Influence of Static Radial Load on Free Vibration Response of MoS_2 and Fly Ash Reinforced Journal Bearing

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Abstract

This research is principally intended to assess the frictional characteristics and vibration study of Self-Lubricating AA2218 based composite material. Selected material has been proposed to prepare the plain bearing. Performance of the composite bearing has been tested by carrying out and the experimental outcomes are to be compared with base metal and the material used for plain bearing. From the detailed literature survey, liquid metal processing method is proposed to prepare the plain bearing. Fifteen percentage of fly ash and constant four percentage of MoS_2 added with liquid metal alloy by stirring continuously. A constructional detail of the experimental setup has been referred from the prior literatures and also reveals the power transmission systems for small scale textile industries in India. The accelerometer and Data Acquisition kit (DAQ) was configured with Lab VIEW data flow visual programming language to acquire vibration signals. Constant radial load of fifty Newton is appliedon top of the bearings with and without supply of lubrication.

Keywords: *AA2218, fly ash, MoS_2, SLAMC and Vibration*

1. Introduction

In the recent years, to reduce pollution and satisfy the environmental standards automotive and aerospace industries are focussing considerably to develop the tailor-made materials like alloys and composites. Particulates embedded with matrix alloy exhibits high strength to low weight and improved structural properties even the temperature is above 300°C with low density [1]. Scientist pay their attention on the development of Metal Matrix Composites (MMC) to overcome the recent industrial standards. These materials are well known for their outstanding characteristics, such as high modulus, stiffness, wear resistance, fatigue life, strength-to-weight ratio and custom-made co-efficient of thermal expansion [16]. With these enhancements in properties, composites are the better alternate material for replacing the conventional structural materials.

Metal matrix composites have emerged as a class of materials that can be used in structural, automotive, aerospace, thermal management, electronic and wear applications. The range of MMC applications is very large. Some of the important metal matrix composite components are used as contacts and structural materials for electrical joints, circuit breakers and printed circuits, boxes and covers, cable tracks, antennas, television covers, housing cells and windmills. In automotive engineering, the parts like automotive body, brake drum, wheel disc, bumper, radiator grill, shield, transmission shaft, suspension spring, chassis, suspension arm, casing, seat, door, silencer, ventilation housing and interior panels. In marine transports, it is used to fabricate hovercraft, patrol boat, trawler, rescue craft, ship, racing boat and canoes. In air transports, MMCs are used to manufacture the aircraft, composite glider, aileron, vertical stabilizer, propeller, transmission shaft, fan blade and disc [2]. For space transports, it is used to build rocket booster, nozzle, shield and reservoir for atmosphere re-entrance. Some of the general mechanical applications are gears, bearings, fly wheels, robot arms, jack body, weaving machine rods, pipes, tubes for offshore platforms and pneumatics for radial frames. It is widely applied in sports and recreation industries to manufacture tennis racket, squash racket, fishing pole, poles used in jumping, skis, surfboards, sails, roller skates, javelins, golf stick, golf ball, bows and arrows, helmets and bicycle frames [9].

Metal matrix composite materials have many advantages over monolithic metals, Ceramic matrix and Polymer matrix composites [2]. In the modern engineering field, there is a budding development to use solid lubricants in excess range of utilization. The solid lubricant-based composites are appropriate for appliance require enhanced hardness, wear resisting property and low coefficient of friction in the company of lesser density value. In engineering applications, most of the bearing failures are caused by improper lubrication. Excessive wear and temperature rise also reduce the life of the bearing. It is extremely hard to uphold the lubrication effect between the mating surfaces for high temperature and heavy loading conditions [3]. Applying the newer material to such areas can minimize the wear and temperature rise of plain bearings [4]. Consequently minimizes the vibration level results with increased life of the component. By considering all these things, the present research is directed to develop alternate material for plain bearing applications [10].

2. Materials

Among aluminium alloys, Al 2xxx series alloys enjoy the highest strength to weight ratio, having wide applications in the automobile and aerospace industries. 2xxx series of Al-alloys have been used extensively as a matrix material for the development of MMCs. AA2218 is applicable for high temperature application, like engine cylinder liner, piston rod and cylinder head. Also, the effect of heat treatment of particles (To improve the wettability of reinforcement particulates) on their morphology may be interesting to learn. The main alloying element is copper and the second is magnesium, which is predominantly added to increase the wetting between matrix and reinforcement. The chemical composition of AA2218 has been listed in Table 1.

