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Mechanical Properties of SiC/Gr Reinforced Hybrid Aluminum Composites after Heat Treatment

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Abstract. Metal matrix composite has been developed to improve mechanical properties for the automotive component application. One crucial factor in achieving excellent mechanical properties is improving the properties of the aluminum matrix of composite by the heat treatment process. The mechanical properties of Al-Mg-Si matrix composites alloyed with Zn and reinforced with 5% SiC and 5%Gr particle were examined after the heat treatment process. The aluminum matrix is melted inside the crucible furnace at 850 °C and is added with SiC/Gr particle, followed by stirring at 7500 rpm to optimize the mixing of the composite. Then, the composite is poured into the preheated mold at 300 °C and then squeezed with 30 MPa of pressure. The heat treatment process consists of three steps; solution treatment, quenching, and artificial aging. The aging process is conducted with variation of temperature (140 °C, 180 °C and 200 °C) and holding time (2, 4, and 6 hours). The test results show that the mechanical properties of aluminum matrix composite tend to increase after the heat treatment process. The optimum mechanical properties are achieved at the aging temperature of 200 ºC for 6 hours, with the hardness value of 60.3 HRA and the impact value of 0.112 Joule/mm^2.

Introduction

The development of aluminum matrix composite with particle reinforcement has been done substantially in automotive component application because its specific gravity is lower than ferrous metal, and it also has high strength and hardness, wear resistance, good tribology, and low thermal expansion coefficient. Recently, the use of aluminum alloy based on Metal Matrix Composites (MMCs) with ceramic particles is increased because it shows promising results in reducing energy and achieving the lightweight requirement. With higher thermal conductivity and lower density compared to the conventional Gray Cast Iron, it can reduce the load up to 50-60% in the braking system.(1) The disc brake should have good mechanical properties, wear resistance, and resistance to shock loads, especially under various conditions of speed, temperature, and environment. It should also have sufficient capacity to receive friction until heat dissipates to prevent damage. The friction is especially critical in repetitive friction at high and low speeds.(2,3)

The composite is a mixture of selected ingredients to produce a new material by adding reinforcement. Aluminum alloy matrix material reinforced with ceramic particulates belongs to the Aluminum Matrix Composite (AMC) composite material. In the engineering process of AMC materials, aluminum alloy metal can be used as a matrix with SiC ceramics and graphite (Gr) used as hybrid reinforcement material.(4,5) Each of these types of reinforcement has a different role to the mechanical properties and tribological properties of the components. The increase in the volume fraction of SiC reinforcement will increase the mechanical properties of the composite, while the increase in the volume fraction of Gr will increase the tribological properties of the composite.(5) The optimal performance of a disc brake component which require good mechanical and tribological properties can be obtained through the development of hybrid composite, namely by adding a combination of SiC and Gr ceramic particulates.

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The alloy composition and the selection of casting process may affect the microstructure of Aluminum Alloys. Adding specific elements, such as Zn, can change the microstructure of the aluminum alloy as well as the cast, mechanical properties, and the excellent capability of machining.(5,6) The increase in Zn can improve hardness particularly after heat treatment through precipitation strengthening. However, the effect of precipitation strengthening needs to be explored on composite reinforced with hybrid ceramic particulate. The aim of this research is to explain the mechanical properties of Al-Si-Mg aluminum composite material with variation of Zn alloying element and reinforcement with hybrid ceramic particulate of 5% SiC and 5% Graphite of volume fraction; also the effect of the composites after the heat treatment process.(7,8)

Method

The matrix material of ingot Al-7Si-6Mg-5Zn are heated in crucible furnace by gradually increasing the temperature to 850 °C, followed by degassing process using the argon gas. The SiC and Gr ceramic particulate as reinforcement material in the size of 37 μm and 20 μm respectively, both in the volume fraction of 5%, are preheated to 1000 °C for one hour. Subsequently, the aluminum alloy material is mixed with the alumina and SiC reinforcement. The liquid composite is poured into the mold which was preheated using a heater at 350 °C to avoid initial cooling as the molten metal enters the mold. Afterward, the squeeze casting process is conducted by giving pressure using a hydraulic system with a compressive force of 30 MPa into the mold.(9) The squeezing process is conducted to minimize the occurrence of void and gas porosity due to the smelting process.(10) Giving pressure in the semi-solid state facilitates the emphasis process until the metal solidifies completely. The heat treatment process is performed by heating the composite at 500 °C for 1 hour, followed by quenching in water at room temperature for 10 minutes, and then aging with the temperature variation of 140 °C, 180 °C and 200 °C for 2, 4 and 6 hours.(10) Furthermore, the composite characterization process is conducted through chemical composition test, hardness test, impact test, and metallographic examination.

