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Effect of Nano BN Addition on the Properties of an Aluminum Metal Matrix Composite

Abstract-*In the present work, the wear rate and hardness of recycled Aluminum alloy based metal matrix composite that reinforced with nano Boron Nitride with (2%, 4%, 6%, and 8%) weight percentage with 33 nm particle size were evaluated. A stir casting process was applied to fabricate composite the mechanical and metallurgical characteristics of the fabricated composite were evaluated through the hardness and wear test. The results indicate that the value of hardness increased and wear rate decreased with increasing the BN percentage due to high surface area to weight ratio for nanoparticles.*

Keywords- *Recycling Al, Nano BN Particles, Metal Matrix Composites (MMCs), Hardness, Wear resistance & stir casting.*

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1. Introduction

Aluminum and its alloys have been widely applied to different fields that include car production, airplane industry and civil engineering due to their small density, excellent resistance to corrosion, and good mechanical and recycling properties. Aluminum metal matrix composite reinforced with ceramic particles has gained a broadly popularity in many technological fields because of the improved mechanical properties when compared with conventional aluminum alloys [1]. They have better mechanical properties than unreinforced aluminum and they are used as a tribological part in some vehicle as a result of their high specific strength and high wear resistance [2]. Different types of ceramic materials, e.g. SiC, MgO, Al_2O_3, B4C and BN are widely used as a reinforcing material that reinforced aluminum. Superior properties of these materials like refractoriness, high hardness, and high compressive strength make them suiTable for reinforcing a matrix in a composite [3]. One example of MMCs is aluminum metal matrix composite reinforced with BN. Hexagonal Boron Nitride (h-BN) also known as white graphite, has a lamellar crystalline structure with excellent lubricating properties. Boron nitride has a high electrical resistance, high thermal conductivity, good thermal shock resistance, low thermal expansion, and low dielectric constant and microwave transparency. Boron nitride has a light weight as a ceramic material with a theoretical density only 2.25 g. cm $^{-3}$ that considered less than that for aluminum [4,5]. There is different fabrication technique that used for production MMCs. These methods are divided into two parts: liquid state process and solid state process. Liquid state process has some advantages such as better particles - matrix bonding, simplicity, better control on structure of matrix, low cost of processing, and give net shape as compared to other processes [6]. Stir casting process used for production of MMCs, in which a dispersed particles (reinforcement phase) mixed with molten matrix material by using a mechanical stirrer. Then the molten composite poured into a mould. The distribution of reinforcement phase in the matrix material can be enhanced if the matrix state is in semi-solid. The process of stirring metal matrix composite materials in semi-solid state is called Rheocasting. High viscosity of the semi-solid matrix material allows better mixing of the reinforced phase [7].

Chen et al. studied the influence of microstructure and particle size of Al powder on the properties of BN reinforced aluminum matrix composite that produced by the semi- solid powder process. The Al-Cu/ h-BN composites showed the best mechanical properties (hardness, compressive strength and fracture strength). At 3wt% h-BN, there was a full densification. [8].

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Yathiraj et al. fabricated a metal matrix composite from aluminum 6061, hexa boron nitride with a particle size (7-11) µm and weight percentage (0%, 3%, 6%, and 9%) by a stir casting process. The microstructural studies showed that the BN was distributed uniformly in the matrix. The addition of BN reinforcement resulted in enhancing the composite's mechanical properties [9].

Harichandran and Selvakumar studied the effect of the addition of h-BN on the dry sliding wear behavior of Aluminum – B_4C nano composite. Hexagonal Boron Nitride and Boron Carbide with a particle size (70 nm, 70 µm) were used as reinforcement in a wt. % 2, 4 and 6 % of B_4C and 2 % of BN. Stir casting and ultrasonic cavitation-assisted casting processes were used to prepare the nano composites. The mechanical and tribological properties were evaluated. The microstructural studies revealed a uniform distribution of reinforcements with a grain refinement and low porosity. The best wear resistance was found at 4% B_4C and 2% BN compared to the unreinforced material. [10].

