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Effect of Graphene Content on the Mechanical and Corrosion Properties of AA5052 Matrix Composites Prepared by Stir Casting Method

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Abstract

This research explores the effect of reinforcing Graphene Nanoplatelets (GNP's) in AA5052 using stir casting process on mechanical and corrosion properties. AA5052 is widely used in marine applications due to its lightweight nature. Graphene, a single-atom-thick material with exceptional strength, thermal conductivity, and stability, was chosen as the reinforcement. Three different GNP's concentration was added, and the composites properties were evaluated through tensile, hardness, wear, and corrosion tests. Micro structural analysis using SEM confirmed the distribution of GNP's within the aluminum matrix. Results indicate that addition of 0.3% GNP's significantly improves hardness by 50%, tensile properties are doubled compared to 0.6% GNP composition and corrosion resistance is better in 0.6% composite.

Major Findings: *Metal matrix composites were successfully prepared with AA5052 as matrix and GNPs as reinforcement with 3 proportions viz. 0.1%, 0.3% and 0.6% respectively. The adhesion of GNP's with the alumini um matrix is less in all composites. The mechanical properties of the composite with 0.3% GNP's are better than the remaining two composites.*

Keywords: *AA5052, Corrosion, Graphene Nanoplatelets, Microstructure, Stir Casting*

1.0 Introduction

Aluminum metal matrix composites are becoming popular in the area of new materials and have become widely used in high-technology structural and functional applications like in the aircraft, automobile, marine, mineral, defence, transportation, thermal management, automotive, and sports and recreation fields[1]. Metal Matrix Composites (MMC's) are a subclass of composite materials with at least two constituent parts, the metal matrix and reinforcing nanoparticles[2]. AA5052 is a very light metal with exceptional ductility and machinability compared to other aluminum alloys[3]. Its primary applications are in the marine field. Due to the impressive qualities possesses by graphene, it is being studied for a wide range of applications. Many researchers have studied the effects of addition of graphene in different aluminum alloys.

The composite with AA5052/3wt.% Ti/5wt.% SiC exhibited the highest tensile strength, elongation, and hardness, measuring 243MPa, 34%, and 93HV, respectively[4]. Most researchers have used the powder metallurgy technique to produce aluminum alloy metal matrix composites with graphene as reinforcement[5-7]. The TiB_2 addition enhances the mechanical and tribological properties of AA5052 composite, increasing

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its applications, especially in lightweight engineering applications in general and marine in particular[8]. Even though the process is not simple and also expensive, researchers have used it to minimize errors in the fabrication process. As the traditional methods like casting are relatively cheaper and accessible to produce, but the defects from casting are bothersome, and there is a high chance of agglomerates formation in casting and uneven distribution as the process cannot be controlled quickly and also the temperature is too high, and this might cause graphene to decompose and degrade[9].

Some researchers even used different fabrication methods, like the friction stir process for aluminum graphene composites. This is also a highly effective method as it can be controlled quickly, and the temperature does not reach too high, which will not make the graphene decompose. This prevents agglomerates and promotes even distribution. The composites made with nano-AA5052/SiC surface by friction stir processing have achieved smaller microstructural grain sizes than micro-AA5052/SiC reinforced surface composites. Consequently, surface composites made by nano SiC show higher microhardness and tensile strength[10]. The reports indicated that the hardness of the Aluminum (Al) Matrix Composites (AMC's) is predominantly improved after they are reinforced with MgO and Carbon Nanotube (CNT), and also after heat treatment (T6)[11].

Researchers also tried different forms of graphene. Background graphene has been reported to be a promising nanofiller in fabricating advanced metal matrix composites[12]. Some researchers used graphene oxide and nanoplatelets[13]. Graphene has recently attracted many researcher due to its superior elastic modulus, high fatigue strength and low density. It is foreseen and predicted that graphene will replace and outperform Carbon Nanotubes (CNT) in near future[14]. Though the elemental compositions are the same, the structures are entirely different, GNP's are considered more stable and relatively more robust than other forms as they are multilayered graphene, whereas graphene oxide is considered relatively more unstable compared to other forms at higher temperatures. Graphene oxide decomposes relatively fast and at lower temperatures than graphene nanoplatelets.

