INFLUENCE OF PROCESSING PARAMETERS FOR GLOBULAR MICROSTRUCTURE FORMATION OF ALUMINIUM 7075 FEEDSTOCK BILLET PRODUCED BY DIRECT THERMAL METHOD

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ABSTRACT: This work aimed to evaluate the processing parameters for forming globular microstructures on billets of aluminium 7075 alloys with a direct thermal method (DTM). Semi-solid metal (SSM) processing is preferred to produce a high-quality product, which reduces casting flaws such as macroscopy, shrinkage, and porosity. It requires a solid globular microstructure in the semisolid aluminium liquid matrix. DTM is a simple SSM technique for creating a globular microstructure in a temperature environment that is typical of nature. In this experiment, molten aluminium 7075 alloys were poured into a cylindrical copper mould at pouring temperatures of 645°C and 665°C, then quenched into the water after holding times of 20, 40, and 60 s. Following that, the microstructure of feedstock billets prepared at a range of pouring temperatures and holding times was investigated. Limited information on aluminium 7075 alloy behaviour, and lack of proper understanding of globular microstructure formation are among the problems that arise in this research field. The influence of parameters on DTM processing should be investigated in detail. In particular, there is a lack of information about the aluminium 7075 effects near the liquidus temperature. Therefore, this study investigates the effects of globular microstructure formation and parameters in aluminium 7075 alloys in detail. A uniform high number of spherical primary particles is expected for a

globular microstructure. The results of this experiment indicated that a pouring temperature of 665°C combined with a holding time of 60 s produced a finer and globular microstructure.

KEYWORDS: *Aluminium 7075 alloy, Direct thermal method, Feedstock billets, Pouring temperature, Holding time, Semisolid metal processing.*

1.0 INTRODUCTION

As an alternative to the traditional metal-forming process, David Spencer introduced a new forming metal technology between solid and liquid states in 1971 [1–3]. Ranjan's review suggests that semisolid metal (SSM) processing offers the best results for all ferrous and non-ferrous metals and metal matrix alloys [4]. From the Nafisi study, SSM processing has been reported to provide several advantages including lower processing temperature, shorter solidification time, and lower energy consumption, thus stimulating interest in SSM processing [5]. It has been proven to perform well due to short solidification time, less shrinkage, ability to quickly fill complex geometries, flow control ability, and ability to form suitable microstructure. Therefore, SSM processing has been recognized as a valuable method for low-temperature casting, improving die life, and accelerating production [6]. There are several suggestions that microstructure formation is important in the rheological behaviour of SSM feedstocks used in the foundry industry to produce high-quality products [7], [8]. A study of the rheological behaviour of semisolid SEED-processed 7075 aluminium alloys revealed that globular structured samples exhibited better deformation behaviour at higher solid content (from 0.42 to 0.53 Fs) [9]. Rogal, and K.P. Sołek studies suggest that rheological properties can be improved by changing the dendrite of SSM into a globular microstructure [10],[11]. Various methods are practised to create a globular microstructure [12–14].

DTM is one of the best methods for producing globular microstructure feedstock billets for the thixoforming process [12]. It is gaining attention due to its unique ability to induce controlled thermal changes in materials. B. Benjunior investigated the feasibility of producing aluminium alloy 6061 feedstock billet by the DTM method. A low superheated molten metal is poured into a high conductive copper mould and then quenched in cold water after a certain holding time to easily form the desired microstructures. Temperature and holding time, cooling rate, and metallic properties have been reported to play a significant role in the formation of globular microstructures. The study results show that the lowest pouring temperature of 660°C and the shortest holding time of 20s produced small and globular grains [15]. But, a study shown that a lower pouring temperature of 660°C and a longer holding time of 60s produced globular grains, showing a discrepancy with the previous study. Additional information can be obtained when changing metals, and processing parameters. Aluminium 7075 alloy is one of the strongest and lightweight metals compared to some steel grades [16]. It has several advantages, such as a high strength-to-weight ratio, excellent mechanical properties, resistance to fatigue, high corrosion resistance, toughness and durability, machinability, heat Treatability, high-stress applications, versatility, and recyclability. However, due to their low fluid flow, solidus cracking, hot shortness, and shrinkage flaws, aluminium 7075 alloys are challenging to cast [17].