Gangatharan et al. improved the tribological properties of composite material for centrifugal pump applications by fabrication a composite material by a stir casting process. These four materials were Al 2024 alloy, red brass (UNS C2300), Al 2024 reinforced with graphite with a weight percentage 4%, Al 2024 reinforced with hexagonal Boron Nitride (4% wt). Wear test and friction properties were evaluated using pin on disk apparatus. For Al 2024 reinforced with graphite and h-BN, the dry sliding resistance was very high as compared to the unreinforced aluminum alloy and red brass and thus a lesser weight loss [11].

2. Experimental Part

Due to its good mechanical properties, the aluminum alloy A201 was fabricated and used as a matrix material.

For the fabrication of A201 aluminum metal matrix composite, Al (AA 2024) alloy (61gm) , Al wire (46gm) and pure Cu (3gm) (as a matrix material) reinforced with BN particles with weight percentage (2 %, 4%, 6%, and 8%) of 33 nm diameter were used. To prepare metal matrix composites liquid stir casting process was used. Chemical composition of Al wire and Al 2024 are shown in Tables 1 & 2 and the chemical composition of the fabricated A201 alloy, as shown in Table 3. The chemical composition was done in Central Organization for Standardization and Quality Control (The Ministry of Planning) by using Optical Emission Spectroscopy.

Table 1: Al Wire chemical Composition

Elements	Composition %
Cu %	0.032
Fe %	0.098
Mg %	0.023
Si %	0.073
Mn %	0.044
Ti %	0.026
Al	Bal.

Table 2: AA2024 Chemical Composition Analysis.

Elements	Composition %
Cu %	4.22
Fe %	0.039
Mg %	1.75
Si %	0.065
Mn %	0.262
Ti %	0.134
Al	Bal.

Table 3: Chemical Composition Analysis of A201.

Elements	**Composition%**
Si%	0.08
Fe%	0.13
Cu%	4.6
Mn%	0.35
Mg%	0.41
Al%	Bal.

A stir casting process are used to produce composite materials; in a graphite crucible Al 2024 and Al wire alloy were mixed and melted with nano hexagonal-Boron Nitride particles using a stirrer. Hexachlorethane was added to the melt as a degassing to get rid of gases and impurities [12]. The speed of stirrer lowered vertically up to 3 cm from the bottom of the crucible. The stirrer speed was gradually raised to 800 rpm. The BN nano particles were added into the melt at 750 °C. The nano particles were covered with aluminum foil. Later boron nitride powder was added, stirring was continued for 10 min to get improved distribution. The melt was kept in the crucible for 1 minute without stirring. Slags and impurities were seperated and the melt was poured in the graphite mold as in Figure 1.

Figure 1: Graphite mold

The rate of wear was calculated from the mass loss per sliding distance using equation (1).

$$\boldsymbol{W.R} = \frac{\Delta \boldsymbol{W}}{\boldsymbol{2\pi rnt}} \quad (1)$$

Where:
ΔW: the weight loss
ΔW: W_2-W_1
W_2: the weight after test (gm)
W_1: the weight before test (gm)
r: sliding distance (cm)
n: disk rotational speed in r.p.m.
W.R: wear rate (gm/cm)

3. Results and Discussion

I. The Particle size analysis

A laser diffraction of particle size distribution analyzer (90 plus particle sizing software ver. 5.34) was used to analyze the particle size of nano boron nitride Figure 2. The results show that the nano boron nitride particles have a particle size dimension in the range of [32.4, 33.5] nm. The mean particle size of nano BN was 33 nm.

II- Micro hardness measurement:

The load that applied was 9.8 N for 15 sec. to eliminate the effect of segregation, minimum three readings were taken on different locations on the specimen's surface. The values of Vickers micro hardness are given in Figure (3). The results show of that the matrix material hardness and its composite increased with the increasing the percentage of nano nitride boron particles. The presence of hard reinforcement particles (BN) with hardness value up to (62 GPa) increases load bearing capacity of the composite material and also limit the matrix deformation by impeding the movement of dislocation. The maximum value of hardness was observed at 6% weight fraction.

In general, the influence of nanoparticles on raising the hardness is mainly because of grain refinement, Hall–Petch mechanism, and particle strengthening effects which act as hinders to dislocations movement [13].

