# Enhancing the Tribological Properties of Composite Materials for Centrifugal Pump Applications

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**Abstract -** *This paper deals with the dry sliding wear, coefficient of friction of Al 2024 in the presence of graphite and hexagonal boron nitride. Aim of this paper is to compare the tribological properties of materials for plain bearings which are used in centrifugal pumps. Here four kinds of materials were taken for comparison. They are as follows. Commercially available Aluminium 2024 alloy, red brass (UNS C23000), Al 2024 reinforced with graphite (4wt. %) and Al 2024 reinforced with hexagonal boron nitride (4wt. %). The above mentioned two composites were produced by stir casting technique. The wear and frictional properties of the four different kinds of materials were established by performing the wear test using a pin-on-disc apparatus. The samples were tested at different loads and sliding velocities. Pin-on-disc apparatus was used to compare the co-efficient of friction. Pin on disc apparatus also used to compare wear resistance of the pins. The volumetric wear loss and co-efficient of friction of aluminium 2024 alloy, red brass and composites with sliding distance at loads 20 N and 30 N and sliding velocities of 0.75 m/s and 1.5 m/s are compared. Wear rate and coefficient of friction are reduced at increased loads and sliding velocities.*

***Keywords:*** **Aluminium 2024, graphite, boron nitride reinforcements, wear, frictional loss.**

## 1. INTRODUCTION

In the past few years, the demand for lighter weight materials with increased specific strength for the automotive and aerospace industries has caused the development and usage of Aluminium alloy based composites. The metal matrix composites (MMCs) are gradually replacing the general light metal alloys like aluminium alloy in different industrial applications where strength, low mass and energy savings are the most important factors. The combination of various properties such as electrical, mechanical and sometimes chemical can be obtained by using the different types of reinforcements such as continuous, discontinuous short and whiskers etc., with the MMCs [1].

Hybrid metal matrix composites (HMMCs) are called as second-generation composites. Here more than one type, shape, and sizes of reinforcements will be used to achieve better properties. Hybrid composites have better properties when compared to single reinforced composites since they include the advantages of their constituents i.e., reinforcements [2].

Adding alumina to aluminium has increased its mechanical and tribological properties. Organic reinforcement such as fly ash, coconut ash has improved the tensile and yield strength. Self-lubricating property of graphite increased the machinability of aluminium. Stir casting technique can be employed to manufacture MMCs with required properties. Using aluminium and its alloys as reinforcements with ceramics particles have marked a desirable increase in the mechanical properties. Adding alumina, SiC, B4C etc. particles in aluminium increases hardness, yield strength and tensile strength when ductility is decreased. Adding graphite with aluminium improves tensile strength and elastic modulus. In this process hardness gets lowered. It notices a decrease in friction coefficient in the tribological behaviour. Organic reinforcements such as coconut ash, rice husk ash improved the mechanical properties of the aluminium along with the tribological behaviour of the composites [3].

Aluminium alloy 2024 possesses desirable machining characteristics, higher strength and fatigue resistance when compared to aluminium 2014 and aluminium 2017. Aluminium 2024 is largely used in aircraft structures, particularly wing and fuselage structures under tension. It can also be used for high temperature applications such as automobile engines and in other rotating and reciprocating parts like piston, drive shafts, and brake rotors and in other structural parts which need light weight and high strength materials [4].

Aluminium alloys offer good mechanical and physical properties that make them important for automotive industries. They offer relatively poor resistance to seizure and galling. Adding aluminium alloys as reinforcements with solid lubricants, hard ceramic particles, short fiber and whiskers produces advanced metal-matrix composites (MMC) with accurate balances of mechanical, physical and tribological properties. Advanced manufacturing technologies like squeeze infiltration of molten alloys with fiber performs can be used to form near net-shape components. Brake rotors, pistons, connecting rods and integrally cast MMC engine blocks are some of the practically possible applications of Al MMCs in automotive industry. This paper offer an outline of the tribological behaviour of Al MMCs reinforced with hard particles, short fibers, and solid lubricants, and the technologies for producing automotive parts from these novel materials [5].