Discussion

The target composition of Al-7Si-6Mg-5Zn matrix composite can be seen in Table 1. The test was done by using a spectrometer with ASTM E1251 standard. The Si element is added to increase castability, while the Mg element is added to increase the hardness through a precipitation strengthening mechanism by forming $MgZn_2$ particles after the heat treatment process.(11) In addition, the Si element from the matrix will also react with Mg to form Mg_2Si. These two particles will further increase the hardness of the composite.(12) The percentage of Fe and Mn element does not significantly affect the mechanical properties of aluminum composite matrix.

Table 1. Composition of Aluminum Matrix of The Hybrid Composite

Sample	Si [wt. %]	Mg [wt. %]	Zn [wt. %]	Cu [wt. %]	Al [wt. %]
Al-7Si-6Mg-5Zn	7.20	6.53	5.45	0.0019	balance

In this research, the effect of temperature and time variation during the aging process towards hardness can be analyzed for its mechanical properties using hardness testing. The data obtained from hardness testing conducted on aluminum hybrid composite with materials of Al7Si6Mg5Zn and 5% SiC and 5% Graphite reinforcements shows that the longer the aging holding time, the higher the hardness value is attained. The hardness value is higher because during the 4 hours holding time; there is a possibility that θ’ phase has been formed. This condition is in accordance with previous theory which stated that longer aging time will encourage a phase creation. The maximum hardness value obtained at a temperature of 180 ºC is around 57.2 HRA, after undergoing the aging process for 6 hours. Low hardness value occurs because a precipitate with ordered Crystal structure is formed;

this phase is named the phase between θ' phase. Meanwhile, the maximum hardness value obtained at a temperature of 200 ºC is around 60.3 HRA, after conducting the aging process for 6 hours.

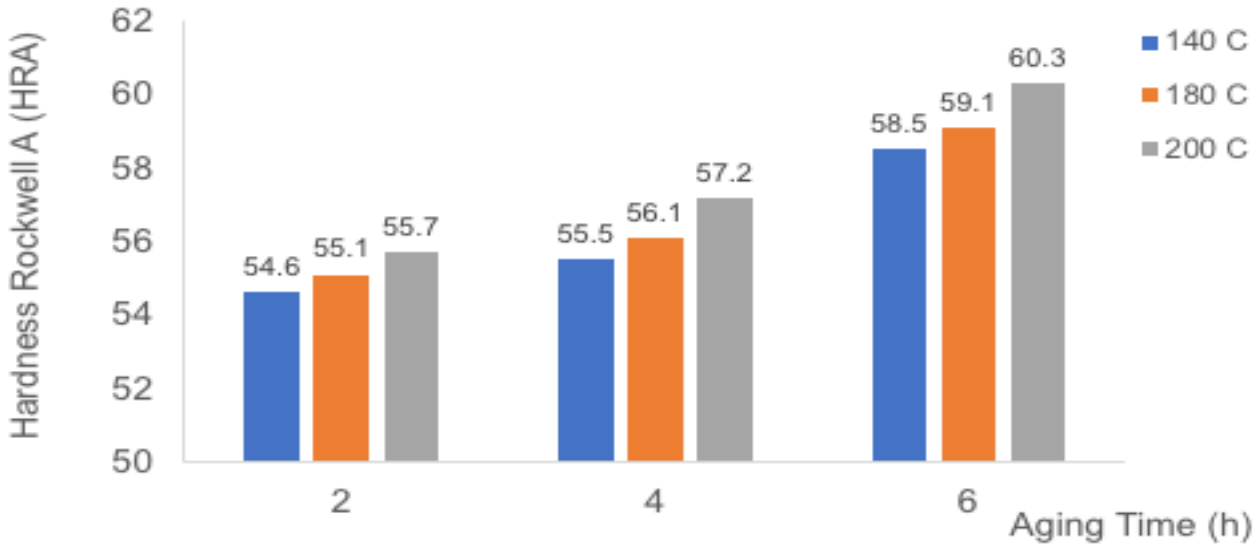

Fig. 1 Hardness test of aluminum hybrid composite at the temperature of 140 °C, 180 °C and 200 °C for 2, 4, and 6 hours.