III- Wear rate measurement:

A dry wear test was performed on the composite specimens using a pin on disc type wear tester according ASTM test standards (EN31) with a sliding velocity 6 cm/min, the disc rotational speed was 950 rpm and load 10 KN. The disc was made of steel with hardness 93 HRC. The pin (specimen) has a dimension 30 mm length and 10 mm diameter. As seen from the Figure 4 for any given wear sliding distance the increasing at 6% weight fraction of BN particles percentages results in a reduction in the wear rate of the specimen. This inverse relationship may be directly related to the improvement in the hardness of the composites as the content of nano BN is increased. This can be attributed to the self-lubricating property of nano BN. The change of wear rate as a function of wt% content for Al/BN nanocomposites is shown in Figure 4. Increasing the BN content resulted in decreasing the wear rate of the composite and reached a minimum at 6 wt. % BN and so 61% less than that of the matrix. Increasing the weight percent result in decreasing the wear rate for nanocomposites when compared to unreinforced aluminum matrix. This increasing in the resistance of wear of the Al- BN nanocomposites as compared to aluminum can be attributed to the presence of nano BN. The boron nitride is a solid ceramic lubricant material that reduced the rate of wear of the composites by the forming of a thin protective lubricant layer between the disc and pin during sliding. Increasing the resistance of wear can be due to the matrix material strengthening owing to hard particle dispersion that can be attributed to the increase in the density of dislocation when reinforcement wt. % increased [14]. However, as the wt% of the nano BN nanoparticles reaches 6 wt. %, the rate of wear of the nanocomposites decreased. The decreasing in wear rate of the nanocomposites at 6 wt. % nano BN is due to the high hardness.

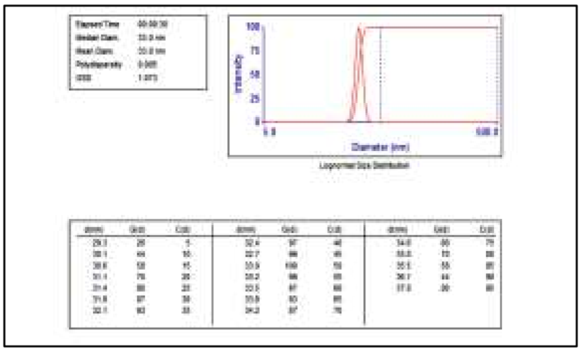


Figure 2: Particle size distribution of nano boron nitride

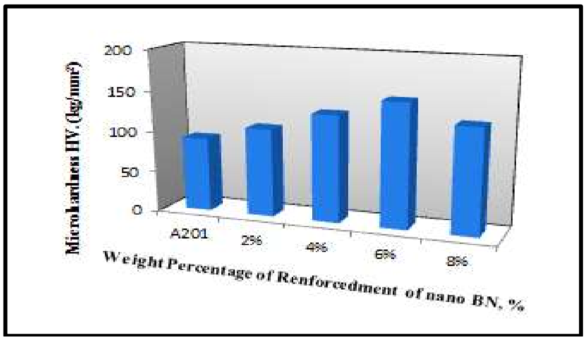


Figure 3: micro hardness values of nano BN reinforced recycled aluminum composites

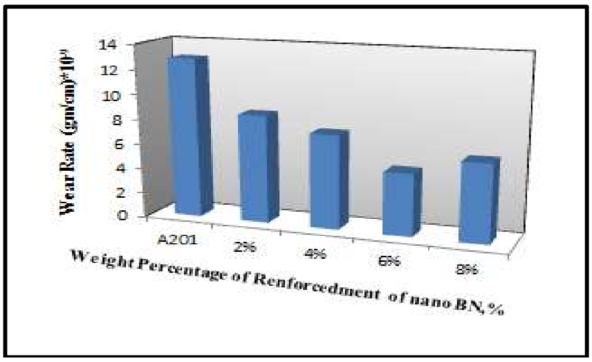
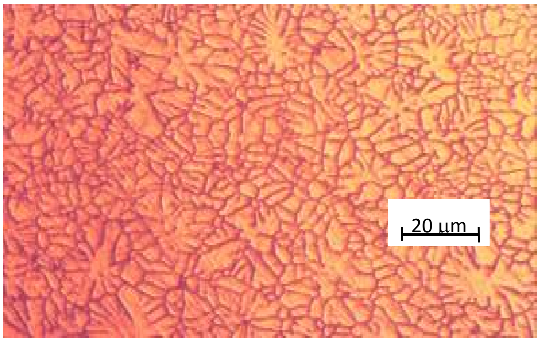