It assesses the dry sliding wear behaviour of aluminium alloy based composites which are reinforced with silicon carbide particles with solid lubricants such as graphite/antimony tri sulphide (Sb2S3). The first one of the composites (binary) consists of Al. with 20% Silicon Carbide particles (SiCp). Another composite possess SiCp and solid lubricants: Graphite + Sb2S3 (hybrid composite) at solid phase. Both the composites are manufactured through P/M route which uses "Hot powder performs forging technology". Density and hardness of the samples are checked by usual methods. The pin-on-disc dry wear tests are used to measure the tribological properties. These tests are conducted for one hour at different parameters such as load: 30, 50 and 80N and speed: 5, 7 and 9m/s. The tested samples are analysed by using scanning electron microscope (SEM) for the characterization of microstructure and tribolayer on the surface of the worn composites. The results shown that wear rate of hybrid composite is less than the wear rate of binary composite. Wear rate is lowered by increasing the load and improved when increasing speed. The results of the tested composites are compared with iron based metal matrix composites (FM01N, FM02) at respective values of test parameters. These iron based metal matrix composites can also be manufactured by P/M route using 'Hot powder perform forging technology'. This study shows that the tested composites have lower friction coefficient, less temperature rise and low noise level; however they have little higher wear rate. It is concluded that the hybrid composite has acceptable level of tribological characteristics with blacky and smooth worn surface [6].

Aluminium acts as a ubiquitous element and it can be used as trace elements which offer moderate toxic effect on living organism [7]. The important disadvantage of this type material system is that these system offer poor tribological properties. Hence the challenge in the engineering community is to produce a new material with higher wear resistance and improved tribological properties. This must be obtained without largely affecting the strength to weight ratio. This scenario caused the development of MMCs [8, 9].Adding the reinforcement considerably increases the tribological behaviour of aluminium and aluminium alloys. The thought which caused the development of hybrid metal matrix composites is to join the required better properties of aluminium, silicon carbide and fly ash. Aluminium offer good properties like improved strength, ductility, increased thermal and electrical conductivities. At the same time it should exhibit low stiffness but silicon carbide and fly ash are stiffer and stronger and offer good high temperature resistance. They are brittle materials [10].

Silicon carbide is a compound of silicon and carbon which have a chemical formula SiC. Silicon carbide was initially produced by means of a high temperature electrochemical reaction between sand and carbon. Any acids or alkalis or molten salts up to 800°C will not attack silicon carbide. In air, SiC produces a layer protecting silicon oxide coating at 1200°C and it van be applied up to 1600°C. The increased thermal conductivity joined with lower thermal expansion and improved strength causes this material exceptional thermal shock resistant qualities. Silicon carbide ceramics with little or no grain boundary impurities are used keep the strength to very high temperatures, nearing 1600°C with no loss in strength. Chemical purity, resistance to chemical attack at temperature and strength retention at higher temperatures have made this material very famous as wafer tray supports and paddles in semiconductor furnaces. It is a good abrasive and have been manufactured and made into grinding wheels and other abrasive products for above one hundred years. Today the material has been produced into a higher quality technical grade ceramic with very good mechanical characteristics. It is used in abrasives, refractories, ceramics and numerous high-performance applications [11].