Keeping the gaps in literature with respect to the usage of GNP's as reinforcement in AA5052 matrix through stir casting route this work aims to present the findings of mechanical and corrosion properties of AA5052 composites with GPN's as reinforcement.

2.0 Experimental Procedure

In the present work, stir casting method was used for making the aluminum-GNP's metal matrix composites. The base material used in this process is AA5052 and its composition is presented in Table 1.

Table 1. Chemical composition of base material AA5052

Elements	Composition (wt.%)
Magnesium	2.2-2.8
Iron	0.4
Zinc	0.1
Copper	0.1
Chromium	0.35
Aluminum	95
Silicon	0.25
Manganese	0.1

AA5052 is chosen in this work as base material because of its good ductility and machinability and additionally because of its excellent corrosion properties.

The reinforcement used in the present work is GNP's, which is one of the best forms of GNP's for use as a reinforcement on its excellent stability at high temperatures. The GNP's were procured from Nano Research Lab, Jharkhand, India. The average particle size of these GNP's were 2-6nm (Figure 1c).

GNP's presence can act as nucleation sites, promoting a finer grain structure in the aluminum matrix. This can further improve strength and toughness by hindering crack propagation. The SEM image of GNP's chosen and the schematic set up of stir casting used in the present work is shown in Figure 1.

The stir casting method is used because of its ease of use. Availability and its low cost. The machine used in this process is a bottom pouring stir casting machine (Figure 1d) with inert gas. During this process, inert argon is used

