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The Impact of Stirring Model on Aluminum Alloys ADC12's Microstructure and Mechanical Properties

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Abstract – *Replacing automotive components made of iron alloys with aluminum alloys is one of the strategies to reduce vehicle weight and increase fuel efficiency in the automotive sector. Semisolid casting is a metalworking process that combines casting and forming processes. In this process, the raw material being processed is in a mixture of liquid and solid phases, and the processing method uses a casting or forming method. This research aims to study the influence of mechanical agitation models on the aluminum alloy ADC12 to microstructure and mechanical properties. By using a metal mold, gravity casting has been used as the research methodology. Mechanical stirrers (round rod stirrers, straight plate stirrers, and twist plate stirrers) have been used to mix the aluminum ADC12 slurry for 60 seconds at a speed of 300 rpm. Additionally, the ADC12 aluminum slurry has been poured into a metal mold at a temperature of 600 °C. Optical microscopy, Scanning Electron Microscopy (SEM), secondary α-Al phase dendritic arm spacing, and Si eutectic phase have been used to observe directly the microstructure features. The hardness and the tensile tests have been used to examine the mechanical properties. ADC12 aluminum alloy with mechanical characteristics of 89.7 HB, tensile strength of 249.96 MPa, and strain of 4.33 percent have been produced by using the straight plate stirrer. A lower particle size value (31.6 mm) and a Shape Factor (SF) of 0.56 corroborate this mechanical quality. More research can be done on various types of aluminum alloys, higher stirring rotation speeds, and the size, quantity, and spacing of stir blades.* **Copyright © 2023 Praise Worthy Prize S.r.l. - All rights reserved.**

Keywords: *Stirrer Model, ADC12, Mechanical Properties, Semi-Solid Casting*

Nomenclature

A	Surface area
ADC12	Aluminum Die Casting 12
Al-Si	Aluminum Silicon
Cu	Copper
DAS	Dendrite Arm Spacing
EDX	Energy Dispersive X-ray
Fe	Iron
Mg	Magnesium
Mn	Manganese
MO	Microscopy Optical
P	Perimeter
Pb	Lead
SEM	Scanning Electron Microscopy
Sn	Tin
SF	Shape Factor
Ti	Titanium
Zn	Zinc
α	Alpha

I. Introduction

Implementation of strategies for reducing vehicle weight is one of the efforts to improve fuel efficiency in the automotive field. Replacing automotive components made of iron alloys with aluminum alloys is one of the implementations of this strategy [1]. Utilization of aluminum alloy for automotive component manufacturers is also followed by development in the field of process technology [2]. A new process called semi-solid forming process is currently under development. Manufacture of automotive products with the semi-solid process is very advantageous because of low cycle time, improved properties, extend tool life/dies and decrease product weight.

Molten metal that has been subjected to a shear force will differ from product to product when creating semi-solids. Among these variables are grain size, grain spreading, and globular shape perfection [3]. The difference in the final product is influenced by the following variables: stirring speed, stirrer diameter, stirring material, starting and finishing stirring temperatures, heated mold, and stirring time [4], [5].

Industrial machinery frequently uses aluminum-silicon alloys (Al-Si) because of its exceptional qualities, including their lightweight, strong thermal conductivity, good casting capabilities, and good welding properties [6]. One type of Al-Si alloy is aluminum dies casting 12 (ADC12). In the two-phase liquid and very thin solid stages of the Al-Si phase diagram, the silicon element in the ADC12 alloy is very close to the eutectic point [6]-[8]. The semi-solid casting method employing the aluminum alloy ADC12 has received extensive press

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coverage from numerous researchers. However, none of them mention semi-solid that has been stirred mechanically. Mechanical stirrers have been used in the metal smelting industry to handle metal solutions together with other techniques including gas injection and the addition of fluxes [5], [9]. Different rotary impeller systems have been used for this purpose.