Table 1. Chemical composition of AA2218

Cu	Ni	Mg	Si	Fe	Ti	Al
3.87	1.90	1.47	0.51	0.16	0.02	Bal

2. Composite Preparation

The experimental procedure for preparing the composite material based plain bearing is summarized in the form of a flow chart in Figure 1.

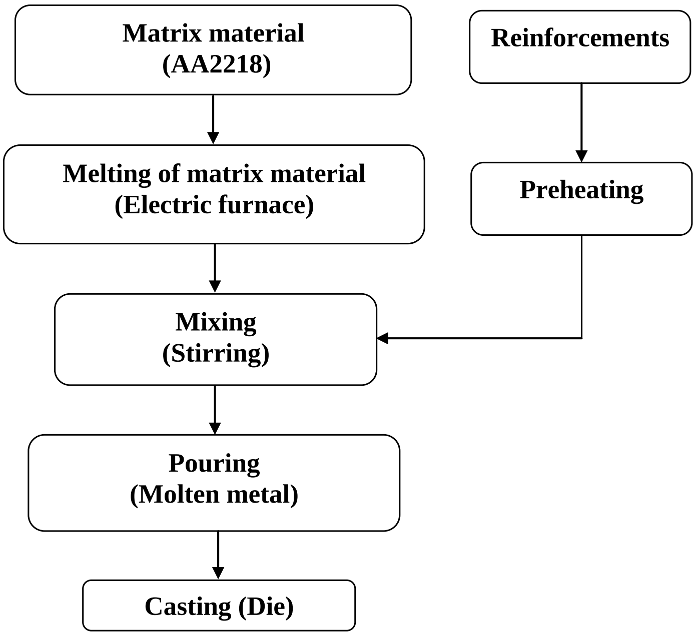

Figure 1. Steps involved in stir-cast method

Electric furnace has been used to prepare the composite specimens as shown in Figure 2. The furnace is equipped with electrical coils to produce the heat to melt the metal which is placed in the crucible. Dispersion of particles incorporated into the base alloy material is uniform [5]. Reinforcement particles and solid lubricant particles are heated to raise the temperature of four hundred degree centigrade for an hour to enhance the exterior effect.

Figure 2. Electric Furnace for Specimen Preparation

Preheated particles are mixed with matrix metal melt through the whirlpool, which was initiated through uninterrupted stirring. Stirrer has maintained to rotate about 10 min with 300 - 400 RPM to achieve correct combination with low porosity [7]. Cohesiveness characteristics of reinforcements with matrix alloy leads to reduce the bonding of matrix alloy with reinforcements [6]. To prevail over this consequence 0.5 weight percentage of magnesium metal is incorporated with the melt to achieve improved bonding with MoS_2 and Fly ash particulates [9]. Self-lubricating composite based plain bearing has been prepared with the combination of Aluminum alloy (AA2218) + Fifteen Percentage of fly ash + four percentage of Molybdenum disulfide [6]. Other two bearings are prepared with AA2218 alloy and red brass [11]. Physical properties of AA2218 alloy is listed in Table 2. Density of composites calculated using Archimedes principle and rule of mixture.

$$\rho_c = \rho_m \vartheta_m + \rho_r \vartheta_r \qquad (1)$$

Where,

ρ_c, ρ_m and ρ_r - Density of the composite, the matrix and the reinforcement (particulates) respectively.

ϑ_m, ϑ_r - Volume fraction of the matrix and the reinforcement (particulates) respectively.

In this present investigation, the density of the composite has been calculated by the rule of mixture and Archimedes principle. There is no significant difference between the experimental and calculated results. The density of Self Lubricating Metal Matrix Composites (SLMMC) is 2.71 g/cm^3 [25]. The experimental result reveals that the addition of fly ash content drastically reduces the density of the composites [8].

