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Article *in* The Journal of Scientific and Engineering Research · May 2017

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Journal of Scientific and Engineering Research, 2017, 4(4):31-38

ISSN: 2394-2630
CODEN(USA): JSERBR

Research Article

Effects of Precipitation Hardening on Mechanical Properties of Multistage Stirred Cast AA6063 Composites

Kareem MO[1], Oluwasegun KM[2], Alabi IO[1], Aderonmu MA[1]

[1]Department of Mechanical Engineering, The Polytechnic Ibadan, Nigeria
[2]Department of Materials Science and Engineering, Obafemi Awolowo University, Ile-Ife Nigeria

Abstract This work studied the effects of precipitation hardening on multistage stirred cast alumina reinforced AA 6063 composite through production of alumina reinforced AA6063 alloy by four stage stir casting method, determination of effect of precipitation hardening heat treatment and characterization of microstructures and some mechanical properties of as-cast and heat treated samples of aluminium matrix composites. The amounts of AA 6063 and alumina particles required for the production of aluminium composites with 0, 3, 6, 9, 12 and 15 volume percent of alumina were determined by charge calculations. The particles of alumina were initially pre- heated at 300 ^oC to enhance wetability with aluminium alloy. The AA 6063 alloy was charged into a gas fired crucible furnace and the liquid was allowed to cool to a viscous mass at temperature of about 600 ^oC so as to introduce alumina particles. Stirring operations were performed manually and mechanically at 750 ^oC and 300 rpm, to ensure uniform distribution of reinforcement within the matrix, before pouring into permanent metal mould. The samples produced were solutionized at 550 ^oC for one hour, quenched in water and later aged at 180 ^oC for 2, 3 and 4 hours. Some samples were reserved for control experimentation. Mechanical responses of the composite were investigated by tensile, hardness and impact test carried out on the samples. The structures of the samples were examined by optical and scanning electron microscopes. The results trend showed that as the volume fraction of alumina and aging time increase, the strength and hardness values also increase with corresponding decrease in impact value. Composite with 15% alumina aged at 4 hours showed highest strength and hardness values of 262.77 MPa and 64.12 BHN, respectively with impact value of 9.86 J. The study showed that multistage stir casting method and precipitation hardening heat treatment are capable of improving the mechanical properties of AA 6063-Al_2O_3 composites.

Keywords precipitation-hardening, multistage stir casting, alumina, AA6063, AMCs

Introduction

Metal matrix composites (MMCs) which are metals reinforced with other metals, ceramic or organic compounds are gaining consequential attention in recent time in many industrial applications owing to their high specific strength, stiffness and heat resistance. They form a new class of industrial materials [1]. They are made by dispersing the reinforcements in the metal matrix. Reinforcements are usually done to improve the properties of the base metal. However, aluminium matrix composites (AMCs) as a typical example of MMCs has one of its constituent as aluminium/aluminium alloy, which forms percolating network and is termed as matrix phase. The other constituent, reinforcement, is embedded in aluminium/aluminium alloy matrix and is usually non-metallic ceramic such as SiC and Al_2O_3. Its properties can be tailored by varying the nature of their constituents and volume fraction. Aluminum matrix composites gain much interest due to their superior properties compared to monolithic aluminum alloys. Strength, stiffness, wear resistance are among several properties which are improved by the hard reinforcement phases.

Aluminium in its pure form cannot withstand much stress under structural and engineering applications; however, they can be strengthened by alloying with various elements (for example copper, silicon, magnesium and zinc.) such that their strength can be as high as that of steel. Due to their excellent castability and good compromise between mechanical properties and lightness, Al-Si-Mg alloys are the most important and widely used casting alloys in wheel production [2].

Furthermore, the increasing application of these alloys has been driven by the possibility to improve the mechanical properties of cast components through the use of heat treatments. Various heat treatments at different combinations of temperatures and times, have been standardized by Aluminium Associations and they are used in aluminium foundry depending on the casting process, the alloy type and the casting requirements [3]. Standard T6 heat treatment is generally applied in wheel production and it comprises three stages [4]: solution heat-treating, quenching and artificial aging.

