Experimental Investigation and Solidification Study of Aluminium alloy Composites

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Abstract. The study on the solidification of aluminium alloys has been reported by the squeeze casting method. In solidification analysis, the formation of casting plays a vital role. To provide quality casting, the preparation of composite is essential. Hence the liquid state processing of the squeeze casting technique is adopted. The application of pressure during the fabrication of composite would change the structure and properties of the developed composite. The squeezing pressure is assigned 30, 60, 90 and 110 MPa, and the melting of the aluminium the selected temperature is 850°C, and the die temperature is 350°C respectively. At 30 MPa, the solidification time is recorded at 69 seconds, and the pressure is increased to 110 MPa the solidification is recorded at 33 seconds. The cooling rate is reduced due to increasing squeeze pressure. K type thermocouple has been used to record the temperature values of the aluminium alloy. The theoretical solidification time is calculated, and the results are close to the values which have been taken from the experimental results. Further, the hardness value is identified to measure the grain structure formation in the aluminium alloy, which is correlated with the solidification process.

Keywords: Pressure; Squeeze casting; Solidification time; Temperature; Aluminium.

1. Introduction
Aluminium alloy-based composites are performing well in recent research in the area of novel materials. The conventional casting process has its own merits and demerits, particularly for developing the composites. The main drawback is defecting during the casting, and that would affect the entire casting process. The defects during the casting process are the formation of blowholes due to the presence of air in it. To develop the quality of casting, some other manufacturing processes have to be adopted. The method should support and overcome all defects. Squeeze casting is a method to approach and eliminate all kinds of casting defects [1,2]. The liquid state processing of aluminium alloys is proved to be satisfied in all sectors, and it’s results are commendable [3]. In powder metallurgy, grain refinement is tedious, whereas this type of work would lead give better output. The liquid state processing is cost-effective, and many researchers are preferred to adopt this method because of its unique properties. Solidification is the
method to evaluate the liquid state processing in terms of its mechanical properties of the cast samples. It is very much essential to study the behavior of materials. In solidification analysis, the quality of the casting is decided by the selection of processing parameters. Hence the processing parameters have to be chosen carefully to develop the cast alloys. And many studies have been reported concerning temperatures. In this work, the effect of squeeze pressure during the solidification is taken into account. Samuel et al. [4] has said that the reinforcement has also affected the process parameters, which is changing the basic properties of the base alloy. He reported that the improper reinforcement has also affected the base alloy. But in this work, the reinforcement may not be affecting the performance or strength of the material. The base alloy function of solidification or formation of solidification is essential that has to be addressed [5]. Rajan et al. [6] studied the behavior of various types of die material for the aluminum alloy from that the solidification time is identified. He has used steel, graphite, and sand dies, and the base alloy is performed differently with different die materials; from the behavior of die material, the cooling rate is calculated. The study concluded that the behavior of dies is one of the reasons for increasing the solidification time. Hanumanth and Irons have reported that similar kinds of surveys in A356 alloys [7]. In this paper, the solidification behavior is studied experimentally, and the pressure is considered for an important parameter. Experimentally the solidification time is identified based on the various processing conditions. In this paper, a solidification study on aluminum alloy has been studied with the support of the data acquisition system. .Net software has been incorporated into the data acquisition system.

2. Squeeze Casting Process

2.1. Materials

A356 aluminium alloy has taken for the preparation of the cast sample, and this possesses excellent strength, fluidity, formability, fatigue strength, and ductility. Table 1 shows the Composition of A356 alloy. K type thermocouple is used for recording the temperature values; from this, solidification time is identified. The thermocouple diameter is 1.5 mm, from which the values are recorded. Besides, to data acquisition system is merged to monitor the values at every second of the time. The maximum time (180 seconds) is fixed for this solidification process. From the specified time, limit the temperature values, and the solidification time is calculated. The diameter and height of the cylindrical-shaped die material is 50mm and 150mm, respectively. Fig.1 shows the experimental set up for stirring set up.

![Schematic sketch of the melt stirring setup.](image)
Figure 2. (a) Squeeze casting process, (b) Cylindrical die with thermocouples.

Figure 2 shows the casting process setup with thermocouples for recording the temperature values. Table 1, 2 shows the composition and thermophysical properties of A356. The properties of SiC are shown in Table 3. The properties of H13 is listed in Table 4. Table 5 shows that the preparation of the sample for various processing conditions.

**Table 1.** A356 alloy and its elements

|   | 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.** A356 alloy thermophysical properties

| Temperature (ºC) | 100 | 200 | 300 | 380 | 400 | 500 | 567 | 614 | 700 | 800 | 900 |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Thermal Conductivity (Wm⁻¹ K⁻¹) | 165 | 162 | 155 | 153 | 153 | 145 | 134 | 65.8 | 67.9 | 70 | 71.9 |
| Enthalpy (J/g⁻¹) | 68 | 162 | 261 | 343 | 364 | 472 | 547 | 1025 | 1144 | 1263 | 1382 |
| Density (Kg/m³)  | 2662 | 2641 | 2620 | 2602 | 2600 | 2578 | 2567 | 2406 | 2379 | 2352 | 2325 |
| Specific heat (J/g⁰K⁻¹) | 0.921 | 0.967 | 1.011 | 1.046 | 1.055 | 1.098 | 1.127 | 1.19 | 1.19 | 1.19 | 1.19 |
Table 3. Properties of SiC

| Material | Density (Kg/m³) | Thermal conductivity (W/m°C) | Specific heat (J/Kg k) |
|----------|----------------|-----------------------------|------------------------|
| SiC      | 3200           | 100                         | 1300                   |