Table 2. Properties of AA2218 alloy

Properties	AA2218
Density (g/cm^3)	2.81
Poisson's Ratio	0.33
Ultimate Tensile Strength (MPa)	345
Tensile Yield Strength (MPa)	280
Elongation (%)	11
Hardness (Rockwell - B)	66
Melting Temperature (^oC)	502 - 638

3. Microstructure Evaluation

The micrographs of AA2218 unreinforced alloy and the developed composite materials with 15% of fly ash and a constant 4% of MoS_2 have shown in Figure 3. From the microphotograph, it has been observed that the reinforcement particulates have been distributed throughout the AA2218 matrix alloy and also shows good interfacial bonding between the matrix and reinforcement particles due to the addition of 1 % of magnesium alloy [11].

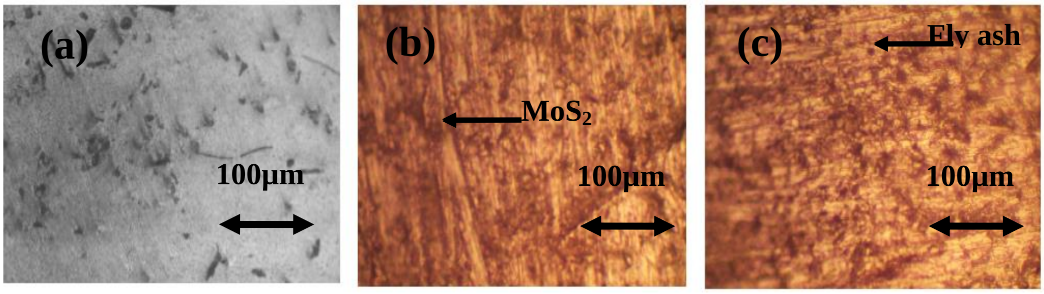

Figure 3. Micrographs of AA2218 alloy and MMCs at 100X (a) AA2218 (b) & (c) AA2218 + 15%Fly ash + 4%MoS_2

The ASTM standards of E3-95 (Preparation of Metallographic specimen) and E340-95 (Etching of metals and alloys) have been carefully followed while preparing the metallographic specimens [20]. The microscopic examination reveals that the homogenous distribution of reinforcement particulates has been observed through micrographs [12]. The matrix and reinforcement interface show considerable closure. Absence of porous and loose reinforcement particles on the specimen surface ensures the fine interfacial bonding of fly ash and solid lubricant particulates with matrix alloy [14]. The matrix shows the reinforcement particles as agglomerated, isolated and dispersed locations in the matrix. The dark grey particles are the fly ash particles. Very few of the reinforcement particles have been randomly dispersed in the matrix phase [13].