Solution heat-treating provides two beneficial effects to cast aluminium alloy wheels, this includes: improved ductility and fracture toughness through spheroidization of the eutectic silicon particles in the microstructure and higher alloy yield strength through the formation of a large number of fine precipitates which strengthen the soft aluminium matrix [5]. Various efforts have been made to investigate the effects of solution temperature and time on microstructure and mechanical properties of Al-Si-Mg foundry alloys [5-9]. Quenching on the other hand is usually carried out at room temperature to obtain a supersaturated solid solution of solute atoms and vacancies, in order to achieve an elevated strengthening in subsequent ageing [3, 10]. The most rapid quench rate gives the best mechanical properties, but it can also cause unacceptable amounts of distortion or cracking in components [11]. Lastly, artificial ageing consists of further heating the casting at relatively low temperatures (120- 210 °C) and it is during this stage that the precipitation of dissolved elements occurs. These precipitates are responsible for the strengthening of the material.

The viability of developing simple, cost effective and technically efficient processing routes for the production of metal matrix composites (MMCs) is currently being explored by materials researchers from most developing countries [12-13]. The motivation for research in MMCs development is its attractive properties and higher performance potentials over traditional metals and alloys [14-15].

Hashim *et al.* (2003) used stir casting method to produce metal matrix composite and reported that large porosity produced was due to gases entrapment in melting [16]. Alaneme and Bodunrin (2013) investigated the mechanical behaviour of aluminium 6063 reinforced with alumina particles developed by two step stir casting method [17]. Low porosity level was observed in their work than what was reported by Hasim *et al*. (2003) [16]. Axen *et al.* (1994) noted that, in a variety of wear conditions, the particulate reinforced composites perform better than the fibre-reinforced composites [18]. Chawla et al. (2009); Christy et al. (2010); and Alaneme and Aluko (2012) reported that AA6063 is processed in large quantities at lower costs in many developing countries but its potentials for use as Al alloy matrix for composite development has not been explored as extensively as the other age-hardenable Al alloy series such as the AA 6061, AA 7075, and AA 2024 series [19-21].

Aluminium matrix based composites are a class of light weight high performance aluminium centric material systems**.** The mechanical and failure properties of these materials are known to be affected by fabrication methods shown in fig.1, distribution and properties of the constituents, shape and size of the particle and volume fraction. AA6063 is processed in large quantities at lower costs in many developing countries, but its potentials for use as Al alloy matrix for composite development has not been exhaustively explored, hence, this study. The aim of this research work is to study the effects of precipitation hardening on multistage stirred cast alumina reinforced AA6063 composites which were achieved through production of alumina (Al_2O_3) reinforced AA6063 alloy, using four stage stir casting method; determination of the effect of precipitation hardening heat treatment on the samples produced; and characterization of the microstructures and some mechanical properties of the cast and precipitation hardened aluminium matrix composite.

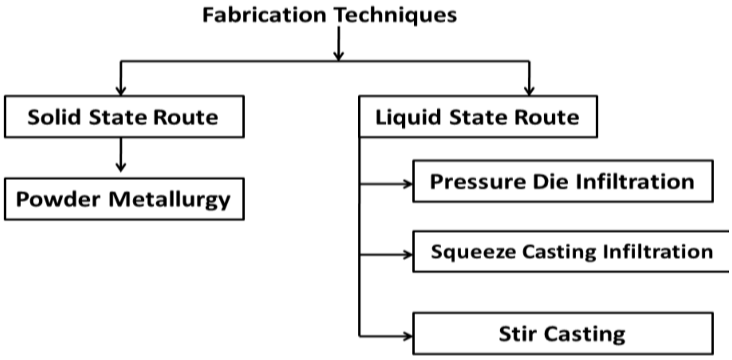


Figure 1: Aluminium matrix composite fabrication techniques

Materials and Method

Aluminium alloy AA6063 and pure Alumina were used for this research work as matrix and reinforcement materials, respectively. The chemical composition of as -receive AA 6063 obtained from Aluminium Rolling Mill, Sango-Ota, Nigeria are shown in Table 1. The cast blocks of aluminium 6063 and bottle of alumina particles are shown in figs. 2 and 3, respectively. The charge calculation was done to evaluate the quantity of AA6063 alloy and alumina (Al_2O_3) particles required to produce composites having 0, 3, 6, 9, 12 and 15 % volume fractions of alumina. The particles of alumina were initially preheated at 300 ^oC for 5 minutes to help enhance wettability with aluminium alloy. The AA 6063 alloy was charged into a gas fired crucible furnace operating at 750 ^oC and the liquid was allowed to cool to a viscous mass at temperature of about 600 ^oC so as to introduce alumina particles and stirred manually until slurry was formed. Second stirring was performed using a mechanical stirrer. The stirring operation was done for 8 minutes at a speed of 300 rpm to help improve the distribution of alumina particles in the molten matrix. The manual stirring was repeated at the corners of the crucible to avoid clustering of alumina particles that could have segregated to the crucible corners not accessible by the blades of the mechanical stirrer. The final mechanical stirring was performed on the molten composite before pouring into metal mould. An external temperature probe (thermocouple) was utilized to monitor the temperature of the furnace and composite.