However, unlike other fields like chemical engineering, food processing, and biotechnology, the treatment of molten aluminum places severe restrictions on the design of the impeller. There has been a lot of research on the impact of the stirrer model and stirrer parameters on liquid flow patterns [9]-[12], but there has not been much done on the impact of stirrer models on the microstructure and mechanical properties of aluminum alloys. Stirring effectiveness affects inclusion removal, bubble injection, flux treatment efficiency, and degassing (Yamamoto [12]).

Numerous studies have been conducted on the impact of stirring settings on the microstructure and mechanical characteristics of aluminum and alloying metals (Fatchurrohman [13], Ramakoteswara [14], Qi [15], Prasad [16], Alhawari [17], Wan [18], Rasyid [5], Rasyid [19]). However, in the literature that has been reported does not explain the shape or model of the agitator used.

Mechanical stirrers can alter the mechanical characteristics and microstructure of ADC12 aluminum alloys from dendritic to non-dendritic (Rasyid [5]). The speed of the stirrer affects how well the ADC12 aluminum alloy's mechanical qualities work (Pola [20]).

Mechanical stirrers can alter the mechanical characteristics and microstructure of ADC12 aluminum alloys from dendritic to non-dendritic (Rasyid [5]). The speed of the stirrer affects how well the ADC12 aluminum alloy's mechanical qualities work (Rasyid [19]). In this investigation, experiments have been carried out to investigate the effects of mechanical stirring models (round rods, straight plate, and twist plate) in the slurry preparation of ADC12 aluminum alloy on microstructure and mechanical characteristics.

A mechanically oriented stirrer is employed in the semi-solid casting process of the ADC12 aluminum alloy with the aim of creating an equiaxial or globular non-dendritic structure. When the near-solid (semi-solid) liquid metal is disturbed and the dendritic structure is fractured or sliced by the stirring blades, a non-dendritic structure may develop. The novelty of this research is to obtain optimal mechanical properties of ADC12 aluminum through a semi-solid casting process. The results obtained in this research will be very useful not only for researchers who focus on technological materials but it will be useful for material users in the foundry industry.

This paper consists of several parts: Section II provides a general overview of material preparation, semi solid rheocasting slurry, specimen testing, and microstructure analysis. Section III explains the results of the Microstructure and Mechanical Properties analysis, and Section IV presents the research conclusion.

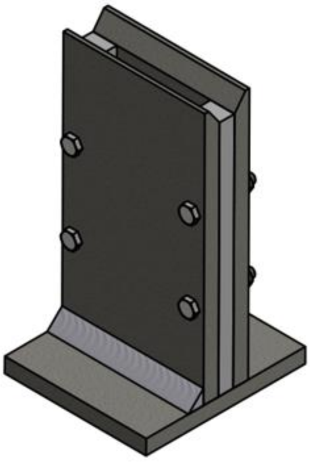
II. Experimental Design

II.1. Material Preparation

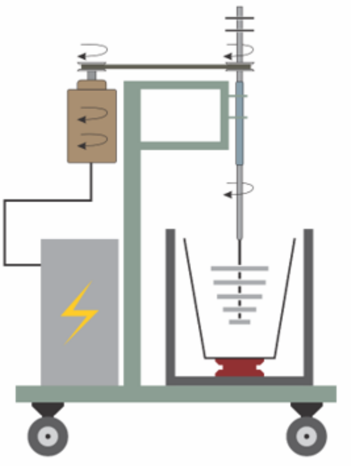
Commercial aluminum alloys (ADC12) are chosen in this study since the automobile sector has made extensive use of them. The chemical composition of the aluminum alloys ADC12 is Si 9.55; Cu 2.01; Fe 0.91; Mn 0.16; Mg 0.22; Zn 1.31; Ti 0.03; Cr 0.02; Ni 0.14; Pb 0.11; Sn 0.02; Al 85.49 (wt.%).