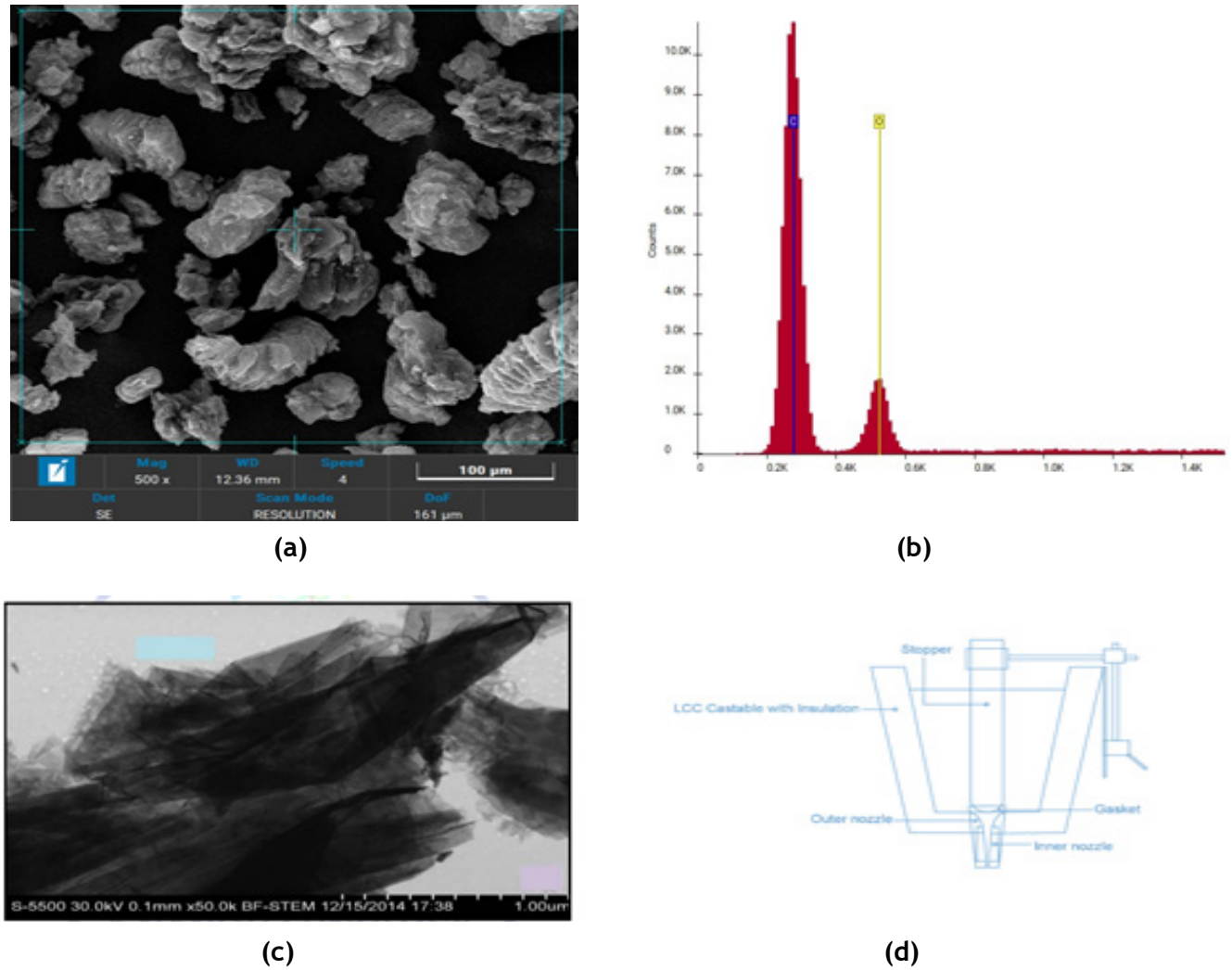


Figure 1. **(a)** SEM image of GNP's particles chosen in this work **(b)** Elemental analysis of GNP's **(c)** TEM analysis of GNP's **(d)** Schematic representation of the stir casting setup.

to create an inert atmosphere and prevent any gases like hydrogen from entering the cast as hydrogen might cause surface defects like blow holes and pinholes.

The major objective of this research is to find the impact of GNP's on the mechanical properties and corrosion behaviour of AA5052 and to achieve this object, various tests like Vickers hardness test, tensile test, wear test and corrosion tests were conducted and the results obtained were reported. The obtained mechanical and corrosion properties were validated with the support of optical and SEM images.

The composite specimens were cut into pieces of convenient sizes for microstructure inspection, hardness testing, and pitting corrosion behaviour. The specimens were polished to remove surface roughness using emery papers of grit sizes 120, 280, 400, 800, 1200, and 2000 until the required surface finish was reached prior to the hardness, corrosion, and microstructure investigation. After that, the specimens were fine-polished using alumina powder on a polishing cloth that was fixed on a revolving disc. To observe the microstructures, Keller's reagent was used to etch the polished specimens. Following etching, the microstructure and elemental analysis of the composite specimens were investigated using a field emission scanning electron microscope (TESCAN MIRA model) and an optical microscope (Leica make).

Using a 200g load and a 10-second dwell time, micro hardness tests were performed using a Shimadzu

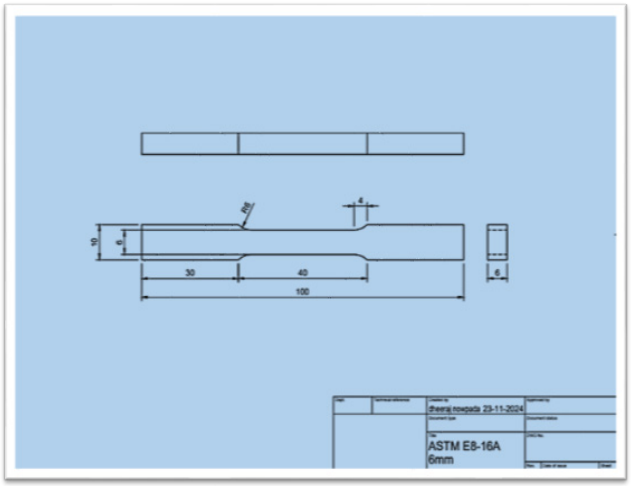


Figure 2. The tensile test specimen dimensions.

hardness tester. A minimum of 5 readings were taken at each location and the average hardness value was reported.

