Effects of stirring parameters on the rheocast microstructure and mechanical properties of aluminum alloy ADC12

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Abstract. In this study, effects of stirring time and stirring speed on the microstructure of semisolid rheocast (SSR) aluminum alloy ADC12 were examined. The research method was done by gravity casting using a metal mold. The aluminum ADC12 slurry is stirred by a mechanical stirrer (round rod stirrer) at 610^{O}C with a variation of speed 0, 250, 300, 350 rpm for 0, 20, 40, 60 seconds. Furthermore, the aluminum slurry of ADC12 is poured on a metal mold with temperature 600^{O}C. The microstructure characteristics were examined by direct observation using optical microscopy, secondary α-Al phase dendrite arm spacing, shape factor, and Si eutectic phase were identified. The mechanical properties were investigated by hardness test and tensile test. A short period of stirring below the liquidus temperature to form a non-dendritic structure. The final morphology of the primary particles after a short period of stirring time has little impact as the stirring time increases. The optimal mechanical properties (hardness and tensile strength) were obtained at 20 seconds of stirring time and 300 rpm of stirring rate.

1 Introduction

Aluminum alloy processing with semisolid technique is developing rapidly as an alternative to traditional casting and forging processes. Semisolid metal processing is a manufacturing technology with alloy formation which takes place at a solid temperature and liquid state [1].

In order to improve the mechanical properties of aluminum alloys, a semisolid metal forming process is formed by partial solidification and partial melting where solids are present as nearly perfect spheroidal particles [2].

The effect of mechanical stirring parameters on the mechanical properties of aluminum and alloying metals has been widely reported in the literature [3-8]. However, this literature has been reported generally use mechanical stirrer models round rods of copper or graphite material. Thus, in this study will be used round rods models of stainless steel material that are believed to increase the shear force on the slurry preparation aluminum.

There are differences in grain size, grain dispersion, and globular shape perfection on one product with other products experiencing shear forces in semi-solid production. The speed of stirring, stirring diameter, stirring material, starting and ending temperature of stirring, preheated mold, and stirring time are the factors that differentiate and affect the product's differences [9].

The combination of rapid heat extraction from the melt in short stirring below the liquidity temperature can form a non-dendritic structure. The addition of stirring time after the initial compaction step has little effect on the final morphology of the primary particles [10]. As the stirring time increases, the average primary particle size becomes larger. However, it seems that the main effect on the particle growth takes place in the initial stages of solidification by the creation of more driving force for particles growth through increased concentration gradient in front of the solid-liquid interface [10].

Aluminum-silicon alloys (Al-Si) are generally used in industrial machinery because of their superior properties such as; Lightweight, good thermal conductivity, good casting properties, and good welding properties [11]. Aluminum dies casting 12 (ADC12) is one kind of Al-Si alloy. The silicon element in the ADC12 alloy is very close to the eutectic point in the Al-Si phase diagram and the two-phase liquid and very thin solid states. Despite the widely publicized semi-solid technique with aluminum alloy material, but research using aluminum alloy material ADC12 with semi-solid technique is still lacking.

In this study, the experiment was conducted to study the effect of stirring parameters (time and speed stirring) in the slurry preparation ADC12 aluminum alloy to microstructure and mechanical properties.

2 Experimental procedures

In this study, the secondary ADC12 alloy was used. The chemical composition of this alloy is shown in Table 1. The liquidus temperature of this alloy is 582^{O}C. The chemical composition of the aluminum alloy ADC12 is seen in Table 1.

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Table 1. The composition of ADC12 aluminum alloys.

ADC12 Aluminum Alloys	Weight %											
	Si	Cu	Fe	Mn	Mg	Zn	Ti	Cr	Ni	Pb	Sn	Al
	9.55	2.01	0.91	0.16	0.22	1.31	0.03	0.02	0.14	0.11	0.02	85.49

Table 2. Experimental conditions used for SSR processing of the samples.