4. Fabrication of Experimental Setup

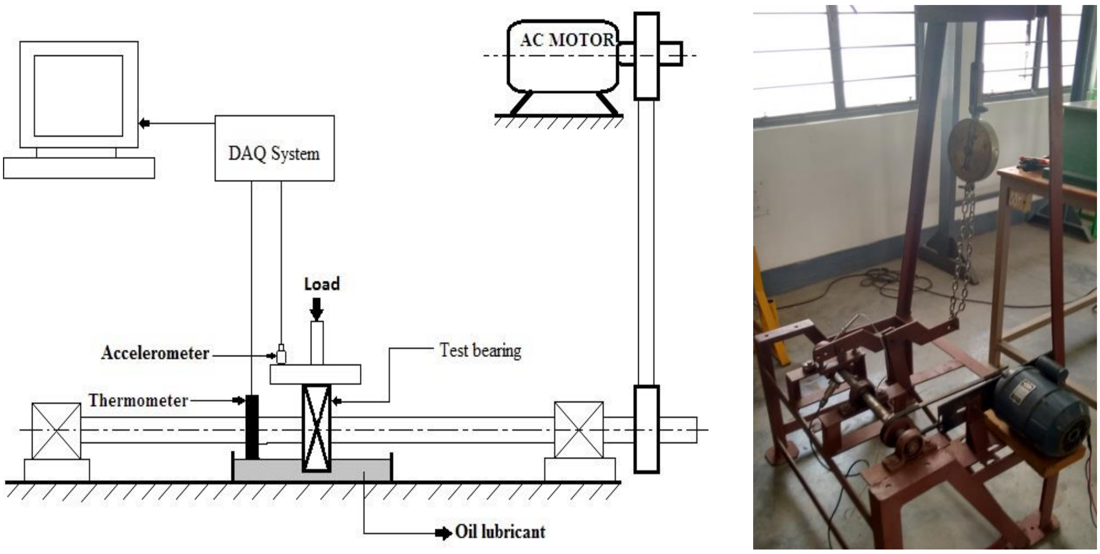

Figure 4. Experimental setup

The proposed model of the experimental setup has been prepared based on the previous literatures and it reflects the arrangements of transmission shaft in small scale textile industry [18]. Figure 4 illustrates the two-dimensional view of the proposed setup. Experimentation arrangement consists of twenty-five-millimeter diameter MS solid circular shaft driven by 240 volts, 1.5 HP Alternative Current (AC) based induction motor and the bearing is loaded by coil spring arrangements. The rotating shaft is supported by three ball bearings which are rigidly fixed to the base [15]. Plain bearing is fitted in the Plummer block, which is connected to loading arm. The outer surface of the plain bearing is rigidly fixed by means of lock pin arrangement and the shaft rotates inside the plain bearing. Bearing housing fitted with spring balance and the series connection with loading screw attachment. Accelerometer fitted on the plain bearing housing and the output of the accelerometer connected with Data Acquisition kit (DAQ). Vibration signals were recorded by the Lab VIEW software. The experiments have been carried out in the plain bearing test rig as shown in Figure 1. corresponding specifications are listed in Table 3.

Table 3. Specifications of experimental setup

Name of the Components		
Sl. No.	**Name**	**Details**
1.	DAQ kit	Model : NI-cDAQ-9172
2.	Software	LabVIEW
3.	Accelerometer	IEPE piezoelectric
4.	Thermocouple	J - Type
5.	Motor	Single phase AC induction motor

5. Experimentation

Three different material based plain bearings have been casted and machined for required size. Sliding surface of the bearings and shaft material are finished with abrasive paper. The following Figure 5 shows the three different plain bearings used for this investigation.

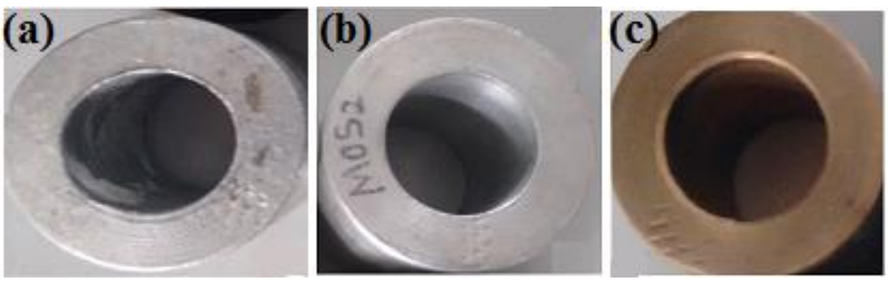

Figure 5. Specimen (a) AA2218 based plain bearing (b) MoS_2 based plain bearing and (c) Gunmetal based plain bearing

The plain bearing was fitted into the experimental setup and the radial load is applied through spring balance weighing system. According to the manufacturer's catalogue, the SAE 20-40 grade oil has been recommended for bearing operated in the selected test conditions [18]. The applied load of 50 N has been used with the purpose of obtaining the vibration response associated to different lubrication regimes in the bearing element contacts.

The tested sliding contact bearing is vertically loaded and oil lubricated. Known value of radial load is applied on the tested bearing through a spring balance attachment with a screw system. During the test run, heating of the sliding surface has been cooled by lubricant oil. A J-type thermocouple fitted in the bearing surface was used to monitor the bearing temperature during the test. Figure 6 shows the graph generated by Lab View during the test.