The challenges and opportunities of aluminium matrix composites have been reported much better to that of its unreinforced counterpart [12]. Fly ash is used as one of the cheaper and lower density reinforcement which is obtained in bulk quantities as solid waste by-product during combustion of coal in thermal power plants. Coal Combustion Products (CCP) is produced in coal fired power stations, which burn either hard or brown coal. Due to the mineral component of coal and combustion technique, Fly Ash (FA) is produced [13]. There is a huge information on utilization of Fly Ash (FA) in building/construction, production of aggregates and more recently for agriculture [14]. In the US alone every year over 118 million tons of coal combustion products are being manufactured. In India it was about 90 million ton during 1995 and it will exceed 140 million tons by 2020. Percentage utilization of fly ash varies between nations such as 95% in Belgium and the Netherlands and 3% in India in the 1990s [15]. The usage of fly ash instead of dumping it as a waste material will be both economic and environmental platforms [16].Even though various processing methods are available for particulate or discontinuous reinforced metal matrix composites, stir casting is the method, which can be used for large quantity commercial production. This technique is most adaptable because of its simplicity, flexibility and ease of production for large sized components. Therefore stir casting technique (also called as liquid state method) is used for this study.

The purpose of this study is to compare the tribological properties of materials for plain bearings which are used in centrifugal pumps. Here four kinds of materials were taken for comparison. They are as follows. Commercially available Aluminium 2024 alloy, red brass, Al 2024 reinforced with graphite (4wt. %) and Al 2024 reinforced with hexagonal boron nitride (4wt. %). The above mentioned two composites were produced by stir casting technique. The wear and frictional properties of the four different kinds of materials were established by performing the wear test using a pin-on-disc apparatus.

### 1.1 MATERIALS

The matrix material i.e., commercially pure aluminium alloy 2024, red brass and reinforcements graphite and hexagonal boron nitride were purchased from Coimbatore metal mart, Coimbatore, Tamilnadu, India.

**Fig -1**: Graphite

**Fig -2**: Hexagonal boron nitride

## 2. EXPERIMENTAL WORK

### 2.1 Specimen Preparation

Stir casting technique is being used for the manufacture of hybrid composite materials. In this process a dispersed phase is being mixed with a molten matrix metal through mechanical stirring. The liquid composite material is then cast by using conventional casting methods and this may also be included for further processing by conventional metal forming technologies. This technology is simple and low cost. The method of stirring metal matrix composite materials in semi-solid state is called as rheo casting. Distribution of dispersed phase may be improved if the matrix is in semi – solid condition. High viscosity of the semi – solid matrix material enables better mixing of the dispersed phase. For the present work, Al 2024/Graphite, Al 2024/ hexagonal boron nitride, Composite were prepared by using stir casting technique. For this purpose, we have selected two different types of composites. Each composite consists of aluminium 2024 alloy as matrix material which occupies 96 wt. %. For each composite, reinforcement occupies 4wt. %. Graphite acts as reinforcement for one composite and boron nitride acts as reinforcement for another composite.

**Fig -3**: Stirrer


**Fig -4**: Stir Casting Machine

Aluminium 2024 have been melted by using a resistance furnace. After melting, the melt have been casted by means of a clay graphite crucible and it was degassed by purging hexachloro ethane tablets. The melt temperature has been increased up to 720°C. After that, the melt have been stirred by means of a turbine stirrer which is made by mild steel. The process of stirring has been continued for 5 to 7 min with 200 rpm as the speed of the impeller. For increasing the wettability, the melt temperature was being maintained at 700°C while adding reinforcement particles. The dispersion particles were being achieved through vortex method. The melt with reinforced particulates was poured into the desired sand casting. The pouring temperature has been kept at 700ºC. After that, the melt was allowed for solidifying in the cast.

## 2.2 Wear test

A pin- on- disc test machine have been used for investigating the dry sliding wear behaviour of the Aluminium 2024 alloy and its composites as per ASTM G99-95 standards. Hardness of the specimens are being tested by using Brinell hardness testing apparatus. The wear sample with a size of 8 mm in diameter and 32 mm in height was machined and cut from the cast samples. These specimens are then polished through metallographically. The wear tests have been performed with loads 20N and 30N at two different sliding velocities of 0.75 m/s and 1.5 m/s .This is carried out with a constant sliding distance of 1000 metres.