To investigate the pitting corrosion behaviour of composite specimens, potentiodynamic polarisation tests were performed using a software-based basic electrochemical system. Platinum and Saturated Calomel Electrodes (SCE) served as the auxiliary and reference electrodes, respectively. Every experiment was carried out in solutions containing 3.5% NaCl. For these trials, a 0.126 cm^2 area was exposed in each specimen. The corrosion potential (E_{corr}) was obtained and it is the point at which current sharply increases. Better resistance to pitting corrosion was thought to be exhibited by specimens with comparatively higher positive potentials or lower negative potentials.

Tensile test was done on the specimens prepared to understand the effect of addition of GNP's on strength of aluminum alloy. INSTRON servo-hydraulic testing machine. Two specimens in each composition were tested and INSTRON 8801 was used to test the specimens. The specimen used for tensile test was shown in Figure 2 and are prepared according to ASTM E8 standards.

The wear test was conducted on the specimens to understand the tribological characteristics of the composites on the DUCOM TR20 series NEO Pin on the Disc tribometer with 40N load. The sliding distance maintained is 40mm and sliding velocity is 15 mm/s.

3.0 Results and Discussion

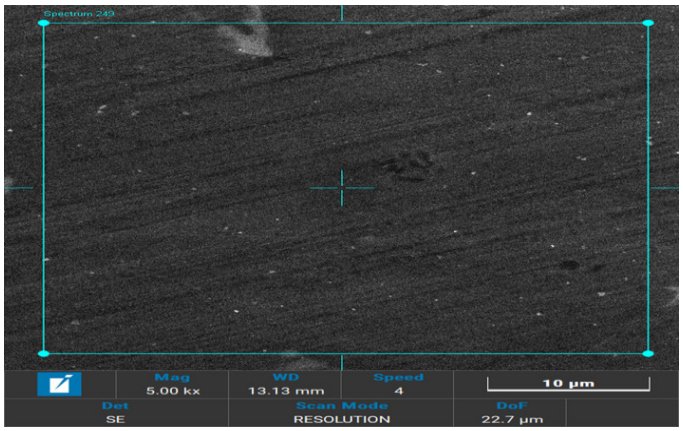
The results obtained in various tests on the composites were presented here.

3.1 Base Material Studies

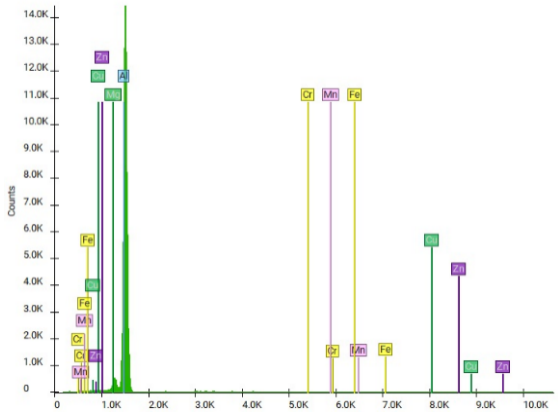
The mechanical and corrosion properties of the base material AA5052 were presented in Table 2.

Table 2. Mechanical and corrosion properties of base material AA5052.