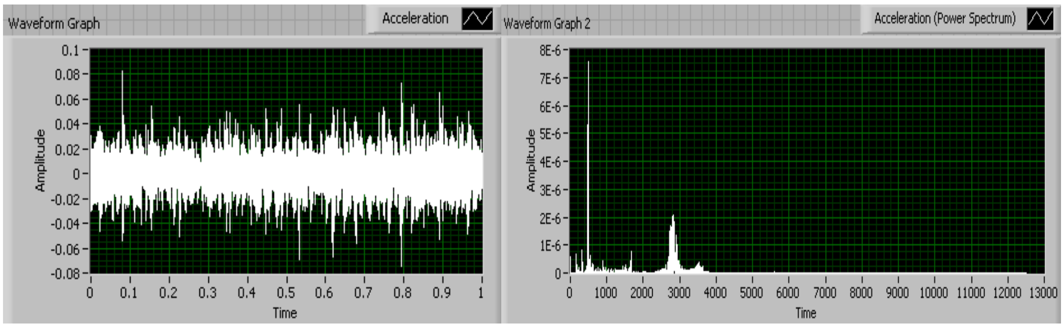

Figure 6. Vibration characteristics

Radial vibration signals of the bearing were measured by piezoelectric accelerometer which is fitted in the bearing housing. Low band pass filter has employed to measure the amplified and filtered vibration signals. Vibration signals were gained through the acquisition panel at sampling rate. In this experimentation, every obtaining signal had a number of 1, 00, 000 data, resultant to five second acquisition time. All recorded results were analysed with regard to Root Mean Square (RMS) value [19]. With the intention of verifying the consequence on the journal bearing vibration caused by increasing in bearing surface temperature, vibration signals were attained at every 15 min, during the one hour of testing at constant speed of 2000 rpm. This procedure was applied to this test with and without lubrication. Experiments were repeated several times to ensure the repeatability of results.

6. Results and Discussions

6.1 Vibration Characteristics of Bearing with and without Lubrication

The Figure 7 and 8 shows the variation of vibration signals of MoS_2 compared with Red brass and base alloy based plain bearings supplied with and without lubricating oil under the radial load of 50 N, the other plain bearings exhibits higher vibration level compared to composite bearings. A significant difference was observed in Figure 7 and 8. The plain bearings are hydro dynamically lubricated with lubricating oil and/or solid lubricants [18]. As per the manufacturer catalogue the gap between shaft and journal is maintained at a range of 0.25 to 0.5 mm. During the starting period, the shaft hits the bearing surface rapidly. Due to this effect the shaft gets deflected, the deflection of shaft results with increase in RMS value proportionate to the time. Even through the bearings are hydro dynamically lubricated, when the effective formation of tribo layer completes the RMS value of vibration get normalized.