Stirring speed (rpm)	Stirring times (s)
0	0
300	20
300	40
300	60
0	0
250	20
300	20
350	20

2.1 Preparation of SSR slurry

Metal molds are prepared and heated to a temperature of ±300^{O}C. Aluminum alloy material ADC12 is prepared (±280 gram). The alloy material of aluminum ADC12 is melted to 650^{O}C temperature using gas furnace. Metal mold temperature measurements using infrared temperature gauges and aluminum fluid measurements using a thermocouple gauge. In a temperature of 610 ^{O}C, the aluminum alloy liquid or slurry of ADC12 is stirred with a mechanical stirrer round rod stirrer model of rotation of 250, 300, and 350 rpm at 20 s. Time stirring 20, 40, and 60 seconds at 300 rpm. The liquid or aluminum alloy of ADC12 aluminum is poured into the metal mold. The specimens of casting result are made of the tensile specimen, hardness, and microstructure.

In this study, the effect of time of stirring and stirring speed on size, the main feature of ADC12 rheocast, and recognizing stirring requirements for significant changes in dendritic microstructure was examined. Table 2 shows the details of processing parameters performed in two sets of experiments.

2.2 Mechanical testing and microstructure analysis

The mechanical properties of the foundry are investigated experimentally, including the nature of hardness and tensile properties. Hardness is evaluated by Brinnel hardness tester, where steel ball indenter is used at 613 N load for 5 s. Tensile properties are checked at room temperature using a universal screw driven type screw machine with a capacity of 100 kN. The test specimens were designed based on ASTM B557. Characteristics of microstructures are examined by optical microscopy (MO). The secondary dendritic arm spacing of the α-al (SDAS) phase and the size of the eutectic base phase Si were measured using image analysis.

Image analysis techniques were used to investigate the microstructure of rheocast samples following standard metallographic procedures and. average particle size and average dendritic arm spacing (DAS) dendrite were measured using linear intercept method. The equation used to calculate the particle form factor (SF) of the particle is [12]:

$$SF = \frac{4.\pi.A}{P^2} \quad (1)$$

Where P and A are the perimeter and area of individual particles respectively. A perfectly spherical particle would have a shape factor value of unity, and an infinitely long needle-like particle would have a shape factor equal to zero.

3 Results and discussion

3.1 Effects of stirring time

Picture. 1 (a) - (d) shows the sample microstructure of numbers 1-4. Sample number 1 has a major particle of dendritic morphology with an average SDAS of 24.9 µm and a sample of 2-4 has a major particle of dendritic morphology greater than sample 1 with almost the same value. It is revealed that that stirring below the liquidus temperature during the initial stirring stage (20 seconds) has resulted in a non-dendritic microstructure. This confirms that the powerful cooling and convection combinations provided by the stirrer bar can form early non-dendritic morphology.

The longer agitation effect under liquidus temperature on the shape and size of primary particles is not significant (Figures 1 (c) and 1 (d)). This observation is supported by the secondary arm spacing variation and the primary particle shape factor shown in Fig. 2 and Fig. 3. Fig. 3 indicating that stirring for only twenty seconds has significantly increased the primary particle form factor from 0.26 (sample number 1) to close to 0.43 (sample number 2) but other samples (sample 3 and 4) have a form factor very close to 0.43 regardless of the stirring time.

Under this situation, the particles will have limited but more stable growth and the non-dendritic structure is formed in a short period after the start of solidification.

The insensitivity of the primary particle shape factor to the addition of stirring time can be caused by different reasons. It is now accepted that the initial density of the particles formed just below the temperature of the liquidus corresponds to the time required for the formation of non-dendritic particles after the commencement of freezing directly [12]. This condition is consistent with the results of research conducted by M. Reisi [10].

