Comparison study on dry and wet sliding wear behaviour of aluminium/nano composites

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Abstract. In the present study, the dry and wet behaviour of aluminium/ Nanocomposites is evaluated using a pin on disc method under the dry and wet conditions. Aluminium/ Nanocomposites were fabricated by ultrasonic cavitation stir casting process. The wet wear test was carried out using lubricating oil SAE 20W 50. Wear behaviour of Nanocomposites was evaluated by different loading conditions such as 15N, 30N, 45N and 60N with constant sliding speed. The wear surfaces were analysed by scanning electron microscope. The test revealed that the wear rate in increased with applied load and also more wear is observed in dry condition when compared with wet condition.

1. Introduction:
Consist of more than one material is called as composite materials which are delivered more strength than the individual material [1]. The increased demand of lightweight materials with high specific strength in the aerospace and automobile industries has led to the development and use of Al alloy-based composites.

The metal matrix composites (MMCs) are slowly replacing the general light metal alloys such as aluminium alloy in different industrial applications where strength, low mass and energy savings are the most important criteria. The combination of various properties like electrical, mechanical, and even chemical can be achieved by the use of different types of reinforcements, i.e., continuous, discontinuous, short, whisker, etc., with the MMCs [2]. The MMCs are attractive materials for use in structural applications because they combine favourable mechanical properties, good wear resistance, and low thermal expansion [3].

The tribological behaviour of aluminium and aluminium alloys is not superior and few methods have been proposed in the past to improve the tribological behaviour of aluminium alloys. One method aims to reduce friction consequently deterioration of material under wear condition is applying liquid or solid lubricants. However, in some cases, such as high vacuum environment, high-speed, high applied loads, and extremely low or high temperature conditions, liquid and grease type lubricants are unfeasible [4].

Mechanical properties of composites are defined based on some of the parameters namely size, shape and percentage composition of reinforcement and matrix materials. More research work is
carried out on the carbonous materials to obtain excellent mechanical properties with reinforcing fewer amounts of carbonous materials.

In the carbonous family graphene is most attractive reinforcement material due to its young’s modulus 0.5-1 TPa and tensile strength 130 GPa [5]. The single-layered atom-thick flat belt structure as revolutionized the nanotechnology platform seems its discovery [6].

To date, several atoms have been made to synthesize graphene on a large scale to address the needs of various industries, particularly the industries which is using composites, in which the use of graphene has dramatically transformed the global market for the production of state-of-the-art composite materials. The addition of graphene to a host matrix has achieved a number of enhanced properties with promising applications in many industries, such as aerospace, electronics, energy, structural and mechanical, environmental, medicine, and food and beverage.

Graphene nanocomposites at very low loading show substantial enhancements in their multi-functional aspects, compared to conventional composites and their materials. It is not only make the materials lighter with simple processing, but also makes it stronger for various multi-functional applications [7].

Li et al [8] investigated on aluminium/graphene composites fabricated through cryomilling and it was reported that addition of 0.5 wt.% graphene nano flakes have increased the strength of composites significantly.

Perez-Bustamante [9] have reported on hardness behaviour of aluminium reinforced with graphene nano platelets synthesized by mechanical alloying with various wt.% of graphene such as 0.25, 0.5 and 1.0 wt.% dispersed by type. Three different milling duration such as 1, 3 and 5h have been considered the experimentation and it was concluded that milling time and the addition of graphene nano platelets have a positive effect on hardness values.

Zhai [10] investigated on aluminium matrix reinforced with multi-layer graphene, and it was reported that mechanical properties were increased with the addition of graphene content upto 1%. Another investigation reported that copper reinforced with GNP's strengthens the copper composites which was prepared by the combination of ball milling and hard pressing processes. During the investigation of the mechanical properties of yield strength observed was 114 MPa at 8 vol% of graphene.

Ruoff et al. have reported a pressure less sintered graphene/Al2O3 composite where, together with a mechanical property, the wear resistance needed to be improved by one order of magnitude [11]. They compared graphene oxide, reduced graphene oxide and exfoliated graphene platelets and they concluded that the last one was the more appropriate to use for the improvement of mechanical and wear properties due to the lack of defects. In terms of wear behaviour, most studies have been published using carbon nanotubes as filler.