II.2. Preparation of Semi-Solid Rheocasting Slurry and Tensile Test Specimen

A temperature of around 300 °C is used to prepare and heat metal molds (Figure 1(a)). ADC12, an aluminum alloy material, is manufactured (around 280 grams, based on die volume). By using a gas fuel furnace, the aluminum alloy ADC12 is melted to a temperature of 650 °C (Figure 1(b)). The capacity of the crucible shown in Figure 1(b) is 2 kg. Its dimensions are 150 mm in height and 50-70 mm in diameter. Aluminum fluid and metal mold temperatures have been measured with thermocouple gauges and infrared temperature sensors, respectively.

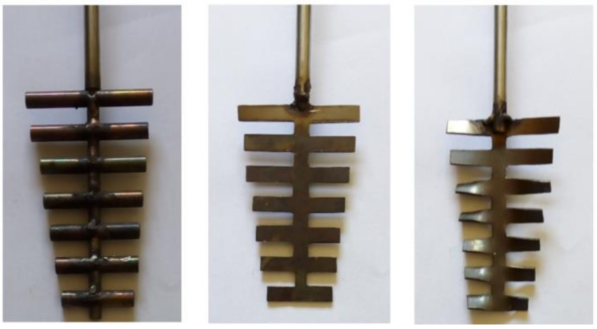


(a) Metal Mold



(b) Gas fuel furnace

Figs. 1. Metal mold and gas fuel furnace



(a) Round rod stirrer (b) Straight plate stirrer (c) Twist plate stirrer

Figs. 2. Mechanical stirrer models

Fig. 3. Specimens cast results

The aluminum alloy liquid or slurry of ADC12 is swirled for 60 seconds at 300 rpm by using several mechanical stirring models (Figures 2) at 610 °C. Seven stirring blades, each one measuring between 35 and 50 mm in length, make up the mechanical stirrer shown in Figures 2. The spacing between the blades is 50 mm. The liquid or ADC12 aluminum alloy is poured into the metal mold at a temperature of 600 °C. The foundry specimen (Figure 3) is split into five sections (10×10×160 mm in size). The 10×10×160 mm specimens have been formed into tensile specimens of size d_0 = 8 mm, and L_0 = 50 mm (Figure 4).

II.3. Mechanical Testing and Microstructure Analysis

Experimental research is done on the foundry's mechanical characteristics, including the type of hardness and tensile characteristics.

The Brinnel hardness tester uses a steel ball indenter and an 1840 N load for 5 seconds to determine the degree of hardness.

Fig. 4. Tensile specimens

By using a 100 kN capacity universal screw driven type screw machine, the tensile characteristics are examined at room temperature. The test specimens have been created by using ASTM B557 as a guide. Optical Microscopy (MO), Scanning Electron Microscopy (SEM), and energy dispersive X-ray spectroscopy are used to evaluate the characteristics of microstructures (EDX). By using image analysis, the size of the eutectic base phase Si and the grain size of the α-al phase have been determined.

II.4. Microstructure Analysis

On identical rheocast samples, microstructural analyses have been performed utilizing image analysis methods and typical metallographic procedures. A linear intercept approach has been used to calculate the average Dendritic Arm Spacing (DAS) and main particle size.

The following equation (Rasyid [5]) has been used to calculate the Shape Factor (SF) of the particles:

$$SF = \frac{4\pi A}{P^2} \tag{1}$$

The letters P and A, respectively, stand for a particle's perimeter and surface area. While an endlessly long needle-like particle would have a value of 0, a completely spherical particle would have a value of unity. On the agglomerates, microstructural investigations have been also carried out. Similar techniques have been used to measure the features' size and form factors. According to the agglomeration-disagglomeration theory (Joshi [1] and Jin [21]), primary particle sintering causes agglomerates to form. The pseudo-particle/pseudo-cluster concept has not been able to account for the findings of this study because it has been intended to explain the formation, growth, and separation of primary particles from crucible walls under mild temperature gradients (Sivabalan [22], Biswas [23]), not the development of semisolid microstructures.

