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Effect of Solution Treatment Process on Hardness of Alumina Reinforced Al-9Zn Composite Produced by Squeeze Casting

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***Abstract*—Characteristics of aluminium matrix composites reinforced by alumina have been developed to improve mechanical properties. One of the determining factors in the development of this material is parameter of solution treatment process. This study discusses the performance of the composite matrix of Al-9Zn-6Mg-3Si reinforced by alumina powder of 5 % volume fraction. Composite are manufactured by squeeze casting process with the pressure of 20 Ton in the metal mould. To improve mechanical properties, the precipitation hardening process is conducted through variation of temperature of solution treatment of 450, 475 and 500 °C and holding time of solution treatment of 30, 60 and 90 minutes. Materials are characterized by hardness testing and microstructure observation. The results showed that the optimum condition of hardness was produced by solution treatment temperature of 500 °C and 90 minutes holding time of 86 HRB.**

***Keywords*—aluminium matrix composite, alumina, squeeze casting, hardness**

I. INTRODUCTION

Various engineering components in manufacturing technology need of material with good mechanical characteristics. Many innovations have been made to create a new kind of lightweight materials with excellent mechanical properties. Composite materials can be used as one of the alternatives to answer this challenge. Composite material can combine the excellent properties of consisting constituents to produce a new material with better characteristic, which offer several properties excellence such as high strength and stiffness, good toughness, good strength in high temperature, high wear resistance and having high ration strength to weight [1,2].

In the current development, aluminium matrix composite is very promising, not only its good mechanical properties but also relates to its low density. Aluminium alloy is chosen as the matrix because this metal is light in weight, relatively cheap and easy to fabricate. Moreover, aluminium is a metal that have been produced independently in Indonesia, therefore it can be developed even further as many application for domestic needs.

The drawback is this material has lower strength than other commercial material such as cast iron, steel or copper. However the strength of aluminium can be increased through alloying, cold working and heat treatment through precipitation hardening process.

One of the aluminium alloys is Al-Zn, which exhibits the highest strength and in many cases they have higher strength than steel. This alloys is the combination of zinc and magnesium that produce the AA7xxx alloy which can be heated and formed a very high strength. For example, AA 7075 with composition of: Zn 5.0-6.0%, Mg 2.0-3.0%, Cu 1.0% - 2.0% gives specific tensile strength of 580 MPa [3]. Zn element will increase hardness optimally, after the heat treatment precipitation hardening process [4], The increase in Zn element up to 9% can increase hardness particularly after precipitation hardening, however Zn content in present study was limited to 9% because the higher the content, the possibility for hot cracking to occur is increase [5]. Based on this, in order to increase the hardness, Zn and Mg alloy elements added. Then heat treatment is conducted by precipitation hardening process on the composite to optimize the hardness. This research studies the influence of precipitation hardening parameter such as solution treatment temperature and holding time towards hardness of the aluminium matrix composite.

II. EXPERIMENTAL METHODS

Material used in this research is Al-3Si ingot added with alloying element, with 6 wt. % Mg and 9 wt.% Zn. Melting process conducted in the crucible furnace on the temperature of 850-870 °C. Powder alumina reinforcement with the size of 0.45 micron was poured with 5 % volume fraction, then stirred with the velocity of 7500 rpm. Composite produced by squeeze casting process with the application of pressure of 20 ton in a preheated mould, in order to optimize the solidification process and minimized defects in the interface. The composite was then underwent heat treatment by precipitation hardening process to enhanced its mechanical properties. Precipitation hardening process on cast composite plate is started by solution treatment with temperature variation of 450, 475 and 500 °C and variation of holding time of 30, 60 and 90 minutes; and followed by quenching in water, and then aging process is performed in temperature of 200 °C for 2 hours. Material characterization is conducted with chemical composition, microstructure observation with optical and electron microscope and hardness testing.

III. RESULTS AND DISCUSSION

Composite characteristic is significantly influenced by the content of alloying elements. Alloying of the matrix was conducted to improve its mechanical properties and the quality of the cast metal. Ingot aluminium with silicone element used for enhanced castability of the casting material. Adding Mg content improved wettability on the interface area between the matrix and alumina reinforcement [6]. It was renowned that the interface condition is very important in determining the needed properties of the composite systems because it functions as the media for transferring the load from reinforce-matrix-reinforce [7]. Whereas, the addition of Zn will increase hardness and strength of aluminium alloy after precipitation hardening process [8].

Table 1. The compositions of the matrix.