Table 4. Properties of H13 material

| Material   | Density (Kg/m³) | Thermal conductivity (W/m°C) | Specific heat (J/Kg k) |
|------------|-----------------|-----------------------------|------------------------|
| H13 steel  | 7761            | 28.6                        | 461                    |

Table 5. Specimen Preparation

| Sl No | Melt Temperature (°C) | Die Temperature (°C) | Pressure (MPa)    |
|-------|-----------------------|----------------------|-------------------|
| 1     | 850                   | 350                  | 30, 60, 90, 110   |

2.2. Solidification Time
The study of solidification time in the aluminium alloy (A356) is considered in this work. The aluminium alloy is kept in a graphite crucible for melting and stirring. The alloy is heated, and the required temperature of 850°C, which is above its melting point. Once the alloy is heated and the stirring process needs to be performed for preparing the solidification analysis. Hexachloroethylene tablet is used for degassing the alloy at regular intervals. The oxide layer formation is completely removed during the stirring process. The stirring speed is fixed at 200 rpm, and 15 minutes is allotted for stirring the alloy. Graphite coating is done in the stirring blades to maintain the wettability between the alloy and blade. H13 steel is selected for the punch and die, and the preheater is used for heating the punch and die separately. Inside, the die walls are coated with wax to remove the cast samples easily. There are six thermocouples used to measure the temperature values during the solidification process. The base plate is used for three thermocouples, and another three thermocouples are inserted in the top surface of the die material. In the base plate, the first thermocouple is placed at the exact center, which is the center of the base plate. From that point, the distance of 10mm is located for the second thermocouple, and from that point, another 10mm is selected for recording the temperature values. The same kind of approach is used for the die material top surface; the distance is maintained are 3mm, 6mm, and 9mm from the inside corner of the die.

3. Results and Discussions

3.1. Theoretical and Experimental Solidification Time
Many factors are influenced during solidification time, which may lead to better shaped casting. One crucial, influential factor is grains that formed during solidification, which may decide the solidification time. The final solidification time is realized, not only the formation of grains and also the heat transfer rate between the die and base alloy [8,9]. If the alloy were not appropriately stirred, it would result in improper casting formation. The grain formation has to be uniform, and the influence of fluidity has played a significant role in fixing the cast alloy.

Further, the temperature loss should not occur in between die and base alloy; this also to be considered in the analysis of the solidification time. The melt and die temperatures are fixed at 850°C and 350°C, respectively. From Fig. 3, it is shown that the pressure at 30MPa, the solidification time has been reported at 69 seconds, and it has reduced 33 seconds at 110MPa. From Fig. 4, it is shown that the pressure at
30MPa, the solidification time has been reported at 71.42 seconds, and it has reduced 32.44 seconds at 110MPa. The temperature distribution is decreased due to an increase in squeeze pressure; it leads to diminishing the solidification time. In the end, the experimental and theoretical solidification time is compared; the values are related to each other. However, these values are compared with the Hardness and Tensile strength of the samples.

![Figure 3. Experimental values observed for increasing the pressures](image)

![Figure 4. Theoretical values observed for increasing the pressures](image)

The following equation (no.1) can used for calculating the theoretical solidification time
The following equation (no.2) can be used for calculating the heat transfer co-efficient

\[
h = \left( \frac{L_1}{K_1} + \frac{L_m}{K_m} \right)^{-1}
\]  

(2)

Table 3 shows the solidification time related to the pressure.

| Pressure (°C) | Experimental Solidification time | Theoretical Solidification time |
|--------------|----------------------------------|----------------------------------|
| 30           | 69                               | 71.42                            |
| 60           | 58                               | 56.34                            |
| 90           | 45                               | 47.31                            |
| 110          | 33                               | 32.44                            |

The effect of pressure would be the leading cause of the process of solidification time. From this study, the applied pressure (110 MPa) is more than 33 seconds would result in increasing the lead time, which may lead to increasing the output time. In this aspect, the significance of solidification time is evaluated.

3.2. Tensile Strength and Hardness
ASTM Standard D3039 is used for a dog bone shaped cast sample. The influence squeeze pressure is taken into account to explore the ultimate tensile stress of squeeze cast specimen, as shown in Fig. 5. The tensile test sample is prepared from the center of the cast specimen. It can be concluded that the squeeze pressure at 110 MPa is giving good tensile strength due to the formation of smaller grain size. There are three experiments have been conducted to find the tensile strength of the solidified alloy. Increasing the pressure would cause the sample to provide better stability. This is due to the better refinement of the grain morphology. It is clear that at 110 MPa, solidification time also decreased.
Hardness is studied for the developed alloy, and the sample is precisely taken out from the center of the cast sample. The piece is machined square shape, and each 10mm distance, three impressions were carried out. The average of those three values is calculated, and it has been plotted in Fig. 6. From the graph, it is clear that increasing the pressure value, the importance of hardness has also been improved.

**Figure 5.** Theoretical tensile strength for various squeeze pressures

**Figure 6.** Hardness values for various squeeze pressures

4. Conclusions
This study has been observed, and the conclusions are
• The application of squeeze pressure directly relates to the important factor for measuring the quality of the casting. The solidification time is observed 69 seconds for the pressure of 30MPa, to 33 seconds at 110MPa. It is proved that increasing squeeze pressure leads to a decrease in the solidification time of the specimen.
• Increasing the pressure increases the value of hardness, which is not showing a huge difference.
• Preparation of melt and die temperature have also to be considered for the preparation of any alloys. In this study, interfacial thermal analysis has not been considered, and that may be used further to study the solidification time.

5. References

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