for die temperature at 260ºC

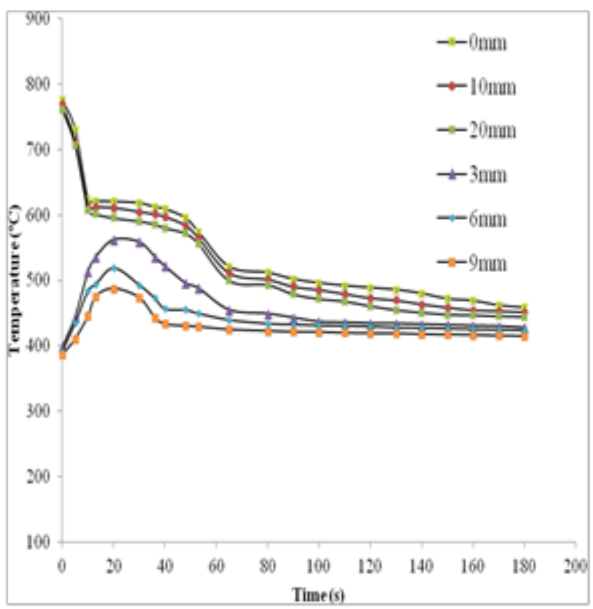

FIGURE 4. Cooling curves for die temperature at 280ºC

homogeneous distribution, preheat the SiC particles up to 1000°C, two hours before mix into the base alloy. Stirring process has to be used for preparing the liquid composite slurry. During the stirring process degassing tablet is used at regular interval. The tablet is used to remove oxide layer formation during the stirring process. The stirring speed is 160 rpm and the stirring time is 15 minutes. The punch and die have to be heated separately with the help of pre heater. The die walls were coated graphite lubrication and also a small amount of wax was also to be applied.

Three thermocouples were inserted in the base plate and another three thermocouples were inserted into the die. The distance of thermocouple inserted in the base plate were one at exactly center, 10mm from the center and 20mm from the center. Similarly, the distance is maintained from the inner surface of the die are 3mm, 6mm and 9mm respectively.

RESULTS AND DISCUSSION

Calculation of solidification time

During the solidification of composite melt there are so many factors are involved to decrease or increase the solidification time. The amount of ceramic particles would extract the heat from the melt leads to increase the solidification time. The second result is that, the presence of low conducting particles can delay the heat transfer during solidification and increase the solidification time. The measured quantity of ceramic particle here in this study is fixed on ten percent with respect to base metal alloy. The particles distribution in the melt may decides the final solidification time [6,8]. If the particles are clustered with melt, would result in improper casting. However, the processing temperatures are also to be considered in the analysis of the solidification time. The die temperatures are fixed from 220°C to 280°C.

From Fig. 1, it was observed that at the applied pressure of 70MPa, melt temperature has reduced by 35°C, also the die temperature has reduced by 9°C. From Fig. 1 and Fig.4 for die temperature of 220ºC & 280ºC the solidification time is 29 & 37 seconds respectively. Heat transfer is reduced due to increase in die temperature; it leads to increasing solidification time. Theories of temperature distribution has been adapted for calculating the solidification time of the squeeze cast samples.

The theoretical solidification time can be verified from Eq. (1).

$$ts = \frac{\rho[H + Cp(T_p - T_1)]}{h[T_1 - T_0]}\left(\frac{V}{A}\right) \tag{1}$$

The heat transfer co-efficient can be determined from Eq. (2)

$$h = \left(\frac{L_1}{K_1} + \frac{L_m}{K_m}\right)^{-1} \tag{2}$$

Table 4 shows the values of experimental and theoretical solidification time.

TABLE 4. Values of various die temperature solidification time.

Die Temperature	Experimental Solidification time	Theoretical Solidification time
220	29	30.32
240	32	31.75
260	35	34.22
280	37	36.28

The solidification time increases with the increase in die temperature. If the squeeze pressure is applied for more than 29 seconds for die temperature 220ºC, results in decreased productivity. And in this aspect, this solidification time assumes their significance.

MICROSTRUCTURE

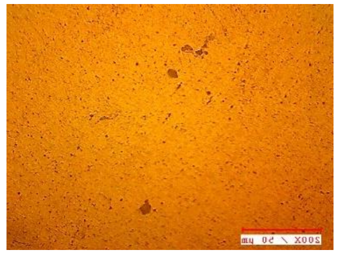

FIGURE 5. Microstruture

Figure 5 shows that optical microscope image of the squeeze cast composite. It shows that SiC particles are distributed uniformly and few particles seem to be scattered. Increasing the die temperature increases the particle distribution. This is may due to the fact that the heat transfer rate may be decreased between melt and die.

CONCLUSIONS

From this experimental and theoretical study, the following observations have been identified

- The solidification time of the casting has directly influenced by the processing temperatures. The solidification time vary from 29 seconds in the die temperature 220ºC, to 37 seconds at 280ºC. It is evident that escalate in die temperature rises solidification time.
- Preparation of melt and addition of ceramic particle have to be carefully considered for the solidification analysis. Heat transfer analysis between cast and die play a major role for finalizing the solidification time.

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