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Effect of Heat Treatment on Micro Hardness and Microstructural Properties of Al 6063 Alloy Reinforced with Silver Nanoparticles (AgNps)

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Abstract

The demand for light weight metals in engineering design has led to the increasing use of aluminum and its alloys. However, conventional high-strength casting aluminum alloys usually exhibit low ductility and toughness, as a result of boundary segregation and coarse dendritic grains which result in its limited application in large-sized and complex shaped work pieces. Also, the possession of a significant low resistance to corrosion of Al 6063 alloys has been a major challenge in applications involving acidic and alkaline media. In this study, silver nano-particle was extracted from a fixer solution. Al 6063 was impregnated with silver Nano-particle at different percentage ratio to form a metal matrix nano composite and the Hardening heat treatment of the reinforced metal matrix nano composite was performed. The elemental composition of Al 6063 prepared from scrap was determined using Light Emission Polyvac Spectrometer. The hardness and microstructural analyses of the composites were evaluated. The micro hardness of the composites was positively influenced by the addition of AgNps and the hardening heat treatment process it was subjected to. The percentage increase in micro hardness of the sample not heat treated but impregnated with 3% and 9% weight nano particles are 20% and 22% respectively. Subjecting these samples to heat treatment further increased the micro hardness to 33% and 37% respectively. The morphology of the composites revealed reasonably homogenous distribution of the reinforcement in the matrix of Al 6063 alloy. It can be concluded that both percentage increase in weight fraction of AgNps and hardening has significantly increased the micro hardness and refined the grain morphology of the Al-AgNps composites.

Keywords; Micro hardness; microstructure; Silver Nanoparticles; Aluminium; hardening

1. Introduction

Aluminum makes up about 8.1% of the Earth's crust which makes it the third most abundant element and the most abundant metal in the crust [1]. Aluminum however has limitation with its strength and thus several elements such as copper, magnesium, manganese, silicon, tin, zinc among others have been alloyed with it in order to improve the strength while retaining its desirable properties, most notably its lightness and corrosion resistance [2]. The strength-density and good fatigue property of Aluminum alloys makes it find extensive usage in engineering applications. Applications that require lightweight materials which include domestics, aerospace and automobiles largely depends on aluminum alloy. The aluminum alloy can be grouped to 1XXX to 8XXX series based material composition. One of these alloy series (6XXX group) have been extensively used in building, aircraft, and automotive industries as a result of their admirable properties [3]. Al 6063 alloy is one of the most popular alloys in the 6000 series, with Aluminum, magnesium and silicon as the major composition. It has generally good electrical conductivity and mechanical properties, it is also heat treatable and can be easily weld. As a result of uneven distribution of softness when casting of Al alloys, heat treatment has been an essential technique used in the fabrication of aluminum metal matrix composites. Homogenizing, annealing, solution heat treatment and ageing are the common methods used to heat treat Al alloys. The desire to develop alloy with low density, high strength, superior creep resistance, high damping capacity and good dimensional stability has become paramount. Nano sized composites are superb materials for structural applications and they have pronounced potential in automotive and aerospace industries. Recently, particles of Nano size are being used in the reinforcement of Al based composites. The result of such reinforcement showed that the addition of a small amount of fine ceramic particles improves the strength of Al based particles significantly [4]. Peng-Xiang *et al.* [5] fabricated and studied the influence of heat treatment (T6) on the microstructural and the hardness properties of Al 7075 alloy reinforced with Nano sized Al_2O_3 by ultrasonic vibration. It was reported that $Mg(Zn,Cu,Al)_2$ phases slowly dissolved into the matrix under solution heat treatment at 480℃ for 5 h. However, it was also reported that the morphology and size of Al-$7Cu_2Fe$ phases stayed unchanged due to their high melting points. The hardness value of the sample under T6 heat treatment was increased by 52% compared with that of as-cast sample [5]. The study carried out an investigation of the influence of the addition of TiC Nano - particles on properties (mechanical) of Al-5Cu alloy. TiC Nano - particles was reported to be effective in refining grain size and secondary dendritic arm of the alloy. The yield and ultimate tensile strength and elongation of the as-cast, solid-solution and T6 Al-5Cu alloy were improved with the addition of TiC Nano-particles [4]. The present study focuses on evaluating the micro-hardness and microstructural properties of heat-treated Al 6063 alloy reinforced with Silver Nanoparticles (AgNps).

2. Experimental Methods

2.1 Material preparation

The base material for this project is Al 6063 alloy and it was selected as matrix due to its huge range of application in engineering sector. The Al 6063 alloy (scrap) used for this study was purchased from Afenifere Sawmill, Ballet bus stop, Itire, Lagos Nigeria and the Silver Nano particles (AgNps) used for reinforcement was extracted from used Fixer Solution. Sodium Sulphide used for the extraction of Silver Nano particles was also purchased from a chemical store at Ojota, Lagos, Nigeria.