**Fig -5**: Pin on Disc Apparatus

Four samples have been tested for each composition. These four types include: red brass, commercially available pure aluminium 2024 alloy, aluminium 2024 composites with graphite reinforcement and with hexagonal boron nitride reinforcement. All these tests are being performed in atmospheric air i.e., at room temperature. A single pan electronic weighing machine with a least count of 0.0001 g is used to measure the initial weight of the samples pins. While performing the test, the pin is pressed against a counterpart rotating against EN32 steel disc which is having a hardness of 65HRc by applying the load. An approximately strain–gauged friction-detecting arm is used for holding and loading the pin samples vertically into a rotating steel disc which is hardened.

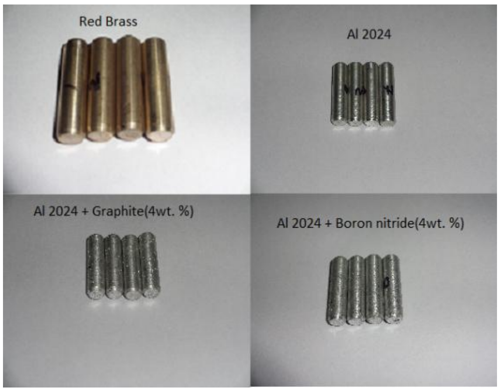


**Fig -6**: Sample Pins

The frictional traction produced because of the pin while sliding is being measured continuously through a PC-based data logging system for testing after the analysis. After running through a fixed sliding distance, the pins were removed, cleaned with acetone, dried and weighed for determining the loss in weight caused by wear. The change in the weight that was being checked before and after the test offer the wear of the sample. The wear rates are being calculated by using the weight loss technique. The wear of the four different materials are being studied as a function of the sliding velocity, load and the speed of sliding. The friction coefficients are being calculated from the friction force and normal loads. Samples that used for measuring the wear rate and coefficient of friction are shown in figure 6.

## 3. RESULTS AND DISCUSSION

Wear loss is being calculated by implementing weight loss method. The loss in weight is then converted to volume loss and then wear data is plotted as a loss in cumulative volume. This cumulative volume loss will act as a function of sliding distance. The wear rate is being determined by using the following expression.

$$W\left(\frac{mm^3}{m}\right) = \frac{\left[\dfrac{M\ (\mathrm{g})}{D\ (\mathrm{g/\,mm^3})}\right]}{Sliding\ Distance\ (\mathrm{m})}$$

Where M is the loss in mass during wear and D is the density of the corresponding composite.

Variation of wear volume loss with percentage reinforcement of composites at a sliding speed of 0.75 m/s and 1.5 m/s with a load of 20 N and 30 N is being studied. Wear of the composites gets decreased when the percentage of reinforcement is being increased. The effect of sliding distance on wear volume loss for different materials at sliding speeds 0.75 m/sec and 1.5 m/s with loads 20 N and 30 N are being studied.

## 4. CONCLUSIONS

Al 2024/4% Graphite, Al 2024/4% Hexagonal boron nitride composites have been manufactured by stir casting technique. Based on the experimental observations the following possible conclusions will be drawn:

Al 2024/4% Graphite composite will provide better dry sliding resistance than the Unreinforced Al 2024 alloy and red brass (UNS C23000). This is due to the self-lubricating characteristics of the composite. Graphite also acts as a solid lubricant.
Al 2024/4% Hexagonal boron nitride composite will provide better dry sliding resistance than the unreinforced Al 2024 alloy and red brass (UNS C23000). This is due to the self-lubricating characteristics of the composite. Hexagonal boron nitride also acts as a solid lubricant.
Weight loss is in the reinforced composites will be lesser than the unreinforced aluminium 2024 alloy and red brass.
Coefficient of friction of the composites will be lesser than the pure aluminium alloy and red brass.
The wear rate of the pure aluminium alloy and red brass will be more than that of the composites.

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