In a semisolid processed slurry, the growth circumstances and evolutionary paths are quite different. In reality, rather than forming on the stirrer surface, it appears that the majority of the solid particles are created close to the stirrer, where significant undercooling has been caused by the effects of highly localized cooling.

III. Results and Discussion

III.1. Microstructure Analysis

Figures 5-7 compare the surface microstructure of a product made of the aluminum alloy ADC12 that has been agitated by using several 200× magnification mixer models. Figures 5-7 demonstrate the non-dendritic microstructure that has been produced after 60 seconds of agitation below the liquid temperature using a round rod stirrer model (Figure 5), a straight plate stirrer model (Figure 6), and a twist plate stirrer model (Figure 7).

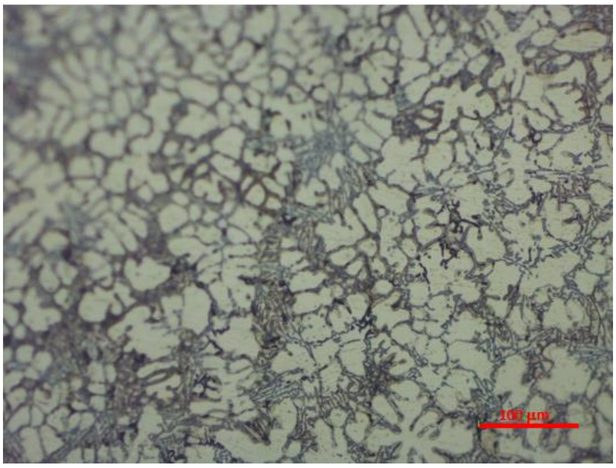


Fig. 5. Photograph of semi-solid casting ADC12 aluminum alloy structure using a round rod stirrer model

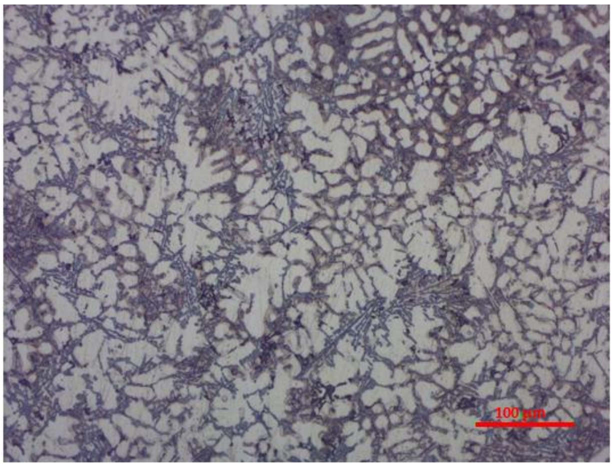


Fig. 6. Photograph of semi-solid ADC12 aluminum alloy microstructure using a straight plate stirrer model

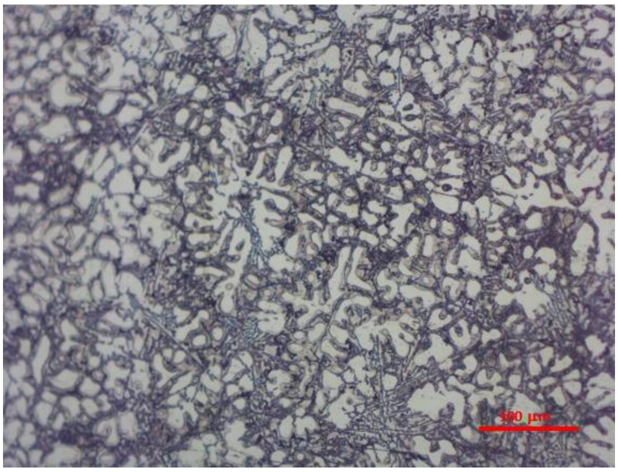


Fig. 7. Photograph of semi-solid ADC12 aluminum alloy microstructure using a twist plate stirrer model

By utilizing the stirrer's convection and powerful cooling capabilities, non-dendritic morphology can be achieved. Figure 8 depicts the grain size of the ADC12 aluminum alloy using different stirrer model changes.