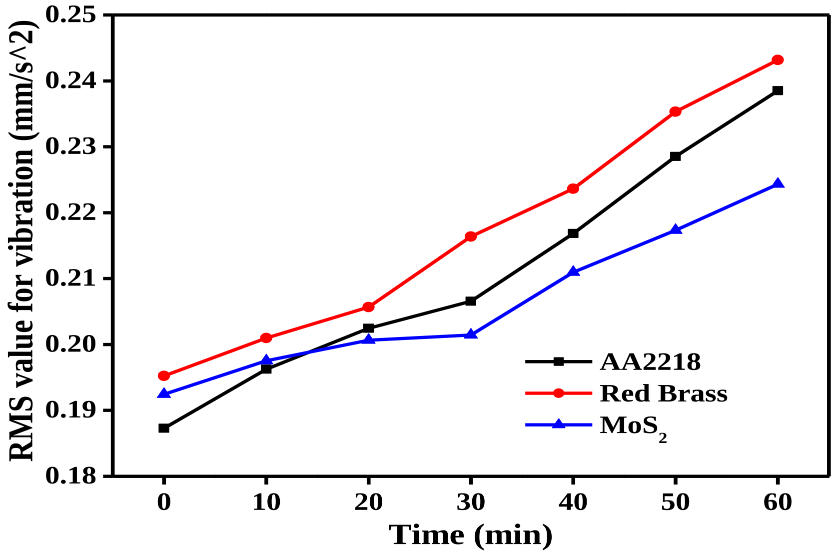

Figure 7. 50 N Load - with Lubrication

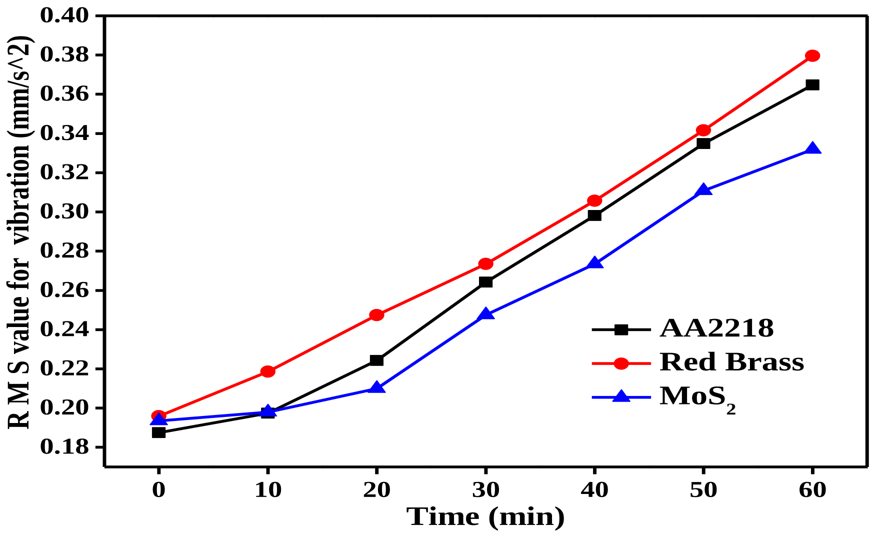

Figure 8. 50 N Load - without Lubrication

The spherical shaped fly ash particulates provide better load bearing capacity to the composites [16&17]. The similar trend was observed in the vibration characteristic curves. Enough thickness of tribo layer will reduce the RMS value by providing damping effect between the contact surfaces. In this test speed of the shaft not influencing on the RMS value of vibration. But in actual case, when the speed of shaft reaches the whirling speed then the vibration get increases rapidly. Once the speed crosses this limit then the vibration get reduces [21]. The present investigation speed and time kept at constant level. In this test composite material based plain bearings exhibits lower level of vibration than aluminium alloy and red brass based plain bearings.

6.2 Temperature rise of Bearing with and without Lubrication

As referred from the research articles and plain bearing manufacturer data, hydrodynamic lubrication of bearings tends to increase the temperature gradually. Initially heat dissipation at sliding interface is lesser than heat generation. Once the sacrificial layer separates the contact surfaces ultimately reduce the heat generation simultaneously heat dissipation by lubricant also increases [22].