Table 1: Spectrometric Analysis of Aluminium 6063 Alloy

Element	Si	Cu	Mg	Mn	Zn	Cr	Fe	Ti	Al
% Composition	0.452	0.004	0.64	0.026	0.002	0.006	0.225	0.033	98.61

Figure 2: Aluminium AA6063 Cast Blocks *Figure 3: Aluminium Oxide*

Samples Preparation

Aluminium AA 6063 composite rods having 0, 3 ,6 ,9, 12 and 15 % volume fractions of alumina were turned into standard gauge length for tensile and impact test according to ASTM E8 and D 256 respectively, on the centre lathe machine.

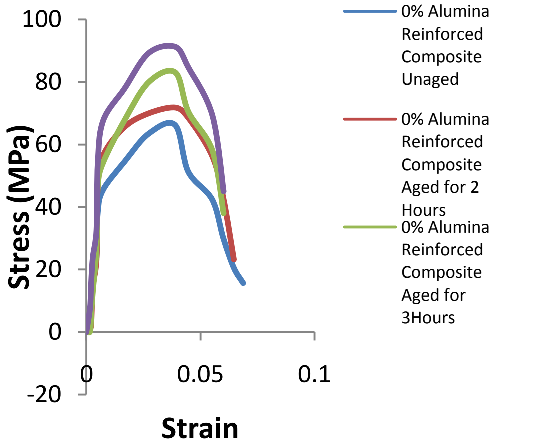
Precipitation Hardening Treatment

Precipitation hardening treatment was carried out on all samples by heating them to a temperature of about 550°C to obtain a single phase solid solution, the solutionized samples were cooled rapidly to retain the high temperature single-phase supersaturated solid solution at room temperature (Quenching) and finally aged at elevated temperature of 185°C for 2, 3 and 4 hours. Some samples were retained for control experimentation.

Results and Discussions

Results

The results of mechanical testing performed on as received and heat treated samples are presented in figures



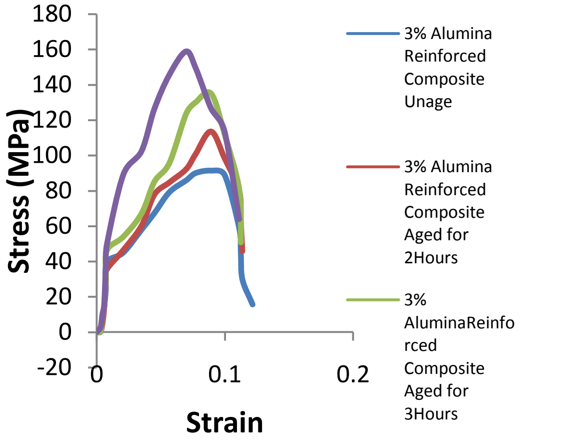
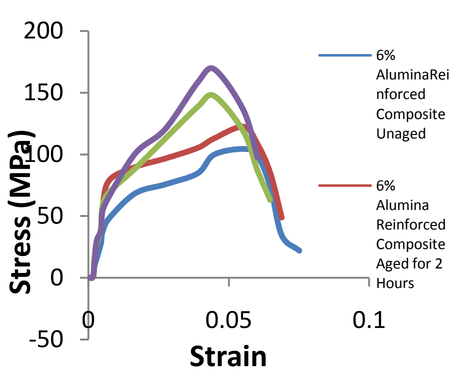


Figure 4: Stress- strain curves for 0% alumina samples *Figure 5: Stress-strain curve for 3% alumina samples*