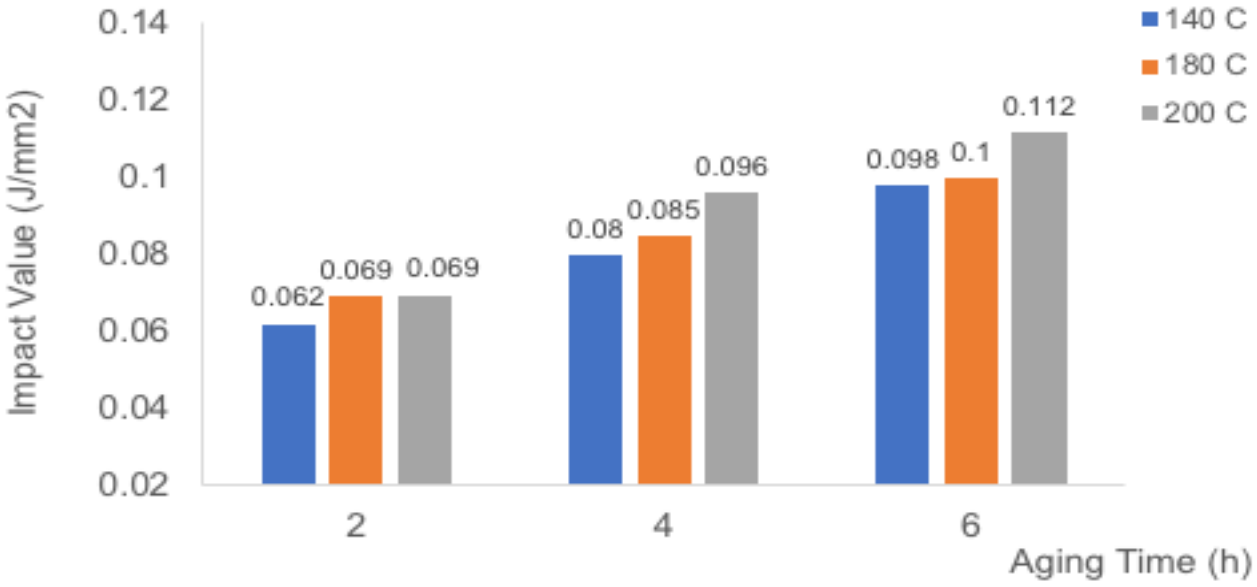

Fig. 2 Impact test of aluminum hybrid composite at the temperature of 140 ºC, 180 ºC and 200 ºC with the holding time of 2, 4, and 6 hours.

To determine the strength and ductility properties of a composite material, an impact test must be performed. The results of the impact test on the composite after the heat treatment can be seen in Figure 2. Increasing the aging temperature from 140 ºC to 180 ºC and 200 ºC and the aging time from 2 to 4 and 6 hours can increase the impact value. Results show that the highest impact value of 0.112 Joule/mm^2 is attained in the temperature of 200 ºC with a holding time of 6 hours.