The SSM process is called thixoforming. It offers excellent opportunities for casting aluminium 7075 alloys. The presence of solid globular grains in the liquid matrix is the most crucial need for the thixoforming process [18]. These globular primary phase structures improve flow behaviour during SSM processing to form near-net-shaped components with superior mechanical properties [19]. Although DTM is considered the best method for globular microstructure formulation. Several findings have reported that lower pouring temperatures provide higher cooling rates and holding time is crucial to provide a globular microstructure. However, the pouring temperature close to the liquidus temperature was not investigated. There is a gap in the influence of microstructure at pouring temperatures close to the liquidus temperature. Holding time effects should also be examined to eliminate contradiction [15], [20]. This study was expected to lead to a detailed understanding of globular microstructure and the influence of processing parameters. It investigated the effects of processing parameters on the globular microstructure formation of aluminium 7075 feedstock billet produced by the DTM.

2.0 Experimental procedures

2.1 Material

In this study, Foundry Master Oxford Instruments' (FMOI) Optical Emission Spectroscopy (OES) was used to analyze the chemical composition of the metal that was obtained. Table 1 displays the results of the chemical composition.

Table 1: Aluminium 7075 alloys chemical composition.

Source	Al	Mg	Cu	Zn	Fe	Cr	Mn	Si	Ti
Wt %	89.7	2.24	1.46	5.8	0.17	0.22	0.04	0.12	0.04

2.2 Feedstock Billet Preparation

A 400 g of aluminium 7075 alloy was placed inside a 30 mm x 80 mm graphite crucible and heated to 800 °C using a 15-kW high-frequency electromagnetic induction heating furnace. The temperature of the melted alloy was measured using a K-type thermocouple connected to a data logger. The melted alloys were poured into a cylindrical copper mould when they attained the required pouring temperature. The copper mould had a diameter of 25 mm, a height of 50 mm, and a thickness of 1 mm. The mould was quenched into normal-temperature water after the required holding period. The billet was removed from the copper mould once it had fully solidified. The liquidus temperature of aluminium 7075 alloy is 640 °C. The cooling rate of this study was 0.7°C/s. Therefore, the temperature range of 645 °C and 665 °C was chosen to be closest to the liquidus temperature, and the holding time was determined to be between 20 and 60 s [20]. Figure 1 displays the DTM's schematic diagram. Meanwhile, Table 2 shows the processing and billet specimen parameters for DTM.

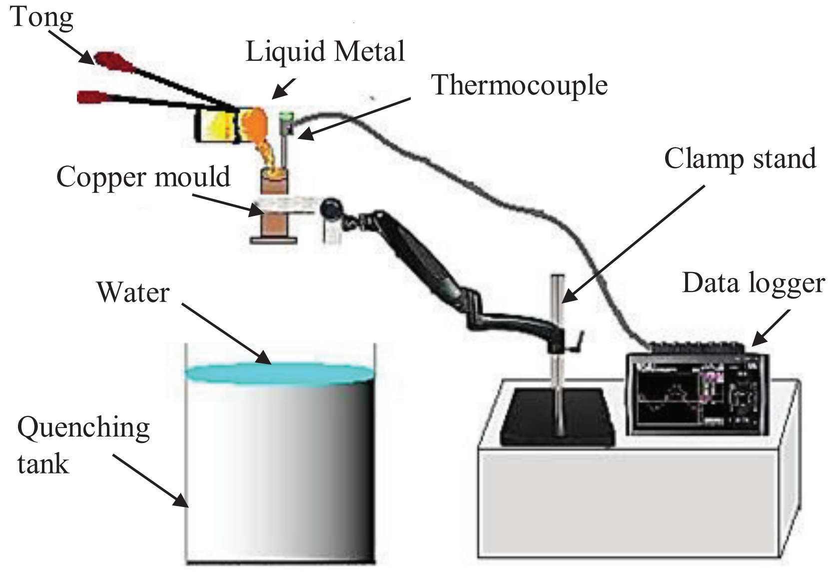


Figure 1: Illustration diagram of the DTM experimental setup.

Table 2: Combination of Processing parameters for DTM.