Graphene reinforced alumina composites appear has a promising material for these types of applications taking into account that, on the one hand, and despite the fact that more studies have to be made, graphene and its derivatives seem to be bio compatible [12] and on the other hand an improvement of the mechanical properties of these ceramic composites has been observed. Fracture strength, particularly important for these types of applications, has been shown to improve up to 50% [13].

S. Venkatesan et al. [14] Investigated on aluminium matrix reinforced with nano graphene through stir casting process. They observed that the presence of graphene is most influencing parameter on tensile strength and more on hardness of aluminium alloy-graphene composite and also the presence of graphene is most influencing parameter on yield strength of the composite.

2. Experimental procedure
Aluminium alloy LM24 & Nano graphene were purchased from Parshwamani metals, Mumbai. & Adnano technologies private limited, Karnataka. Aluminium alloy LM24 is sliced into small pieces by using hydraulic hack saw machine. The proper amount of aluminium alloy LM24 is melted in the form
of liquid metal using bottom pour stir casting Process. At temperature of 680 and 850-degree Celsius and rotational speed of stirrer is 650 rpm.

Set up for bottom pour stir casting technique is displayed in figure 1. At the same time graphene is preheated at 300-degree Celsius for 1-hour period of the introduction into the melted aluminium alloy. After melting the aluminium alloy LM24 in crucible, preheated graphene was added by 6 to 7 times in molten aluminium alloy to avoid clusters formation. Mixed molten mixture was stirred at 650 rpm. For 10 minutes by mechanical stirrer. Constant temperature of furnace maintaining at 850 rpm during whole stirring and its lead to improving ceramic incorporation. Before pouring the liquid metal into the die was preheated at the temperature of 300 degree Celsius to remove the moisture content in the die and also eliminated the occurrence of casting defects and blow holes.

Pin on disc apparatus is used to determine the dry sliding wear characteristics of composite specimen (pin) size of length 20mm and diameter 10mm. Wear test were carried out for sliding distance of 3000m. (Wear test is carried out by taking the parameters like load, sliding velocity and sliding distance (or) the test is performed at varying sliding distance, sliding velocity and load for each specimen and wear and friction force were noted down. Initial weight of the specimen which is cleaned with acetone is measured using an electronic weighing machine with accuracy of 0.0001 gm. The specimen is fixed on steel disc (or) the surface of the pin samples were slides using emery paper (P1000, P1500, P2000, P2500 grit size prior to test in order to ensure effective contact of fresh and flat surface with steel disc). Samples and wear track were cleaned with acetone and weighed by electronic weighing machine with accuracy of 0.0001 gm prior to and after each test.

The wet wear test is also conducted under various loads 15N,30N,45N and 60N at a constant sliding velocity of 300rpm. There is a lesser depreciation in the sample during wet wear test by using the lubricant SAE 20 W 50.

3. Result and Discussion:

3.1. Effect of applied normal load on wear rate

In figure 1 shows the behaviour of wear rate shown in the stable area, for all experimental conditions. It was observed that independently on the parameters of the FSP process (rotation and advancing speed wear ratio observed in effect of applied load on the wear rate.

Figure 1 shows the variation of wear rate as a function of at 60N applied normal load. To dry sliding and wet sliding wear rates on wt.% and nano or composite. It observes that dry sliding wear rate. 1 wt.% of nanographene sample occurred at 3 m/s sliding speed. Dry sliding and wet sliding wear rate for 1 wt. % and nanographene at composite as showing in figure 1.

![Figure 1. Wear Rate of Al / 1% Nanographene.](image1.png)  
![Figure 2. Wear Rate of Al 1.5% Nanographene.](image2.png)

It is shown the variation of wear rate depends on various applied load (15N, 30N, 45N, 60N). The drying sliding wear test at 30N applied load decreasing and increasing. In the dry wear condition of aluminium 1wt. % nano Gr sample, the wear rate gradually increases up to an applied load of 30N and
then slightly increases up to an applied load of 30N and then gradually decreases up to 60N. At wet sliding wear test, wear rate is gradually increased when increasing applied load. But in the case of wet wear condition the wear rate of the sample gradually increases till 60N without any lag and it is also greater in wet wear condition.