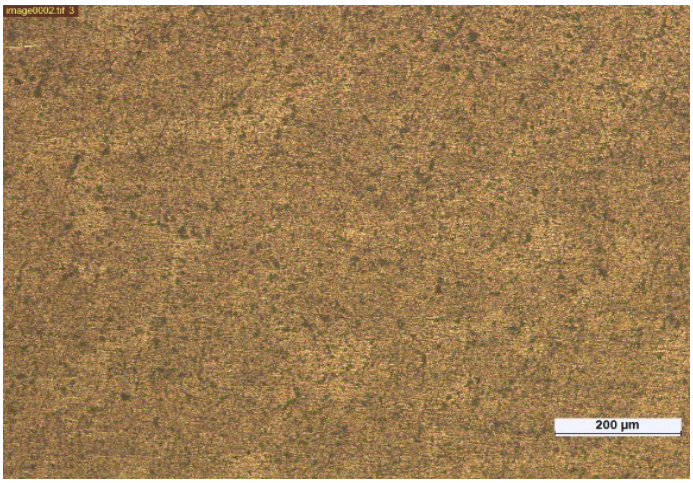
Property	Value
Ultimate tensile strength	184 MPa
Hardness	58.8 VHN
Corrosion potential (Ecorr)	-0.1 V



(a)



(b)



(c)

Element	Atomic %	Weight %
Aluminum	96.57%	96.71%
Magnesium	3.27%	2.95%
Iron	0.12%	0.26%
Manganese	0.03%	0.05%
Chromium	0.01%	0.01%
Copper	0%	0.01%
Zinc	0%	0.01%

(d)

Figure 3. SEM and optical images of base material AA5052. **(a)** SEM image **(b)** Elemental mapping of base material **(c)** Optical image **(d)** Elemental analysis of SEM image.

The optical and SEM images of base material AA5052 are shown in Figure 3. The SEM and optical images of AA5052 show the fine precipitates of Mg_2Al_3[15].

3.2 Composites with AA5052 as Matrix and GNP's as Reinforcement

3.2.1 Microstructure Studies

The SEM images of composites with different GNP's nanoparticles *viz.* 0.1%, 0.3%, and 0.6% were shown in Figure 4. From these images, it is evident that the GNP's were distributed uniformly in the base material matrix.

3.2.2 Tensile Strength

The tensile test results are presented in Table 3. The tensile results show a decrease in the tensile properties of the composite with the addition of GNP's as reinforcement. It is observed that among the 3 compositions, composite with 0.3% GNP's shows good tensile strength compared