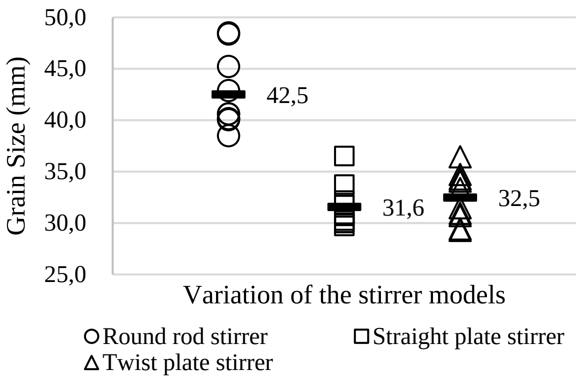


Fig. 8. Graph of the relationship between grain size and aluminum alloy stirring model of ADC12 at semi-solid casting

Aluminum alloy ADC12 stirred with a straight plate stirrer model had a grain size value that has been less than that of the same alloy stirred with a round rod stirrer model and a twist plate mixer model, where the straight plate stirrer model produces a flow zone in very heavy and turbulent metal liquids with a very strong shift when compared with other stirrer models (round rod stirrer model and twist plate mixer model). The results of this study are reinforced by research conducted by Yamamoto [12], where the strength and direction of the release flow are influenced by the torsional angle. The release flow strength decreases as the twist angle increases, and the impeller blade's surface and the distance between neighboring blade gaps both have an impact on the flow's direction.

The stirrer models with the largest grain sizes are round rods measuring 42.5 m, and the stirrer models with the smallest grain sizes are straight plates at 31.6 m. This grain diameter size is above 26.6 mm for a high cooling rate and below 79.0 for a slow cooling rate as stated by Nyiranzeyimana [24]. These results illustrate that a small temperature range in semi-solid casting has a significant influence on grain size. In order to increase the mechanical properties of the ADC12 aluminum alloy, it can be assumed that the preparation of aluminum slurry with alterations in the stirrer model impacts the distance of the secondary dendrite arm. The churning force prevents dendrite formation and increases solidification, which results in smaller grains.

Figure 9 shows the Shape Factor (SF) ADC12 aluminum alloy with a stirrer model variation. The largest Shape Factor (SF) occurred on straight plate stirrer model has been of 0.56, followed by a twist plate stirrer model 0.53, and 0.26 round rod stirrer models.

Inversely correlated with grain size is the value of the form factor. This shows that the fundamental particle shapes are significantly influenced by the variation model of churning at liquids temperature.

Figures 10 display a SEM picture of the aluminum alloy ADC12's surface following three stirring models (500× magnification). Figure 10(a) generally shows a short silicon-eutectic element between aluminum matrices.

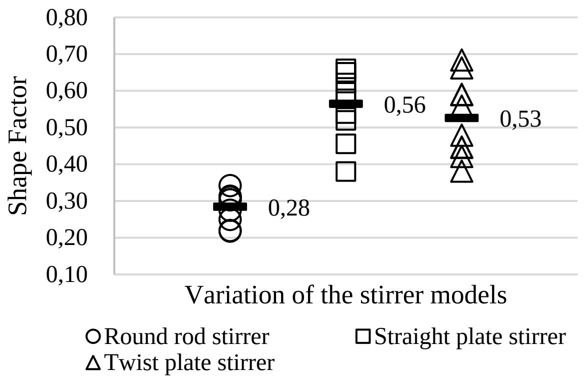
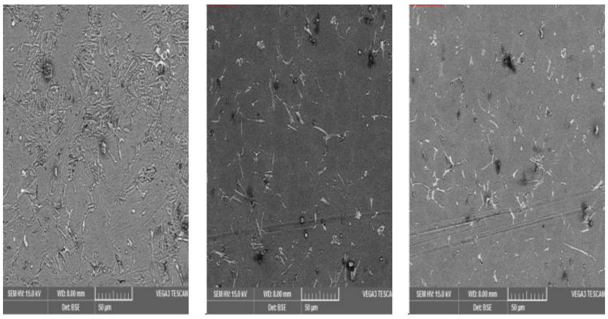