Sample Number	Pouring Temperature	Holding Time
1	645 °C	20 s
2	645 °C	40 s
3	645 °C	60 s
4	665 °C	20 s
5	665 °C	40 s
6	665 °C	60 s

2.3 Metallography Sample Preparation and Measurements

The prepared feedstock billets were first cut 5 mm to remove impurities with a precision cut-off machine, followed by a 20 mm cut to examine the microstructure. The separated sample was mounted using a 60-bar hot mounting machine. The samples were ground with 240, 320, 400, 600, 800, and 1200-grit paper to obtain a smooth and flat surface. The sample was polished with abrasives of 3 microns and 1 micron, followed by automatic polishing at a speed of 250 rpm using colloidal silica and imperial moist cloth. The etching process was performed with Keller etchant reagent to improve the microstructural features. An optical microscope and Image J software were used to measure the primary size, sphericity, and aspect ratio of the microstructure. The equations used for the grain diameter, sphericity, and aspect ratio determination are presented in Eq. (1) to (3).

$$\text{Grain Diameter (GD)}=\sqrt{\frac{4A}{\Pi}} \tag{1}$$

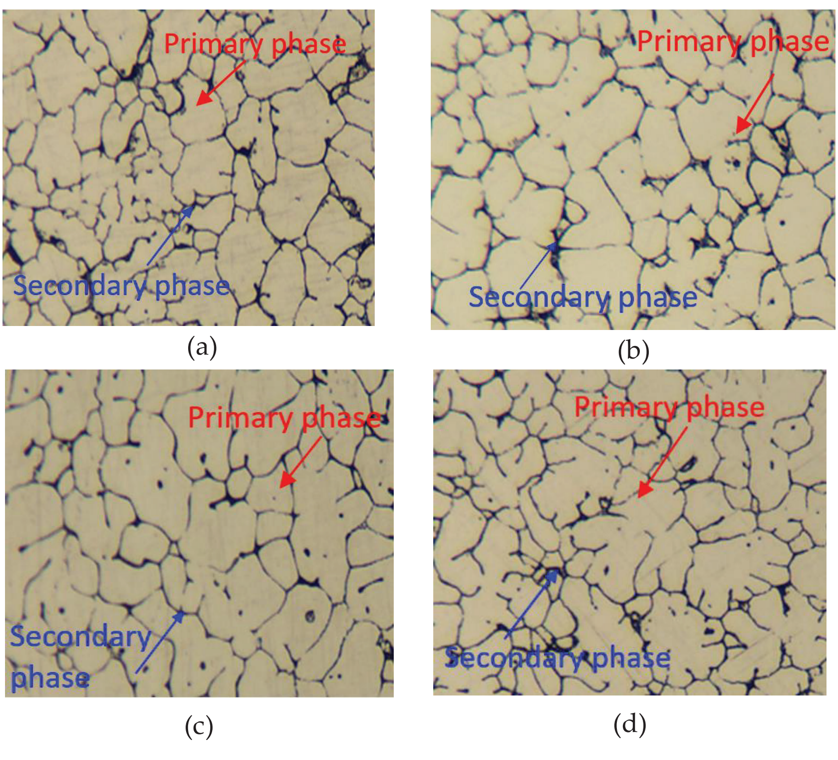
$$\text{Sphericity (S)}=\frac{4\Pi A}{C^2} \tag{2}$$

$$\text{Aspect Ratio (AR)} = \frac{\text{Major length axis}}{\text{Minor length axis}} \tag{3}$$

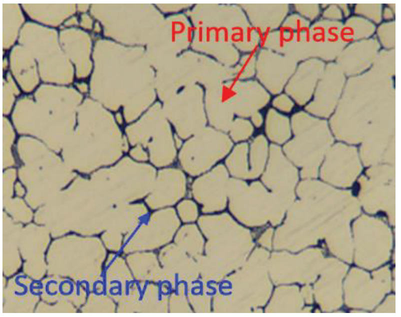
Where A is the total area of the primary particle, and C is the perimeter of the particle. The grain size of selected primary particles with perfect shape was thoroughly investigated.