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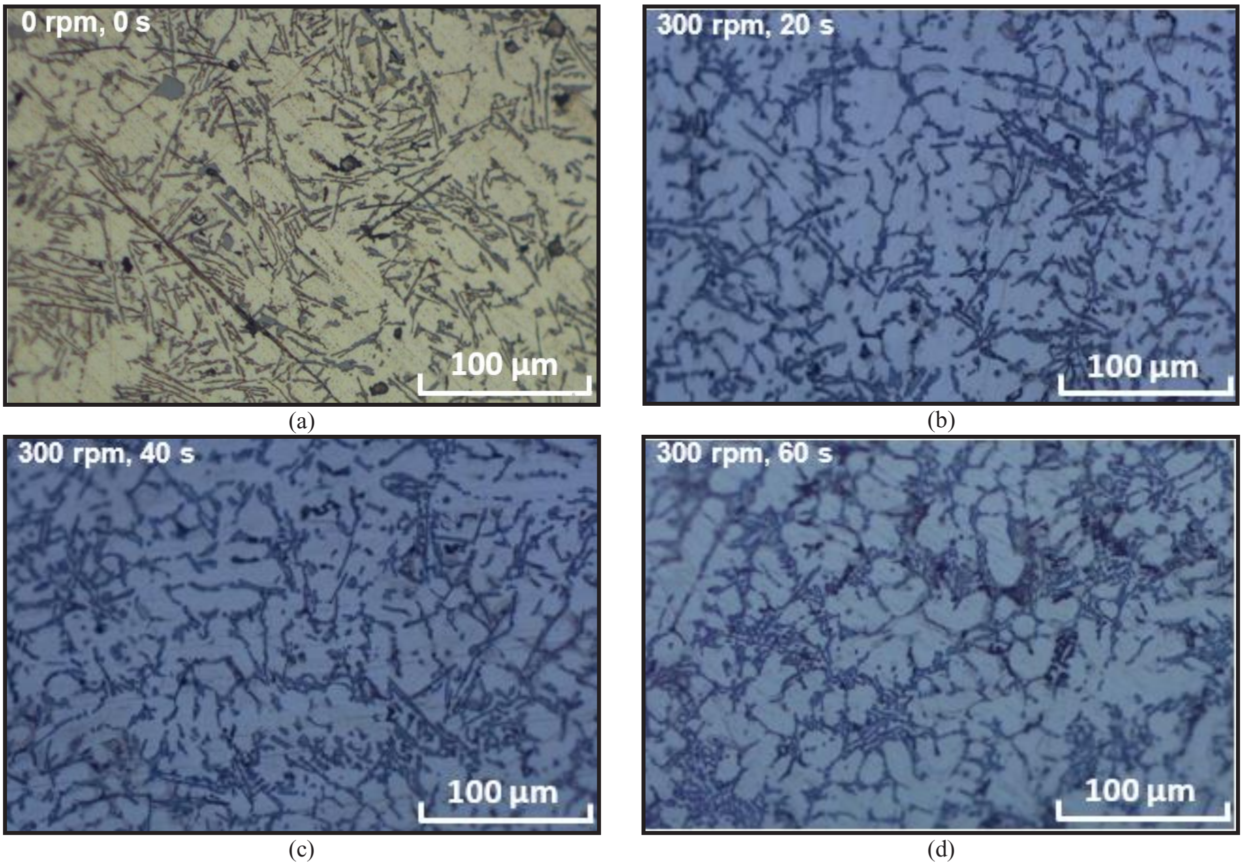

Fig. 1. Rheocast structures after stirring for 0 s (a), 20 s (b), 40 s (c), and 60 s (d) at 300 rpm.

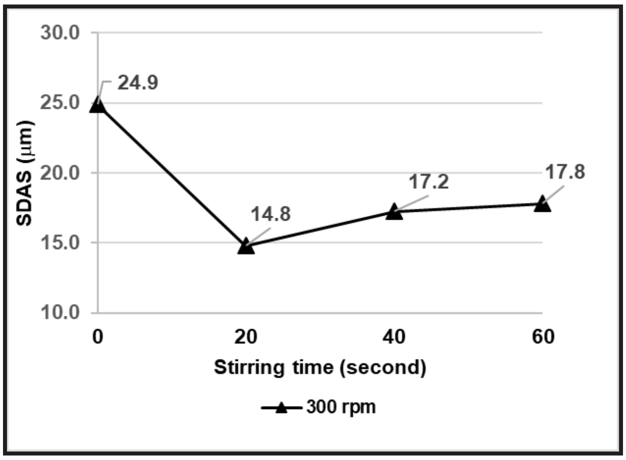

Fig. 2. Effect of stirring time on the secondary arm surface (SDAS).