Fig. 9. Graph of the relationship between the shape factor (SF) and the aluminum alloy stirring model ADC12 in semi-solid casting



(a) round rod stirrer (b) Straight plate stirrer (c) Twist plate stirrer

Figs. 10. SEM aluminum alloy semi-solid casting with a variety of stirrer models: round rod stirrer (a), straight plate stirrer (b), and twist plate stirrer (c)

The silicon-eutectic element looks short, smooth, and blends with the aluminum matrix (Figs. 10(b) and 10(c)).

This shows that the straight plate stirrer model and the twist plate stirrer model have a significant influence in uniting the silicon and aluminum elements so that the mechanical properties of the ADC12 aluminum alloy are higher than the round rod stirrers. Figure 11 depicts the backscattered EDS of an aluminum alloy ADC12, and Table I provides the pertinent elemental analysis.

Position 1 shows the matrix α-Al, Position 2 shows the grey phases are Al-Si eutectic, and Position 3 shows the white phases are CuAl2-Mg (Position 3).

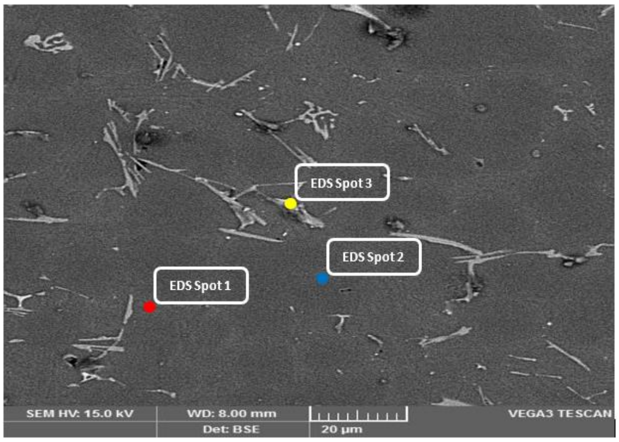


Fig. 11. Photo of the microstructure of EDS aluminum alloy ADC12 using straight plate stirrer model

TABLE I
ADC12 ALUMINUM ALLOY STRUCTURE COMPOSITION

Position	Types of structure that may be formed	Si	Cu	Mg	Al
1	Si-eutectic	27.14	0.93	0.43	71.54
2	Matrix α-Al	1.62	0.83	0.27	97.28
3	$CuAl_2$-Mg	1.47	3.16	0.44	94.92

Figure 11 shows that the main α(Al) alloy is dendritic as-cast, but as it stirs and is supported by Cu and Mg elements, the phase becomes less dendritic. A smooth, spherical primary phase encircled by uniformly dispersed silicon and fractured intermetallic phases is visible in the microstructure of thixoform alloys. Eutectic silicon is transformed into thin, fibrous particles from scaly, needle-shaped forms. It is evident how magnesium affects eutectic silicon during semisolid processing.

Large polygonal primary Mg_2Si particles were replaced with smaller, more spherical ones. The thixoform alloy's hardness, yield strength, and ultimate tensile strength all greatly enhanced as a result of these findings, but its elongation to fracture dropped (Alhawari [17], Pola [20], Ji [21], Biswas [23]). The composition of the aluminum alloy's structural elements in ADC12 at the indicated position in Figure 15 is illustrated in Table I.