2.2 Extraction of Silver Nano particle (AgNps)

Silver Nano particle (AgNps) of 300g with average particle size of 300 μm was extracted from 100 litre of used Fixer Solution by adding 1 kg of Sodium Sulphide. The solution was thoroughly stirred, covered and allowed to stay overnight so that the Silver Nano particles present in the used fixer solution can precipitate. The solution was then siphon and the silver slug (Fig 1a) was heated until it dries completely. The Silver was sieved and graded into particle size of 300 μm (Fig 1b). The silver dust was weighed using a sensitive scale and stored in an air tight container.

Figure 1: (a)Silver sludge (b) Silver Nano particle AgNp

2.3 Preparation of Al 6063 alloy

Al 6063 alloy (Fig 2a) was charged and melted in a crucible pot placed in a diesel fired crucible furnace (Fig 2b). The charge was heated to about 850^{o}C, after which the crucible pot containing the molten material was removed from the furnace, the slag floating on top of the melt of Al 6063 alloy due to plated paint on it was screamed off the surface of the melt. The melt was degassed (to control the porosity) and formed into billets by pouring the melt into an ingot metallic mould (Fig 2c) to produce the unreinforced Al 6063 Alloy billets (Fig 2d). The billets were removed from the mould and weighed to be 13 kg.

Figure 2: (a) Scrap of Al 6063 alloy (b) Crucible Furnace (c) Ingot metallic moulds (d) Billets of Al 6063 alloys

2.4 Preparation of Al 6063 reinforced with Silver Nano particle

Al 6063 alloy was reinforced with Silver Nano particle of average size of 300 µm at 3 and 6 wt. % to achieve the sets of the reinforced (Al-AgNps) composite. 6 Kg of the prepared Al 6063 alloy billet was charged into the furnace for second melting. The melt was then removed and poured into a split metallic cylindrical and rectangular mould which has been preheated to about 200℃ to obtain the un-reinforced Al composites (Fig 3a) which was removed from the mould and marked as control sample. The remaining molten metal was then returned back into the furnace and 3wt.%of AgNps was added to melt together. The mixture was brought out after the Silver Nano particle has melted and slag were removed. The mixture was stirred mechanically by improved mobile stirrer at a speed of 140 rpm for 2 min before being poured into the split metallic cylindrical and rectangular mould. This stirring speed and time were carefully selected, taking into consideration the capacity and dimensions of the crucible pot and pouring temperature. This was used to produce the 3% reinforced (Al-AgNps) composites (Fig 3b) [6]. The composites were removed and marked as 3 wt.% samples. The remaining molten metal was then returned back into the furnace and the same procedure was used for the 6 wt.% samples (Fig 3c). The composites were removed and marked as 6 wt.% samples. Two cast samples were produced for each composition for characterization. One cast sample for each composition was hardened at 450℃ and soaked for an hour using a heat treatment furnace and rapidly quenched in water, taking into consideration the size and dimensions of the specimens.

Figure 3: (a) Unreinforced Al composites (b) 3 wt.% reinforced Al-AgNps composites (c) 6 wt.% reinforced Al-AgNps composites

2.5 Composition analysis

The chemical/elemental composition of the control sample was obtained using Light Emission Polyvac Spectrometer (Model No: RU83840U1)

2.6 Hardness Test

The prepared samples were grinded and polished progressively using a grinding and polishing machine. The micro hardness specimens as shown in Figure 4 were prepared with fine grained emery polishing papers. Micro hardness test of the sample was carried out on a micro-hardness testing machine and average values were computed after three trials.

Figure 4: Micro hardness test specimen

2.7 Microstructural analysis

The prepared samples were grinded and polished progressively using a grinding and polishing machine which was followed by etching. The polished and etched specimens were subjected to microstructural examination using a Scanning Electron Microscope (JSM-7900F Model).

3. Results and Discussion

3.1 Elemental composition

Table 1shows the elemental composition of the aluminum 6063 alloy used in this experiment. The major elements present in it apart from Al were Si, Fe, Cu, Mn, Mg, Zn, Cr, V, and Ca. These elements influence the phase reactions formed when reinforcements were added at various percent weight fractions.