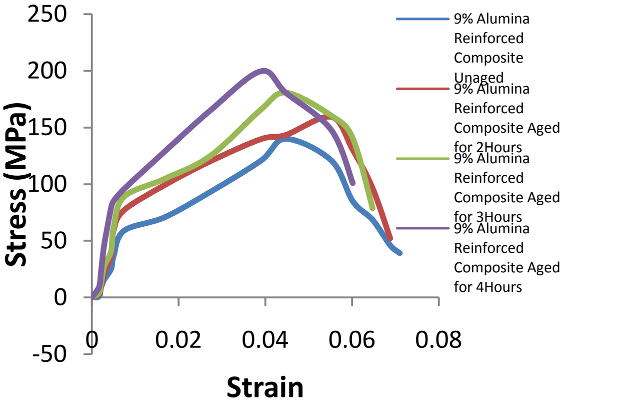
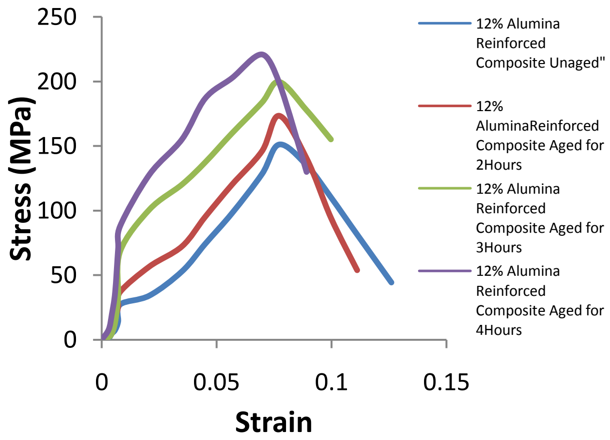


Figure 6: Stress-strain for 6% alumina samples *Figure 7: Stress-strain curves for 9% alumina samples*



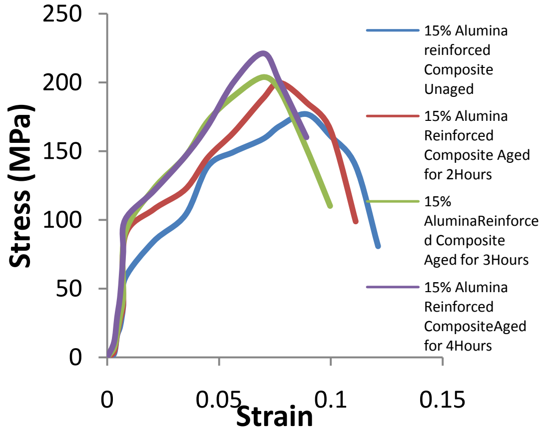


Figure 8: Stress- strain curve for 12% alumina samples *Figure 9: Stress- strain curve for 15% alumina samples*

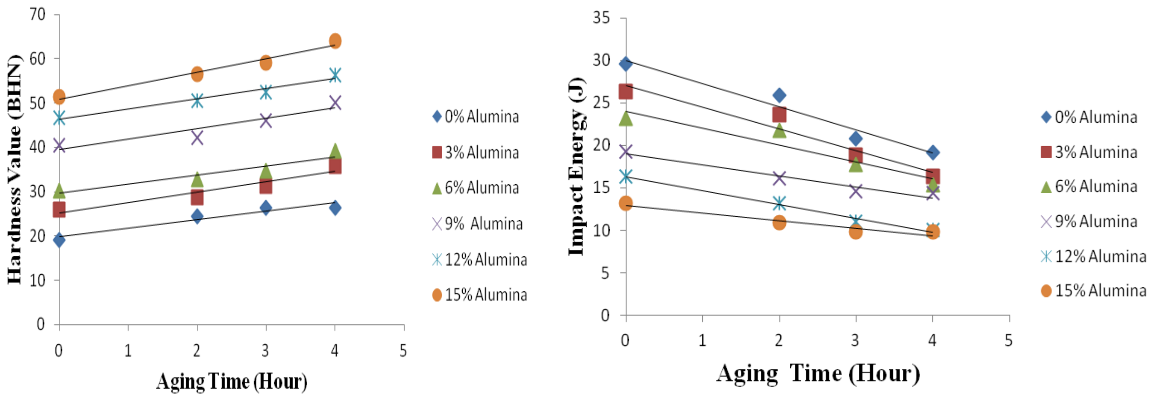


Figure 10: (a) Hardness value versus aging time (b) Impact energy values versus aging time