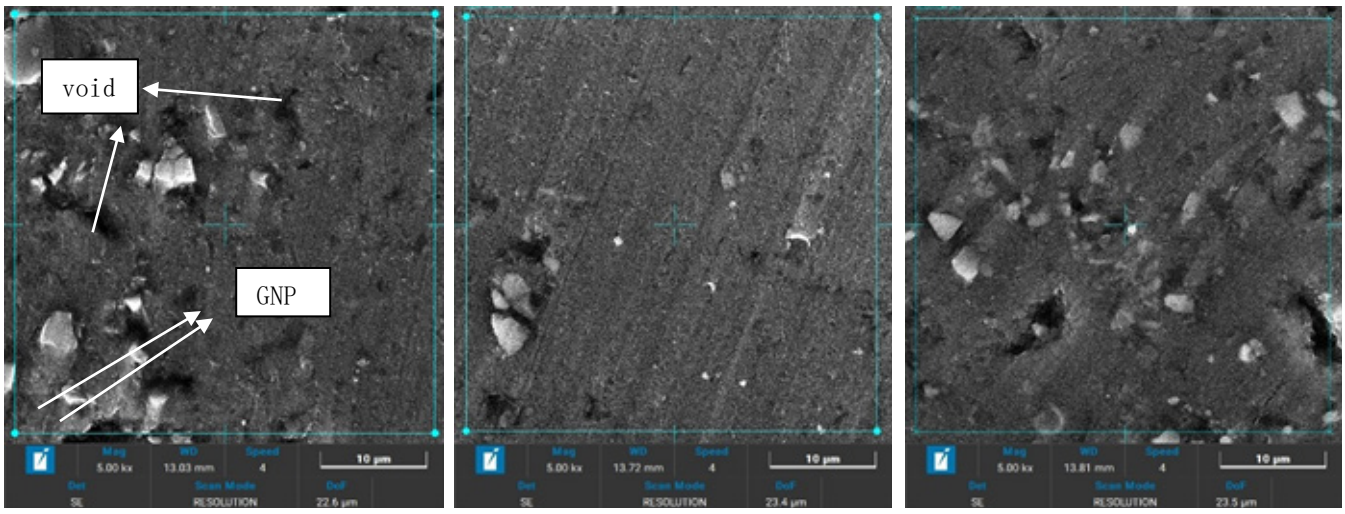


Figure 4. SEM images of composites with different GNP's. **(a)** 0.1% **(b)** 0.3% **(c)** 0.6%.

Table 3. The tensile test results of base material and composites

Specimen	UTS(MPa)	Tensile Stress at Yield (Offset 0.2 %) (MPa)
AA5052 base material	184.06	74.77918
Composite with 0.10% GPN	26.9	23.684
Composite with 0.30% GPN	96.32	52.78292
Composite with 0.60% GPN	47.89	26.40297

to the other two compositions. This concludes that the maximum concentration for optimum tensile strength is 0.3 wt. %.

Various reasons may cause a decrease in the tensile strength of aluminum composites. One of the reasons could be the formation of clusters or agglomerates of GNP's in the matrix, which would show a determinantal effect on the composite. The reason could be the inadequate interfacial bonding between GNP's and aluminum, which prevents effective load transfer, and the GNP's orientation plays a crucial role in load transfer. But, it is not easy to control the reinforcement orientation in a casting process. The other reason could be the formation of Al_4C_3 in the aluminum matrix. The primary reason for the formation of Al_4C_3 could be the high temperatures in the casting process as at a specific temperature, mostly 500^0 C, the degradation of carbon will start, which is the breakage of the carbon bonds, and this carbon is responsible for the formation of Al_4C_3 in the matrix.

3.2.3 Hardness

The hardness values of the base material and composites with different wt.% of GNP's reinforcement were presented in Table 4 and graphical representation is shown in Figure 5. Here also it is observed that the hardness of composite with 0.3% GNP is more compared to the other two wt.% of GNP's. However the hardness of composites is less than base material. This is attributed to the fact that the addition of GNP's has not much contributed to the improvement of hardness of the composites but the composites with 0.3% GNP's shows better hardness as the

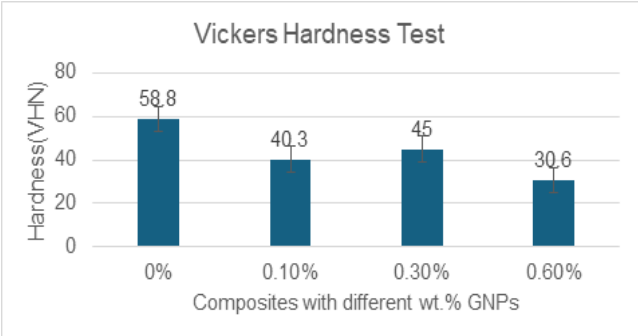


Figure 5. Graphical representation of hardness values of base material and composites.

cluster formation of these GNP's in 0.3% composite is less compared to 0.1% and 0.6% composites.