3.0 Results and Discussion

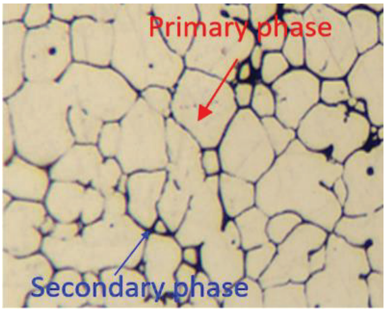
The microstructures were successfully evaluated to determine the grain size of the samples. The microstructure of the samples obtained by an optical microscope is presented in Figure 2. It demonstrates that, in contrast to other samples, the primary phases were more homogeneous and smaller at 665°C pouring temperature and 60 s holding period (Sample 6).



(a) (b) (c) (d)



(e)



(f)

Figure 2: The microstructure of the samples prepared as per Table 2 with (a) 645°C & 20s; (b) 645°C & 40s; (c) 645°C& 60s; (d)665°C& 20s; (e) 665°C& 20s°C & 40s; and (f) 665°C &60s (scale bar =100μm).

Figure 3 presents the grain diameter of the microstructures obtained at various combinations of holding times (20, 40, and 60 s) and pouring temperatures (645°C and 665°C). The microstructure was greatly affected by pouring temperature and holding times as evidenced by varying grain sizes. The pouring temperature, which is closely related to the cooling rate, is the main factor influencing how the microstructure changes. Higher pouring temperatures resulted in less heat dissipation, which accelerated the formation of the primary and secondary phases. The primary phase size increases as holding time increases, the grain size of samples 1 to 3 clearly illustrates the change in primary phase size. The sample's grain size is not uniform and increases with the holding time. A higher pouring temperature leads to a slower cooling rate, which allows sufficient time to produce a globular grain (Samples 4 to 6) as adjacent dendritic particles coalesce to form fine spherical grain sizes in larger units per unit volume. Furthermore, higher temperatures created better mobility of the particles within the microstructure. As the holding period increases, the primary phase is constructed in a developed state. This experimental study shows that the microstructure obtained at 665°C pouring temperature is more spherical than that obtained at 645°C.

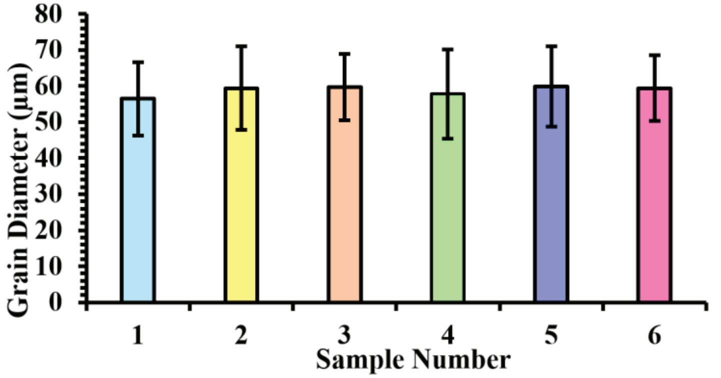


Figure 3: The grain diameter of the samples at different pouring temperatures and holding times.

Samples 3 and 6 of Figure 4 were close to the spherical structure. The longer holding before quenching, the heat released from the molten mixture delay the formation of the dendritic microstructure, preventing it from freezing immediately before reaching a uniform grain size, thus forming a perfect spherical structure, which is deemed consistent with previous research findings [12]. Other samples produced a less spherical morphology when quenched while in the more liquid state.

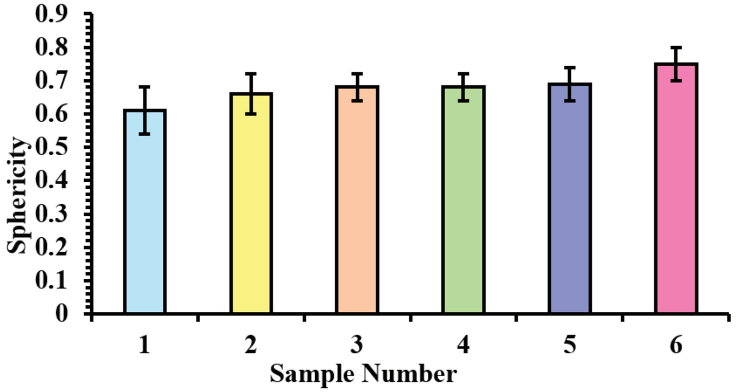


Figure 4: The sphericity of the samples at different pouring temperatures and holding times.