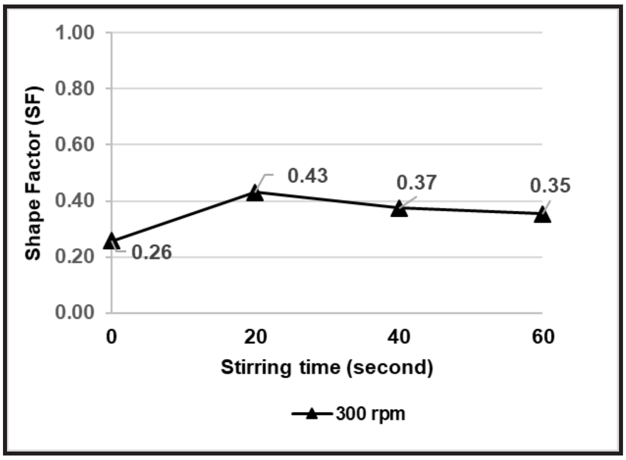

Fig. 3. Effect of stirring time on the shape factor of the primary particles.

M. Reisi [9] states that further stirring will only accelerate maturation and influence the main particles size as will be shown later. In contrast, if in the initial stages of compaction formed a small density of particles, the distance between large particles and the overlapping diffusion field occurs later in the freezing. Therefore, primary particles will have more chances and space for unstable growth. Thus, under the influence of stirring, they will mature into roses and then become spheroids and their form factor increases gradually. Under such conditions, longer stirring time is required for the formation of non-dendritic structures.

In Fig. 4, the results of the aluminum alloy hardness test of ADC12 in semi-solid casting process (Rheocasting) without stirring and with stirring with variation stirring time at 300 rpm. The hardness of aluminum alloys ADC12 after stirring is higher than before stirring [11]. The highest hardness occurred at stirring proses at 20 seconds of 135.8 HB. Longer stirring times (40 and 60 seconds) do not show significant changes and tend to decrease. The results are consistent with results of previous studies on an aluminum composite material with a stirring time variation [10].

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In Fig. 5, the results of the aluminum alloy tensile test of ADC12 in semi-solid casting process (Rheocasting) without stirring and with stirring with variation stirring time at 300 rpm. The tensile strength of aluminum alloys ADC12 after stirring is higher than before stirring. This condition is similar to the results of research conducted by S. Rashid [13]. The highest tensile strength occurred at stirring proses at 20 seconds of 246 Kg/mm^2. Longer stirring time (40 and 60 seconds) do not significant changes and tend to decrease. The results are consistent with results of previous studies on an aluminum composite material with a stirring time variation [10].

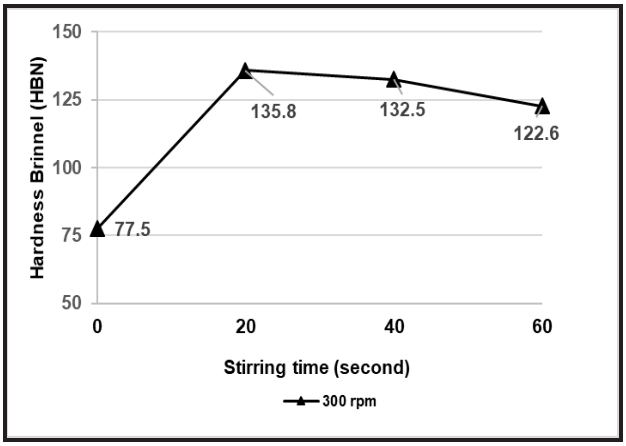


Fig. 4. Effect of stirring time on the hardness.