III.2. Hardness Properties

Figure 12 displays the outcomes of the ADC12 aluminum hardness test conducted by using a range of mechanical stirring models during a semi-solid casting process. The hardness of aluminum alloy ADC12 varies.

The straight plate stirrer has the highest hardness at 89.7 HB, followed by the twist plate stirrer at 87.5 HB and the round bad stirrer at 79.1 HB. This suggests that the agitator model has an effect on the hardness properties of the aluminum alloy of ADC12. This suggests that the agitator model affects the aluminum alloy ADC12's hardness characteristics. The agitation process affects grain size and shapes factor. This is reinforced by the grain size (Figure 8) and the Shape Factor (SF) (Figure 9) from the measurement of the microstructure of the aluminum alloys ADC12. Above all, the hardness value using the straight plate stirrer models has been higher than the other stirrer models for small grain size and shape factor is greater.

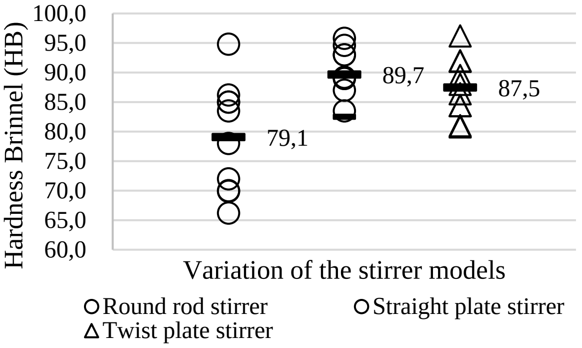


Fig. 12. Graph of the relationship between hardness value and ADC12 aluminum alloy stirring model on semi-solid casting

Figure 13 shows the correlation between grain size and hardness of the three samples of the agitator model.

The decline of grain size will increase the value of violence. Smaller grain size will increase the resistance to dislocation movement, increasing mechanical characteristics, according to the Hall-Petch relationship.

Similarly, the Shape Factor (SF) of the microstructure of the aluminum alloys of ADC12 stirred with straight plate stirrer has been higher when compared with other stirrer models (Figure 9). Zimpel [25] has provided confirmation of this outcome. The hardness values of the various rheocast magnesium alloys determined by hardness testing are compared with those anticipated by the empirical, according to the report. Semi-solid casting possesses superior mechanical qualities than those of traditional casting, according to research by Li et al. [26].

III.3. Tensile Strength Properties

ADC12 aluminum alloy tension at semi-solid casting with a variety of mechanical stirrer models, with a straight plate stirrer having a larger tensile stress value than other variations of stirring model, is shown in Figure 14 as the results of tensile testing. The highest drag occurs in the straight plate stirrer model of 249.96 MPa and the lowest tensile stresses in the 205.73 MPa round rod stirrer model and the twist stirrer model have tensile stress between the straight plate stirrer and round rod stirrer model of 235.51 MPa. The rise in fracture strain is also a result of the tensile phenomena of the aluminum alloy ADC12 in the semi-solid casting process with the adjustment of the agitator model, as illustrated in figure 15. This makes it possible to produce the ADC12 aluminum alloy through the forming process. This is reinforced by grain size (Figure 7), Shape Factor (SF) (Figure 8), and finer Si-eutectic (Figure 10) from the measurement of the microstructure of aluminum alloys ADC12.

The rise in fracture strain is also a result of the tensile phenomena of the aluminum alloy ADC12 in the semi-solid casting process with the adjustment of the agitator model, as illustrated in Figure 15. This makes it possible to produce the ADC12 aluminum alloy through the forming process.