The results of this investigation on the sphericity microstructure showed that sample 6 produced smaller grains than the other samples (grain diameter: 57.28 µm) when it was formed at a pouring temperature of 665°C and a holding time of 60 s. A longer holding time leads to uniform cooling and improves nuclear performance due to the constant cooling of natural air, However, quenching within 60 s is expected to stabilize a homogeneous spherical structure. In the bar chart of this study, the heights of some of the bars in Figure 3, 4, and 5 are close, suggesting that examining low and high pouring temperature variation may show differences.

The sphericity of the microstructure determines the exact round shape of the primary phase. A sphericity value near 1.0 suggested that the grain had a perfect round, whereas a value near 0 indicated that the grain was elongated. The maximum sphericity of sample 6 with 665°C temperature and 60s holding time combination parameters was 0.75. Due to the longer holding time, the uniform motion between the particles within the microstructure created less collision, which led to better grain separation in the primary and secondary phases, which is consistent with previous research findings [20]. A greater pouring temperature results in a slower rate of cooling, so the nucleus is improved when given a longer holding time. Bar graphs for the aspect ratio values obtained in this study are presented in Figure 5. As the aspect ratio value increases, it indicates elongated particles and as it decreases, it indicates a round shape. The aspect ratio for each sample presented in Figure 5 is slightly different from the others. The ratio value of sample 6 decreased due to the slower solidification of the larger primary particle. Sample 6 had an aspect ratio value of 1.41.

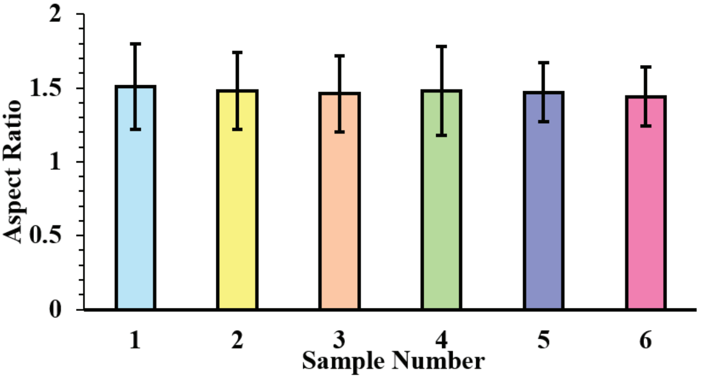


Figure 5: The Aspect ratio of the samples at different pouring temperatures and holding times.

Overall, from the study results, the combination of a pouring temperature of 665 °C and a holding time of 60 s resulted in a fine and spherical microstructure. The grain diameter, sphericity, and aspect ratio values were 57.28 µm, 0.75, and 1.41 respectively.

4.0 Conclusion

This experiment successfully examined the impact of short and long holding times at temperatures close to liquidus on the microstructures of aluminium alloy 7075 feedstock billets produced using DTM and yielded acceptable results. At pouring temperatures close to the liquid state, uniform primary particles are not obtained even though the grain size is small. Similarly, a grain size similar to a globular shape is obtained at longer holding times. The results of the investigation show that when the holding time is short and the pouring temperature is extremely close to the liquidus temperature, the globular microstructure cannot form because of the difference between convection and superheat. Based on the experimental results, the combination of 665 °C pouring temperature and 60 s holding time resulted in fine and globular microstructure in aluminium 7075 alloys. The best grain diameter, sphericity, and aspect ratio were at 57.28 µm, 0.75, and 1.41 respectively. The influences and effects of processing parameters on DTM, provide an understanding of globular microstructure formation in aluminium 7075 feedstock billet.

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AUTHOR CONTRIBUTIONS

Experiments were carried out and data was collected by A. Megalingam, A.H. Ahmad, N.A. Alang, M.M. Rashidi S. Naher guided the compilation of this information.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and has not been considered by other journals. All authors have approved the review, and agreed with its submission, and we certify that there are no conflicts of interest in the manuscript.

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