Table 4. The hardness values of base material and composites

Specimen	Hardness (VHN)
AA5052 base material	58.8
Composite with 0.10% GPN	40.3
Composite with 0.30% GPN	45
Composite with 0.60% GPN	30.6

3.2.4 Corrosion Resistance

Table 5 represents the pit potential values obtained in base material and composites with varying proportions of GNP's. The Figure 6 shows the potentiodynamic

Table 5. Corrosion potential (E_{corr}) (V) of base material and composites

Specimen (wt.% GNP)	E_{corr} (V)
0% (Base material)	-0.1
0.10%	-0.2
0.30%	-0.27
0.60%	-0.14

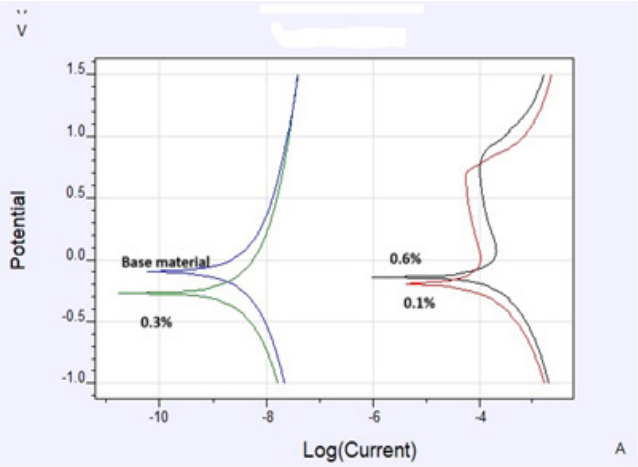


Figure 6. Graphical representation of potentiodynamic polarization curves of base material and composites.

polarization curves of composites and base material. This table and curves show that the composites with varying amounts of GNP's exhibit less corrosion resistance when compared to the base material. But the composite with 0.6% GNP's shows better corrosion resistance among the three composites prepared.

3.2.5 Wear Resistance

The wear test results are shown in Figure 7. The wear test results show that there is a clear trend that with increase in the GNP's concentration there is increase in the wear of the material. With this we can come to a conclusion that

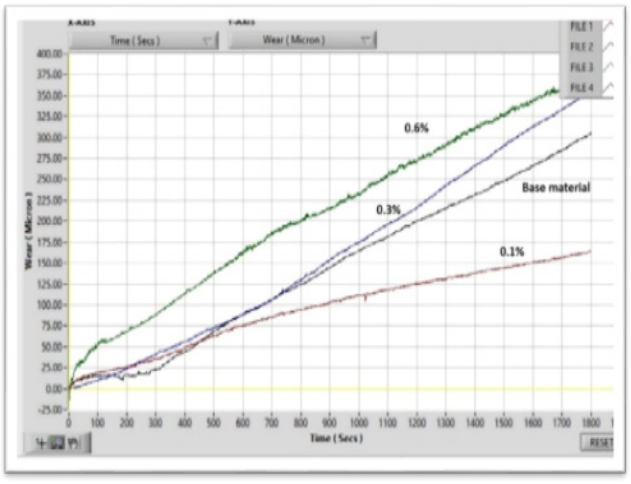


Figure 7. Graphical representation of wear test results of base material and composites.

adding GNP's to the aluminum MMC will decrease the wear of the MMC in general. But the composite with 0.1% GNP's nano particles show good wear resistance among the other two composites.

4.0 Conclusions

The following conclusions are drawn from this work.

1. Metal matrix composites were successfully prepared with AA5052 as matrix and GNP's as reinforcement with 3 proportions *viz*. 0.1%, 0.3% and 0.6% respectively.
2. The adhesion of GNP's with the aluminum matrix is less in all composites.
3. The hardness of composites is lower than the base material due to the poor bonding between the matrix and the GNP's. However, among the three composites prepared, the composite with 0.3% GNP's exhibits more hardness.
4. The tensile strength of composites is also poor compared to the base material, but the composite with 0.3% GNP's shows better strength compared to the remaining two composites.
5. The mechanical properties of the composite with 0.3% GNP's are better than the remaining two composites, and the corrosion resistance of the composite with 0.6% GNP's is better compared to the other two composites.

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