Content (wt. %)							
Zn	Mg	Si	Fe	Mn	Cu	Ni	Al
9.16	6.12	2.90	0.22	0.003	0.003	0.206	Balance

Table 1 shows the chemical compositions of the composite. As listed in the table, besides the intentional additions, other elements such as Fe, Mn and Cu are also present. Even small amount of these impurities causes the formation of a new phase component [9]. Through casting various intermetallic phases are formed between aluminium dendrites [9,10]. These intermetallic phases have different structures, stabilities and mechanical properties. Based on this reason, the cast composite require solution treatment to improve mechanical properties. During this treatment some transformation of intermetallic phases such as plate-like β-Al_5FeSi into more rounded discrete α-$Al_{12}(FeMn)_3Si$ particles; and dissolution of β-Mg_2Si particles [11]. These transformations will give maximum hardness after aging process [11,12]. The hardening process is conducted in order to improve hardness and toughness of a matrix. The heat treatment process will decrease Mg_2Si on grain boundary and increase volume fraction of α-aluminium on matrix, which then will produce precipitate $MgZn_2$, which settle in the grain, due to aging process [8].

The microstructure of the studied alloys is given in Figure 1. The heat treatment process will optimize the Zn function though precipitation mechanism, this could be seen from other particle morphology/second phase, distribution and shape. The figure shows that the matrix have more globular shaped structure with solution temperature of 500 °C. It indicates that the higher temperature of solution treatment will dissolve dendritic structure. The higher solution treatment temperature the hardening process started earliest and proceeded fastest. The figure also shows the squeeze casting technology seen to be succesfully in preventing the occurance of shrinkage due to the solidification process.

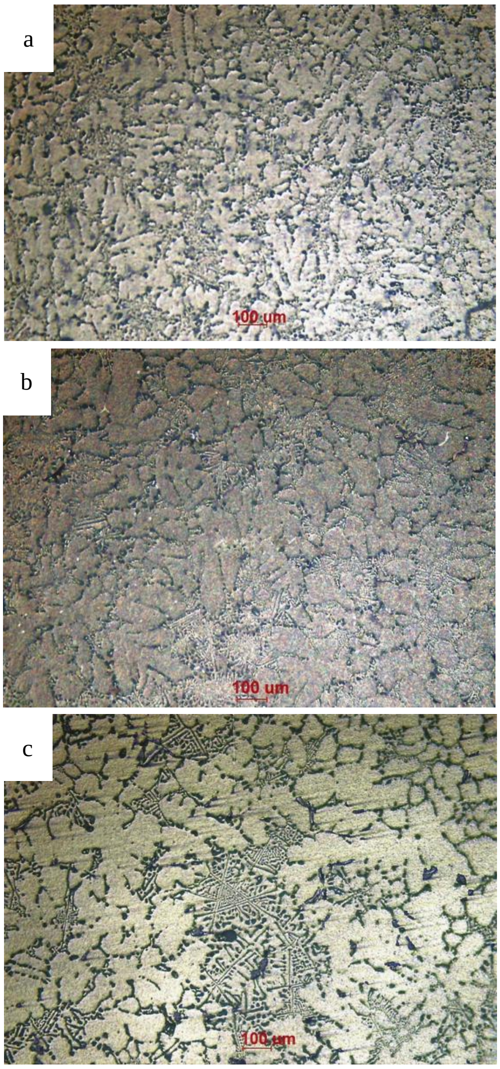

Figure 1: The microstructure of the composite with variation of solution treatment temperature: (a) 450 °C; (b) 475 °C; (c) 500 °C.

To observe the presence of presipitate more clearly SEM/EDS examination was conducted, as seen in Figure 2. Micro analysis using the SEM-EDS result on the Table 2 showed that there was $MgZn_2$ presipitations present in the matrix that inhibit dislocation process resulting in the increase in mechanical properties of the Al-9Zn-6Mg-3Si composite [13]. Alumina in the composite showed to be distributed evenly so that it can be concluded that the stirring process with 7500 rpm seen to be distributing the alumina particles evenly.