Table 1: Elemental compositions of the control sample (Al 6063 alloy) used in this experiment

Element	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**
Composition (%)	98.26	0.4712	0.6154	0.0374	0.0367	0.3085
Element	**Zn**	**Cr**	**V**	**Ca**	**Others**	
Composition (%)	0.0707	0.0203	0.0132	0.0081	0.1585	

3.2 Hardness

Figure 5 shows the weight fraction effect of AgNps on micro hardness property of Al 6063 Alloy. It is very clear that reinforcement of Al 6063 with AgNps has a significant effect on the micro hardness of the composites. Observation clearly revealed that the weight fraction of reinforcement is directly proportional to micro hardness that is increase in weight fraction of the reinforcement results in increase in the micro hardness of the composites. This was ascribed to the increase in surface area of the matrix which then decreases the particle sizes [7]. The presence of reinforcing particles with such hard surface area also tends to offer more resistance to plastic deformation, thus, an upsurge in hardness. When compared to the hardness value of the un-heated control sample (111.2 HV), the composites showed increase in hardness. With respect to 300 µm particle size of AgNps, about 20% was observed for 3wt. % of AgNps and increases to 22% for 6 wt.% fraction of AgNps for the un-heat treated composites. The micro hardness was enhanced by 33% for the heat treated control sample, 37% and 41% when the composites were reinforced with 3 and 6wt. % fractions of AgNps, respectively and heat treated by hardening.

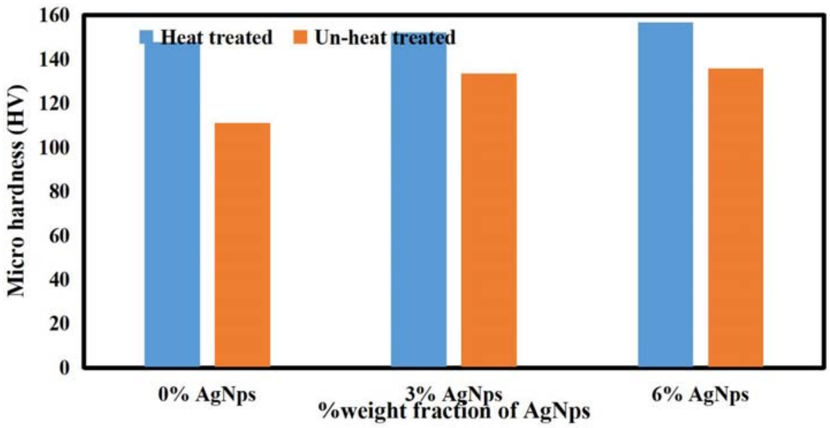

Figure 5: Micro hardness property of Al 6063 alloy at different % weight fraction of reinforcement (AgNps).

3.3 Microstructural analysis

The micrographs that shows the grain morphology of the heat treated and un-heat treated Al-AgNps composites are shown in Fig. 6 a-d. The properties of a particulate composite have been reported to be influenced by the morphology, density, type of reinforcing particle and its distribution. [8]. Fig. 6 shows reasonable homogenous distribution of the reinforcement in the matrix of Al 6063 alloy. The refined structure and reduced particle size observed in structures of the composites can be attributed to the percentage weight fraction of AgNps and the effect of heat treatment on the composites.

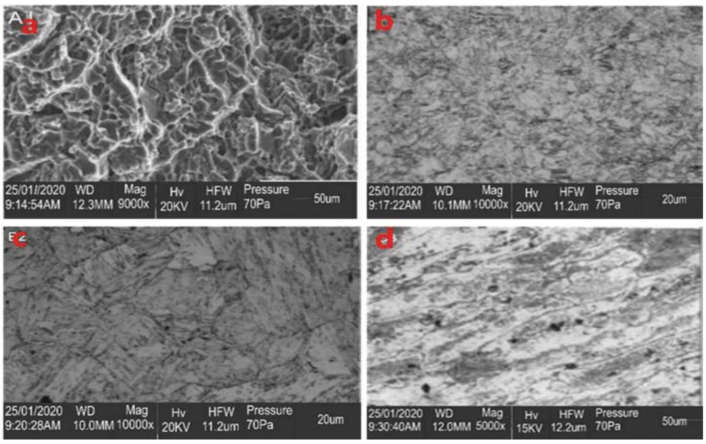

Figure 6: Micrographs of (**a**) Al 6063 alloy (b)3% Al-AgNps composite (c) 6% Al-AgNps Composite (d) Heat treated 6% Al AgNps composite alloy

4. Conclusions

The composites of Al-AgNps were successfully developed and heat-treated using hardening method. The micro hardness of the composites when compared with the control sample increased by 20 and 22% for 3 and 6% wt. of AgNps, respectively for the un - heat treated composites and 33, 37 and 41% when the composites were heat treated The morphology of the composites revealed balanced and homogenous distribution of the reinforcement within the matrix of Al 6063 alloy. The micro hardness of the composites was significantly enhanced via the addition of AgNps and the hardening heat treatment.

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