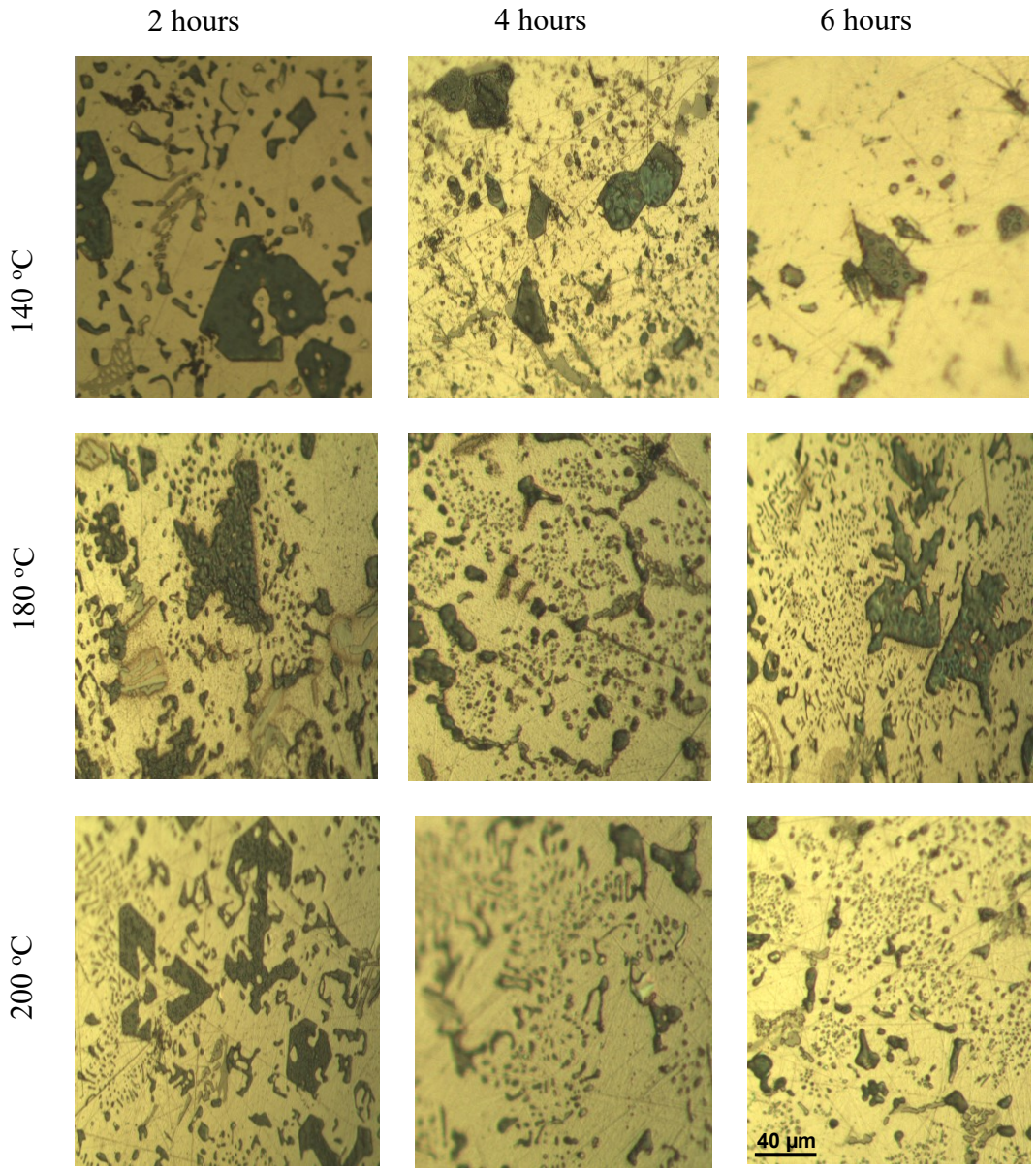

Fig. 3 Microstructure observations with 500x magnification on Al-7Si-Zn-Mg composite reinforced with SiC and Gr after aging at a temperature of 140 ºC, 180 ºC and 200 ºC for 2, 4, and 6 hours.

Metallographic examination is conducted to get an overview of the macro and micro-structure of the aluminum hybrid composite specimens after the aging process with temperature variations of 140 ºC, 180 ºC, and 200 ºC and holding time variations of 2, 4, and 6 hours as shown in Figure 3. The aging process at a temperature of 140 °C shows that the porosity and the dendritic structure of the aluminum hybrid composite are present. The dendritic structure has not been dissolved and diffused into the aluminum composite in this temperature. However, at the aging temperature of 180 °C, it can be seen that with the increasing aging time, the precipitate increases in size and became more even. Furthermore, a difference in structure can also be seen, where the dendritic structure became smaller. Meanwhile, at the aging temperature of 200 °C, a significant structural difference can be observed, where the dendritic structure became even smaller than the previous size and it has been dissolved and diffused into the aluminum composite.

Conclusion

The aim of this study is to improve the mechanical properties of aluminum hybrid composite that is given heat treatment process. At the aging temperature of 140 ºC, the longer the holding time (from

2, 4, to 6 hours), the higher the hardness value obtained (54.6 HRA, 55.1 HRA, and 55.7 HRA respectively). This also occurs at the aging temperature of 180 ºC and 200 ºC. The highest hardness value of 60.3 HRA is attained at the aging temperature of 200 ºC with 6 hours of holding time. Based on the impact testing, the highest impact value is achieved at the aging temperature of 200 ºC for 6 hours, with the impact value amounting to 0.112 Joule/mm^2.

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