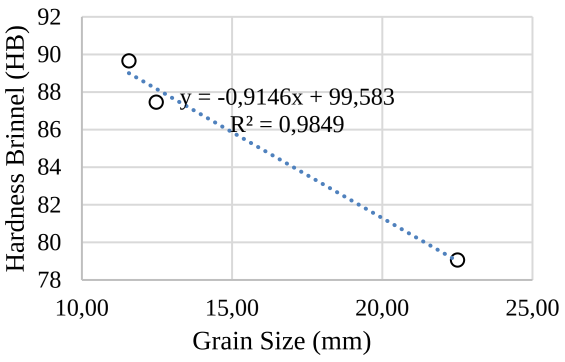


Fig. 13. Graph of the relationship between grain size and hardness of aluminum alloy ADC12 at semi-solid casting

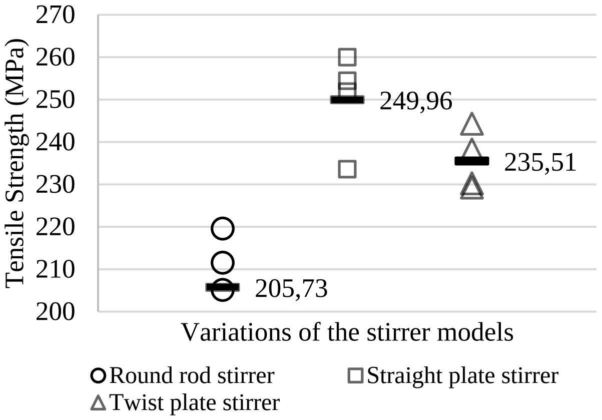


Fig. 14. Tensile stress and aluminum alloy mixer model of ADC12 on semi-solid casting relationship graph

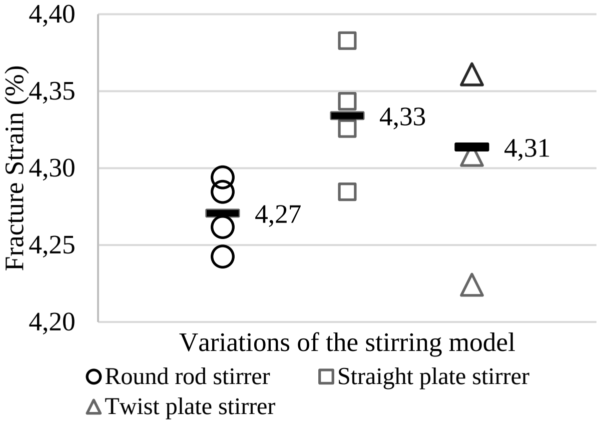


Fig. 15. Relationship between the fracture strain and the semi-solid casting's ADC12 aluminum alloy mixer model

According to Sivabalan [22], shrinkage porosities have been seen in the tensile fracture side views of gravity-cast A356 samples while the tensile fracture course of rheocast A356 inclined to shear eutectic phase.

The results of the aluminum alloy ADC12's fracture tests on semi-solid casting are shown in Figure 15.

Fracture strain on straight plate stirrer models higher than other mixer models. However, differences in fracture strain are not too great. It can be concluded that the variation model of the stirrer does not significantly influence the fracture strain.

IV. Conclusion

The purpose of this study is to examine how aluminum ADC12's microstructure and mechanical characteristics are affected by mechanical stirrer factors throughout the semisolid casting process. The observed results suggest alterations in the mechanical characteristics and microstructure of aluminum ADC12.

The round bar stirrer model and the twisting plate stirrer model yield inferior mechanical qualities compared to the straight plate stirrer model. ADC12 aluminum alloy with mechanical characteristics of 89.7

HB, tensile strength of 249.96 MPa, and strain of 4.33 percent is produced using the straight plate stirrer. A lower particle size value (31.6 mm) and a form factor (SF) of 0.56 corroborate this mechanical quality.

More research can be done on various types of aluminum alloys, higher stirring rotation speeds, and the size, quantity, and spacing of stir blades.

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