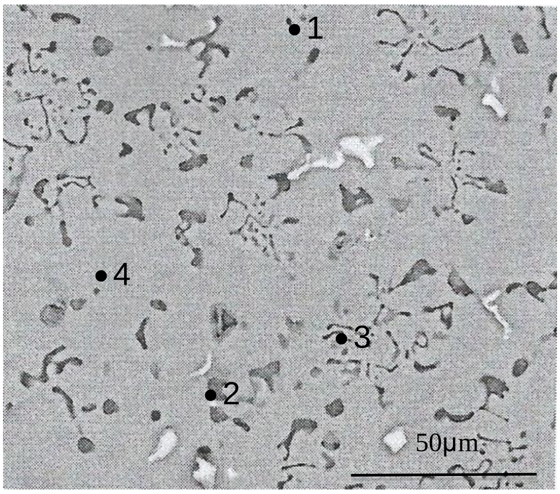

Figure 2. SEM examination on the composite with Al-9Zn-6Mg-3Si matrix with 5 % alumina reinforcement, dissolution temperature of 500 °C, holding time duration of 30 minutes, and aging temperature 200 °C .

Table 2. EDX on Al-9Zn-6Mg-3Si composite with alumina reinforcement, on position according to Figure 3.

No.	Composition (wt. %)					Phase
	O	Mg	Al	Si	Zn	
1	-	2.49	85.55	-	11.97	$MgZn_2$, α-al
2	11.49	17.37	44.69	20.04	6.41	Matrix, alumina
3	4.45	3.15	77.36	4.16	10.87	Matrix, alumina
4	3.14	4.16	78.07	3.91	10.72	Matrix, Alumina

Figure 3 shows the effect of solution temperature and holding time on hardness after aging process of the composite. Increasing solution treatment temperature of 450 to 475 and 500 °C improves hardness for all holding time of 30, 60 and 90 minutes. It has been discovered that the hardness is well correlated by the solution heat treatment temperature with linear characteristic. This condition is owing to fact that the amount of alloying elements in a supersaturated solution will form the hardening particle of $MgZn_2$ phase precipitated during aging process, rises along with increasing of solution treatment temperature. The figure also illustrates that the duration of dissolution as much as 60 or 90 minutes did not exhibiting significant influence. This was possible due to the Zn has been diffused completely into the Al matrix during the duration of dissolution as much as 60 minutes, thus with the reason for energy efficiency the optimum condition design for the duration of dissolution taken was 60 minutes.

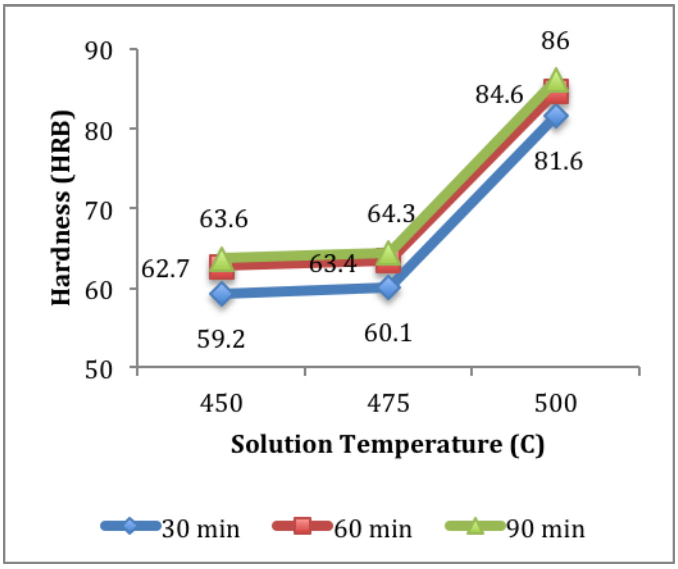

Figure 3: Effect of solution treatment temperature to matrix hardness of Al-9Zn-6Mg-3Si reinforced with 5 % alumina fraction volume, with various holding time of solution treatment of 30,60 and 90 minutes.

The higher solution treatment temperature maximalized the dissolved Zn in the matrix, whereas increasing the hardness by forming $MgZn_2$ phase precipitated in matrix, which inhibits the dislocation movement. In the present study, the Zn content was limited to only 9 wt. % Zn because increasing Zn content will lead to hot cracking.

IV. Conclusions

From the testing and analysis on Al-9Zn-6Mg-3Si matrix composite with 5% volume fraction of alumina reinforcement it can be concluded that:

1. Increasing solution treatment temperatur from 450 °C to 475 and 500 °C improved the hardness of the composite with the highest value was HRB 86.
2. Increasing solution treatment holding time from 30 minutes to 60 minutes improved the hardness of the composite, while the improvement was slight by rising holding time from 60 to 90 minutes.
3. The improving hardness after heat treatment process was caused by the formation of $MgZn_2$ phase precipitation in composite.

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