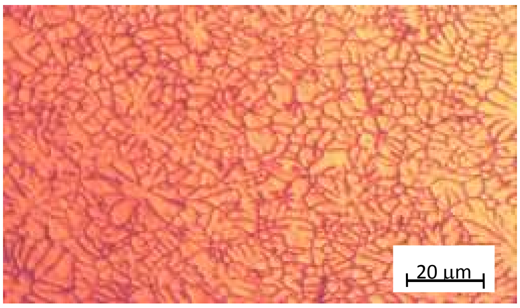
Figure 4: Wear rate values of nano BN reinforced recycled aluminum composites

IV-Microstructure Analysis

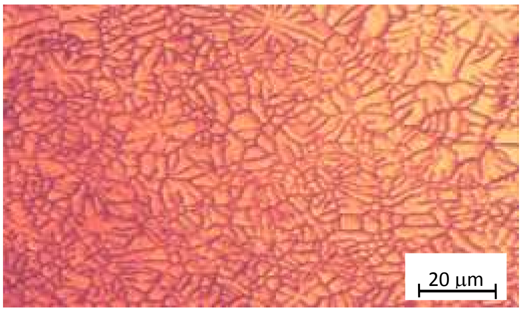
Figure 5 show the microstructure, it illustrates better distribution of reinforcement particles in the matrix. It was observed no indication of agglomeration of reinforcement particles in the matrix, as the nano BN weight percentage increases in the matrix, The microstructure is found to be dendritic; because of mechanical stirring the primary dendrites are fragmented that explains the enhancement in the mechanical properties. Optical microscope shows indication for the possibility of nano-sized particles to incorporate and entrap within the interdendritic interface developing during the solidification of the reinforced alloys.



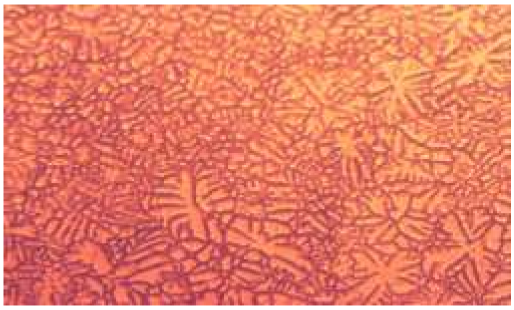
A –Base alloy



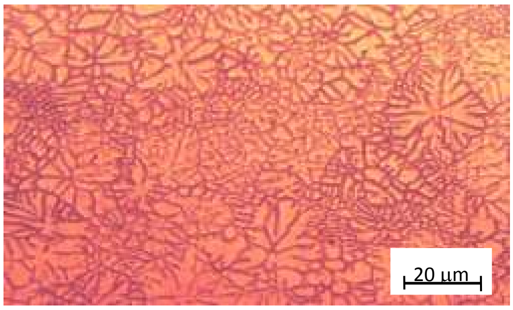
B- 2% wt.



C- 4% wt.



D - 6% wt.



E - 8% wt.

Figure 5: Microstructure of Al composite at different weight percentages of nano boron nitride particles in recycled Al alloy- matrix

A) Base alloy B) 2% wt. C) 4% wt. D) 6% wt. E) 8% wt.

4. Conclusion

From the testing results, we conclude the following:

1. The prepared composite exhibited higher values of hardness and wear rate as compared with the base alloy by stir casting.
2. The highest hardness was obtained at 6% nano BN particle reinforcement sample, which was (150.7HV) that means an increase of hardness of 66%
3. In the wear test, the minimum value of wear rate was (4.98 *10^{-9} gm/cm) for 6% wt of nano BN particulate, and so 61% less than that of the base alloy.
4. The microstructure was dendritic; the primary dendrites were fragmented.

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