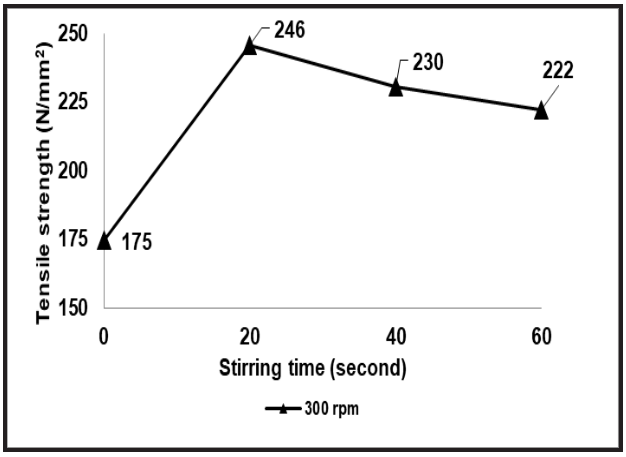
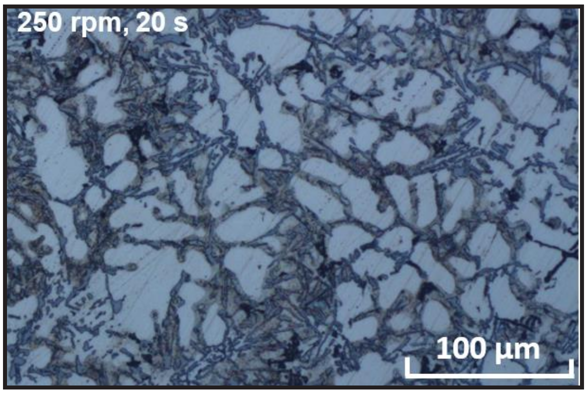


Fig. 5. Effect of stirring time on the tensile strength.

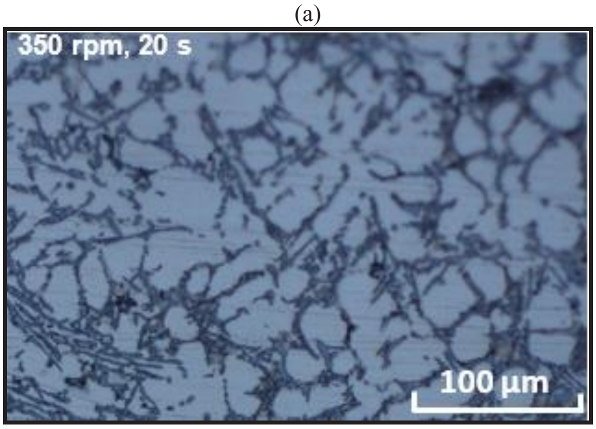
3.2 Effects of stirring speed

Fig. 6 (a) and Fig. 6 (b) show the microstructures of samples number 5 and 6, which were stirred at speeds of 250 and 350 rpm, respectively. The microstructures of the samples processed at 0 and 300 rpm were shown previously in Fig. 1 ((a) and (c)).

Fig. 7 shows the effect of stirring speed on the secondary arm surface (SDAS). The variation of the shape factor of primary particles with stirring speed is shown in Fig. 8. This figure demonstrates that only a moderate stirring speed of 300 rpm can dramatically increase the shape factor.



(a)



(b)

Fig. 6. Rheocast structures after stirring for 250 rpm (a) and 350 rpm (b) at 20 seconds.

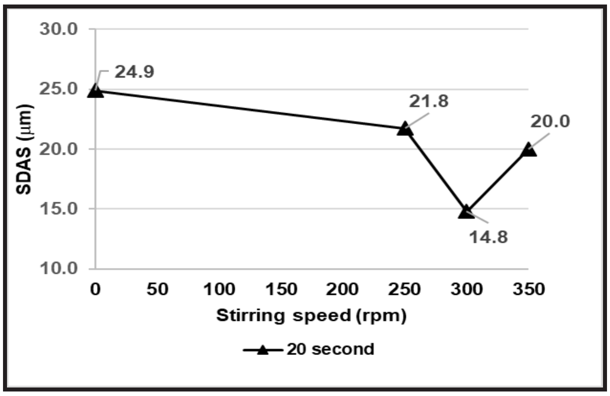


Fig. 7. Effect of stirring speed on the secondary arm surface (SDAS).

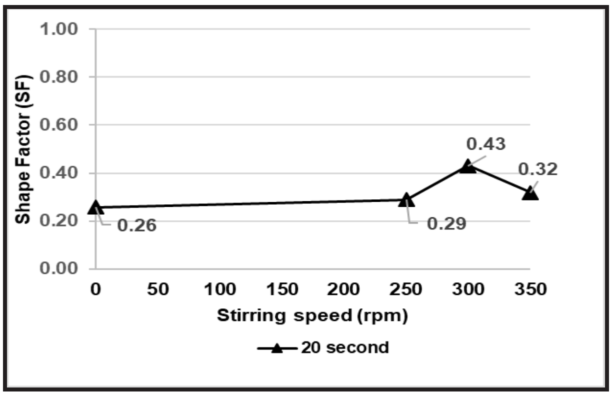


Fig. 8. Effect of stirring speed on the shape factor (SF).