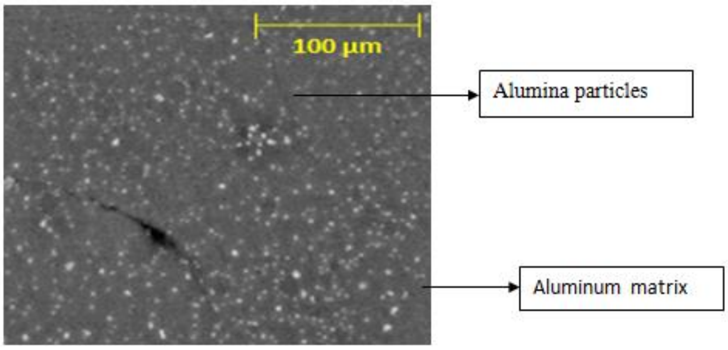
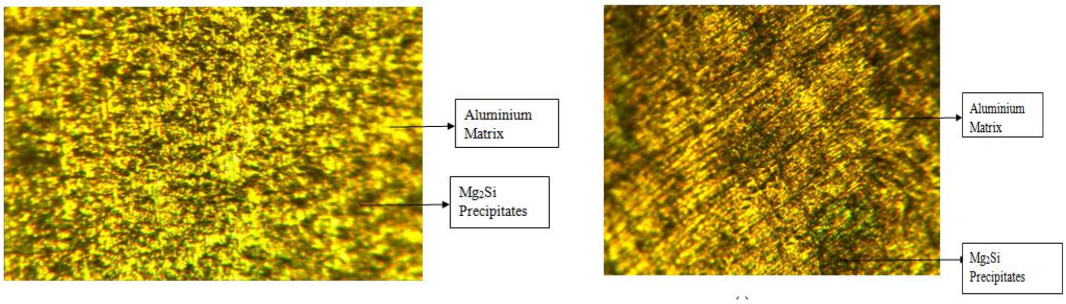
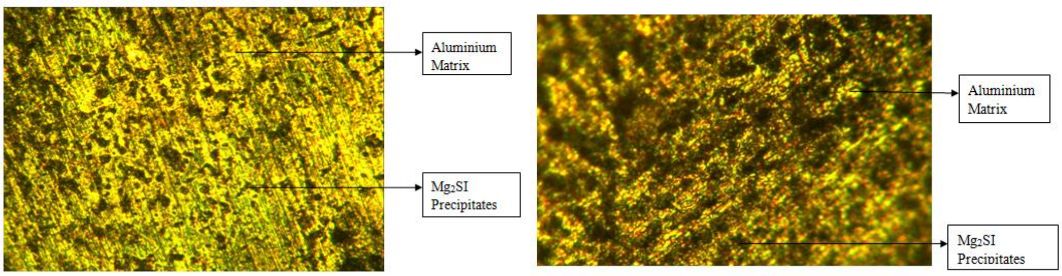


Figure 11: SEM micrograph of AA6063 composites with 9% alumina reinforced unaged



(a) **(b)**

Figure 12: Optical micrograph (x400) of AA6063 composites with 3% alumina at (a) 3 hours and (b) 4hours aging time.

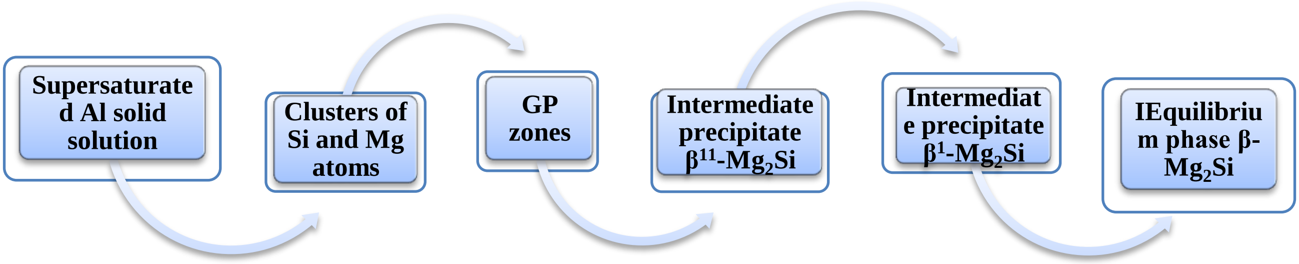


(a) (b)

Figure 13: Optical micrograph(x400) of AA6063 composites with 15% alumina at (a) 3 hours and (b) 4hours aging time.