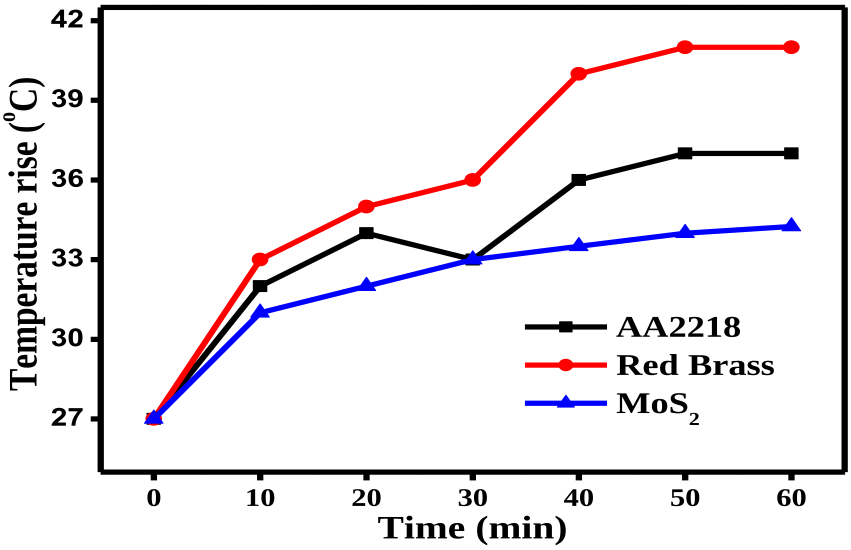

Figure 9. Temperature rise with Lubrication

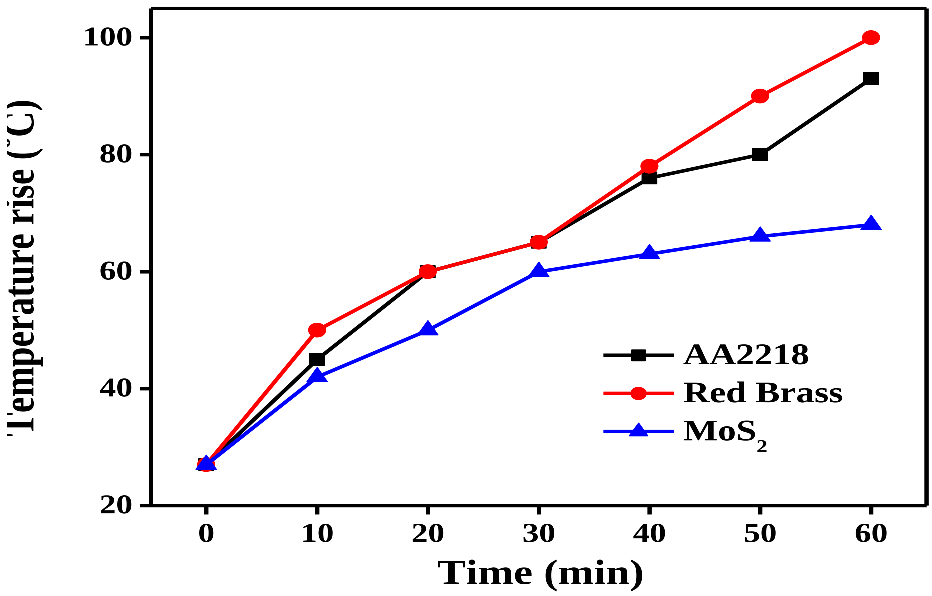

Figure 10. Temperature rise without Lubrication

The Figure 9 and 10 shows the temperature rise bearings with and without lubrication. The detailed study on plain bearing reveals that the temperature rise is initially high then the curves get normalized gradually. The maximum temperature variation between the base alloy and gunmetal, the temperature varies from 3 to 9°C (10 to 40°C for without lubrication condition). At the same testing condition, base alloy and gunmetal exhibits excessive frictional heat than the composite materials. This observation confirms the self lubrication effect of composite on sliding friction [23]. Testing of bearings without lubrication also gives the same kind of results. The performance of bearing can be validated through noise level. Without lubrication, composite bearing generate comparatively less noise than base alloy and gunmetal. Embedded solid lubricant particles generate the sacrificial film at the bearing interface. The formation of tribo layer predominantly reduces the sliding friction between the mating surfaces [24]. Comparing the results in these figures, two major interpretations have been identified. Initially temperature and RMS curves have a tendency to amplify and balanced with test time. Further, vibration intensity with lubrication supply is less significant when compared without lubrication condition.

6.3 Analysis of Wear Mechanism

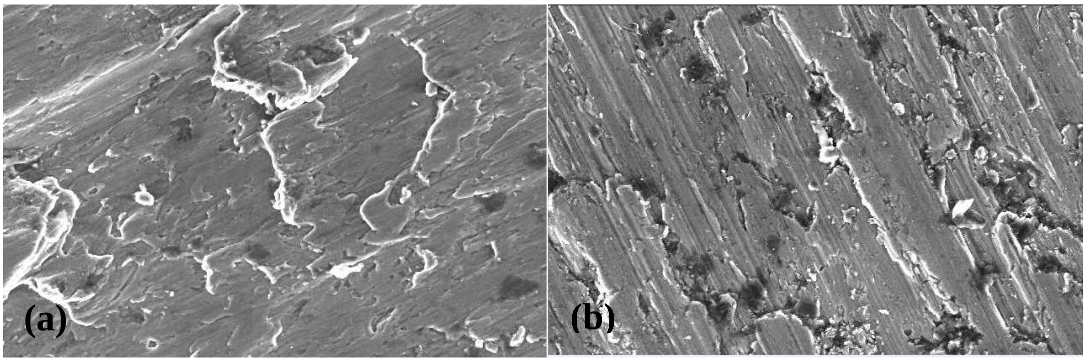

Figure 11. Micrographs of SLMMC - (a) with lubrication and (b) without Lubrication

Wear mechanism of MoS_2 and fly ash reinforced composite, tested in vibration analysis tester with and without lubrication, can be observed in the Scanning Electron Micrographs (SEM). It is noticed that the formation of oxidative layer at sliding interface of the surface. Wear debris and plowing or scratching are presents over the without lubrication surface. It is seen the presence of wear mechanism by adhesiveness on both the surfaces [3]. In with lubrication, the lubricant continuously wipeout the debris, results with absence of plowing action over the surface (a). Formation of oxidative layer at sliding interface ensures the lowest wear rates of the sliding surfaces.