Fig. 9 shows the results of the ADC12 aluminum hardness testing in the semi-solid casting process (Rheocasting). The preparation of ADC12 aluminum slurry is without stirred and with a stirrer at 250 rpm, 300 rpm, and 350 rpm for 20 seconds. There is a difference of hardness of aluminum alloy of ADC12, the highest hardness occurs at the 300 rpm of 135.8 HB. This suggests that the agitator model has an effect on the hardness properties of the aluminum alloy of ADC12. This is reinforced by the size of secondary arm spacing (SDAS) (Fig. 7) and the shape factor (SF) (Fig. 8) from the measurement of the microstructure. The hardness testing also uses to determine the mechanical properties of friction stir welding of aluminum alloy [15].

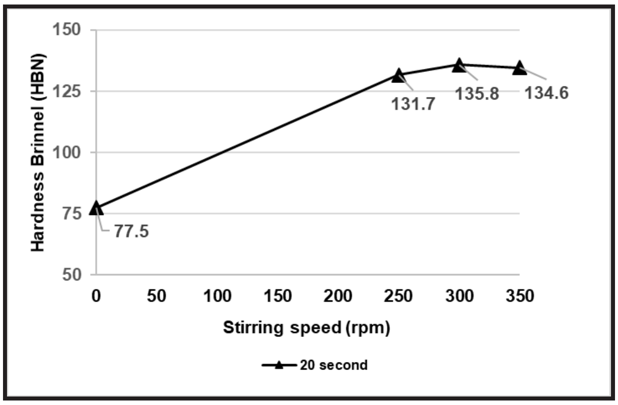


Fig. 9. Effect of stirring speed on the hardness.

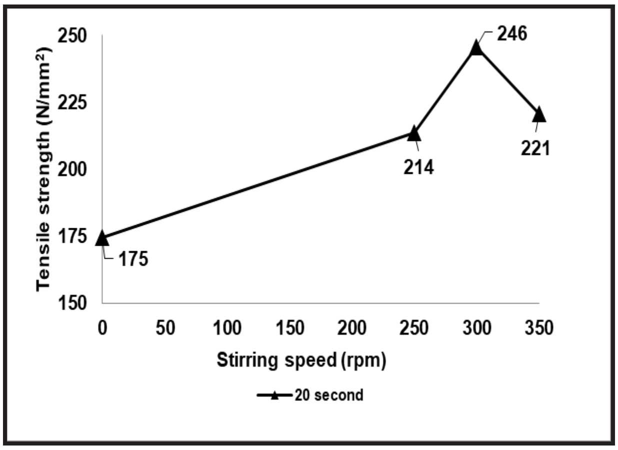


Fig. 10. Effect of stirring speed on the tensile strength.

Fig. 10 shows the results of the ADC12 aluminum tensile testing in the semi-solid casting process (Rheocasting). The preparation of ADC12 aluminum slurry is without stirred and with a stirrer at 250 rpm, 300 rpm, and 350 rpm for 20 seconds. There is a difference of hardness of aluminum alloy of ADC12, the highest hardness occurs at the 300 rpm of 246 HB. This suggests that the agitator model has an effect on the hardness properties of the aluminum alloy of ADC12. This is reinforced by the size of secondary arm spacing (SDAS) (Fig. 7) and the shape factor (SF) (Fig. 8) from the measurement of the microstructure.

4 Conclusion

The microstructure and mechanical properties of aluminum alloys ADC12 made with semi-solid rheocasting casting technology using several parameters stirring have been studied, and the results obtained can be synergized as follows. A short period of stirring below the liquidus temperature to form a non-dendritic structure. The final morphology of the primary particles after a short period of stirring time has little impact as the stirring time increases. The optimal mechanical properties (hardness and tensile strength) were obtained at 20 seconds of stirring time and 300 rpm of stirring rate.

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