Discussion

The mechanical properties of 0 % alumina reinforced samples are presented in Figure 4. The Figure shows variation of stress with strain for 0 % alumina reinforced samples at various aging time. It was observed from the curves that strength increases with aging time. The sample aged for 4 hours recorded highest strength value of 72.39 MPa as against 66.27 MPa, 68.87MPa,70.63MPa for samples aged at 0, 2 and 3 hours respectively. The hardness values also increase with aging time as shown in Fig. 10 (a). However, the impact values for these samples show inverse response to aging treatment that is, as the aging time increases the impact values reduce as shown in Fig. 10 (b). The responses displayed by these samples could be ascribed to the presence of small precipitates within the aluminium matrix which kept precipitating out from solid solution as the aging time increases. The combined mechanisms of dispersion and precipitation hardening really improved mechanical properties of the samples. Figs. 4- 11 show that there is an increase in strength and hardness as aging time increases with corresponding decrease in impact energy values. This improvement is suspected to be achieved by precipitation hardening, consisting of fine, uniform precipitation of Mg_2Si obtained by ageing from the supersaturated state of α-Al. The sequence of precipitation hardening is as follows [22].



The age hardening characteristics of an alloy are generally modified by the introduction of reinforcement. These modifications are due to the manufacturing process, the reactivity between the reinforcement and the matrix, morphology and volume fraction of the reinforcement. The sink effect due to interfaces introduced by the presence of the reinforcement also plays an important role in precipitation kinetics. Generally speaking, at ageing temperatures corresponding to the precipitation of a semi coherent phase (like β^1 in Al-Mg-Si alloy), the introduction of the reinforcement will accelerate the kinetics of precipitation [23]. In this work, the composition of iron is 0.225 wt %, this iron will combine to form Al_5FeSi inter-metallic prior to the formation of Mg_2Si compounds. Thus, the reactivity between the reinforcement and the matrix during high temperature solution treatment may lead to a modification of the composition of the matrix such that the kinetics of precipitation become faster in the overall composite as revealed by optical micrographs in Figs. 12-13. The compositional limits for Mg and Si in 6063 alloys range between 0.45 – 0.9 wt% and 0.2 – 0.6 wt%, respectively [3]. In the as-cast structure, the incoherent nature of the Mg_2Si phase does little to increase the strength of the alloy. This is suspected to be responsible for lower strengths of samples aged at 0 hours (i.e. unaged samples) as shown in Figs. 4-9. However, as the volume fraction of alumina increases, in these samples, the strength and hardness increase. To obtain finely dispersed Mg_2Si, a solution heat treatment needs be conducted on the alloy. The process raises its temperature to near the melting point of the alloy but not high enough to initiate partial melting. At the solution temperature (~550ºC for Al-Si-Mg alloys) the Mg_2Si dissolves back into solution with the aluminum matrix. During quenching the alloy quickly cools from solution locking the strengthening elements within the aluminum matrix. The alloy after quenching becomes meta-stable, where some silicon and magnesium crystals attempt to precipitate out as Mg_2Si but cannot, since at room temperature, there is not enough energy for precipitation to occur. In aging, the samples are raised to a high enough temperature (180 ºC) to initiate precipitation of the Mg_2Si. During aging, the precipitates diffuse out as dispersed phases which anchor the matrix and impede deformation resulting in a significant increase in strength and hardness.

Conclusion and Recommendation

Alumina reinforced AA 6063 composites were produced via four stage stir casting method, this is to ensure uniform distribution of alumina particles within AA6063 alloy matrix and the results of the mechanical tests after precipitation hardening heat treatment showed that strength and hardness of the samples increase as volume fraction of reinforcement and aging time increase. SEM and OM micrographs showed distribution of alumina particles and precipitates within the Al matrix alloy which agreed with the results of some mechanical properties tested for. Thus, it can be concluded that the use of multi-stage stir casting method, addition of reinforcement particles and precipitation hardening improve the mechanical behavior of the AA 6063 composite. However, it is recommended that aging time increase further to ascertain the optimum mechanical response value of alumina reinforced AA6063 composites and the treatment repeated for other non-ferrous alloys.

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