6.4 Mass loss with and without Lubrication

In this study, mass loss of plain bearings has been measured by weighing the bearing before and after the one-hour test. Similar trends can be observed during the test when compared with dry sliding wear test.

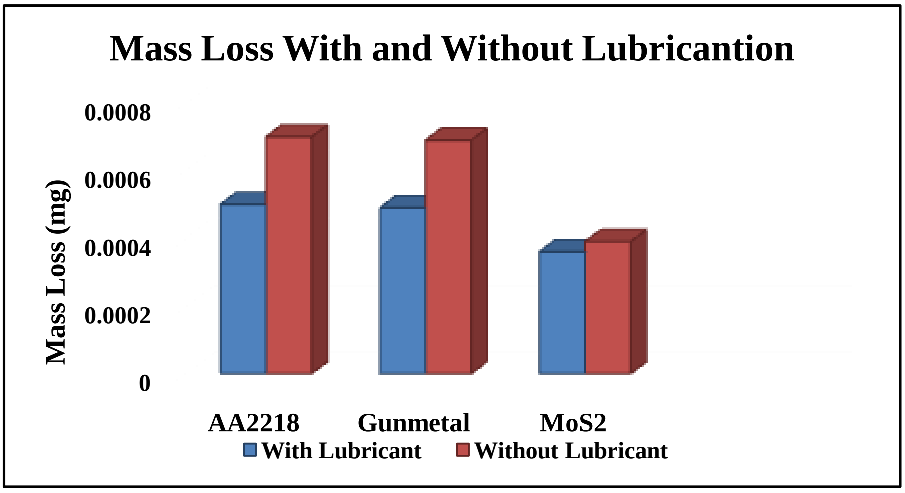

Figure 12. Mass loss with and without Lubrication

Mass loss of bearings increases with an increase in the applied load and the bearings with AA2218 and gunmetal material exhibits higher wear rate than SLMMCs. The experimental results are illustrated in Figure 12. This is because of formation of tribo layer is effective and it provides lesser friction. During the test, noise level is much higher for gunmetal bearing. From the detailed study, it was concluded that MoS_2 based plain bearing produce better results even at no supply of lubrication during the test.

7. Conclusions

The present investigation AA2218 + Fly ash + MoS_2 based SLMMC has been prepared by metal stir casting method. Vibration characteristic of the bearings have been studied in detailed way. From the exhaustive research the following observations were made:

- Spreading of less weighted fly ash particulates interested in the matrix alloy noticeably decrease the density of composites
- Composite material exhibits lesser acceleration of vibration compared with Red Brass and Matrix alloy
- Plain bearing test rig has been utilized for vibration condition monitoring analysis
- Acceleration of vibration increases proportionately with the increase in time
- Self lubricating composite material based bearings exhibit better vibration suppression compared to the matrix alloy and conventional bearing material. Furthermore, MoS_2 based composite material produce lesser RMS value
- High acceleration of vibration leads to increase in the bearing temperature and wear. Ultimately this will reduce the life period of the bearings
- Vibration signals measured from the experimentation are lies between the acceptance level referred as of International vibration severity standard ISO 2372 (10816) small machines category.
- LabVIEW software and DAQ kit have been effectively used for vibration condition monitoring analysis of the bearings made with different materials
- Dry and lubricated condition and temperature rise of the bearing have been lesser in MoS_2 based composite plain bearing specimen
- The mass loss of the bearings has been evaluated and the results are compared for the test with and without lubrication condition
- Vibration condition monitoring analysis reveals the importance of SLMMCs in engineering applications. It has been concluded that SLMMCs is the best alternative material for bearing, piston, rings, liner and other tribological applications

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