3.2. Effect of applied normal load on weight loss
Fig 3 shows that Al/1% Nanographene sample the weight loss of the sample gradually increases up to an applied load of 60N for both wet and dry condition wear tests and the weight loss is more during the wet wear condition of the sample.

![Figure 3. Weight Loss of Al / 1% Nanographene.](image1)

![Figure 4. Weight Loss of Al / 1.5% Nanographene.](image2)

Figure 4 shows that Al/1.5% Nanographene sample the weight loss of the sample gradually increases up to an applied load of 60N for both wet and dry condition wear tests but it remains same at 15N load and then gradually varies. The weight loss is more during dry wear condition.

3.3. Structural analysis
Figure 5 and 6 shows that SEM images of Al/1% Nanographene composite and Al/1.5% Nanographene composite. The SEM structural analysis result it can be seen that the matrix component LM24 aluminium alloy is completely been reinforced with Nanographene to form the required aluminium Nanographene composite. Since the casting is done in aid with the stirring process the Nanographene is evenly distributed in the aluminium alloy. The preheating of Nanographene has further improved its distribution in the composite material produced since the melting point of graphene is much greater than the melting point of LM24 aluminium alloy. This uniform distribution of Nanographene results an increase in strength of the composite produced and the weight is also reduced which in turn results in increase in wear resistance in its application.

![Figure 5. SEM image for particle distribution of 1 wt.% Nanographene.](image3)

![Figure 6. SEM image for particle distribution of 1.5 wt.% Nanographene.](image4)
3.4. Wear mechanism
Figure 7 shows scanning electron microscope (SEM) images of worn specimen of Al/1wt. % Nano Gr particle defragmentation is observed along with the wear grooves could be attributed to micro ploughing. Adhesion wear rate is high and started at 15N normal load to abrasion wear after 30N load.

![Figure 7. SEM image of worn Al/1wt.% Nanographene sample at dry condition.](image1)

![Figure 8. SEM image of worn Al/1.5wt.% Nanographene sample at dry condition.](image2)

Figure 8 shows SEM images of worn specimens of Al/1.5 wt.% Nano Gr composite particle defragmentation observed less compared to as observed in figure 5. The wear grooves may again be attributed to micro ploughing. Very low adhesion wear rate to abrasion wear. Wear rate is very low due to improved hardness.

![Figure 9. SEM image for wearing track of Al/1wt.% Nanographene sample at wet condition.](image3)

![Figure 10. SEM image for wear track of Al/1.5wt.% Nanographene sample at wet condition.](image4)

Figure 9 shows that wear track of Al/1wt.% Nanographene reinforced composites at wet sliding condition. Wear start with adhesion to abrasion wear but wear debris involved in lubricant and slurry formed. Due to slurry in contact surface so wear rate increased to a maximum. Figure 10 shows that wear track of Al/1.5wt.% Nanographene reinforced composites at wet sliding condition. Very less adhesion and abrasion wear started due to improved hardness. No slurry formed in lubrication process due to less amount of abrasion takes due to influence of improved hardness. Lubrication process influence to reduce the wear rate.

4. Conclusion
LM24 aluminium alloy matrix reinforced with 1% and 1.5% Nanographene were fabricated by ultrasonic cavitation stir casting process and the wear behaviour of the composites with different load
(15N, 30N, 45N and 60N) at constant sliding velocity of 300rpm were investigated using Pin-On-Disc apparatus. From the experimental results the following conclusions can be drawn:

The stir casting technique has produced uniformly distributed reinforcement particles in LM24 aluminium alloy matrix. The addition of 1% and 1.5% Nanographene has a considerable effect on the wear resistance of the composites.

Wear rate is reduced due to improved hardness of Al-Nanographene composite with the influence of lubricant.

The experimental results show that the composites retain their wear resistance properties up to 60N at a sliding speed of 300rpm. The Nanographene particles present in the composite have reduced wear and co-efficient of friction.

This reduced wear rate and co-efficient of friction makes it suitable for its application in the areas of high friction. Thus, the reduced wear rate increases the life span of equipment which undergoes high friction contact.

5. References
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