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Experimental Investigation of aluminum doping crumb rubber/epoxy composite in reciprocating motion

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***Abstract*— The experimental investigation of reciprocating motion between the aluminum doped crumb rubber /epoxy composite and the steel ball has been carried out under Reciprocating Friction Tester, TR-282 to study the wear and coefficient of frictions using different normal loads (0.4Kg, 0.7Kg and 1Kg), different frequencies (10Hz, 25Hz and 40Hz).The wear is a function of normal load, reciprocating frequency, reciprocating duration and the composition of the material. The percentage of aluminum presents in the composite changes but the other components remain the same. The four types of composites are fabricated by compression molding process having 0%, 10%, 20% and 30% Al. The effect of different parameters such as normal load, reciprocating frequency and percentage of aluminum has been studied. It is observed that the wear and coefficient of friction is influenced by the parameters. The tendency of wear goes on decreasing with the increase of normal load and it is minimum for a composite having 10%aluminum at a normal load of 0.7Kg and then goes on increasing at higher loads for all types of composite due to the adhesive nature of the composite. The coefficient of friction goes on decreasing with increasing normal loads due to the formation of thin film as an effect of heat generation with normal load.**

Keywords: Epoxy, crumb rubber, aluminum particle wear, coefficient of friction, normal load.

I. INTRODUCTION

In the rapid development of the material, epoxy resin being a thermosetting polymer has been widely used industrially in many applications due to their good mechanical and tribological properties, light weight, cost effective and attractive. But the epoxy resin is very brittle because of its highly cross-linked structure, and exhibits very poor resistance to impact and crack initiation. Hence many efforts have been made to improve the fracture toughness of the epoxy. The epoxy resin is toughening by addition of second phase polymeric particles, such as rubbers [1].

Due to higher stiffness, higher strength, enough toughness, the composite is used industrially in the following applications such as piston ring, gears, transmission belts, grinding mills, clutches, cams etc.where their self-lubricating properties are used to avoid oil or grease lubrication [2].Therefore the tribological nature of material is to be studied to enhance its use. Several researchers observed that the friction force and wear rate depend on roughness of the rubbing surfaces, relative motion, type of material, temperature, normal force, stick slip, relative humidity, lubrication and vibration [3-5]. But limited studies have been conducted on the friction and wear behavior of the said composites. Hooke et.al [6] and Pihtili and Tosun [7] observed that wear behavior of polymer and its composites depends on the applied normal load. Santner, E., and Czichos. H [8], Anderson, J. C [9] and Unal, H. et.al [10] observed that the friction coefficient of polymers and its composites decreases with the increase in normal load. But Stuart, B. H. [11], Unal. H and Mimaroglu, A [12] and SureshaB.et.al [13] observed that value of friction coefficient increases with the increase in load. Mimaroglu, A.et.al [14] was also observed that the coefficient of friction decreases linearly with the increase in applied pressure values. Hence there is a contradiction amongst the results observed. Therefore these studies encouraged me to further study the variation of coefficient of friction with normal load of the polymer and its composites.

On the other hand wear behavior of the polymer and its composites depends on the reinforcement of the polymer. Tsukizoe and Ohmae [15] observed that reinforcement of polymeric material improve the tribological behavior.

Y. M. Pan.et.al [16], S. V. Prasad.et.al [17] and K. S. Al-Rubaie.et.al [18] observed that the addition of hard particles to the matrix of a composite material influences the wear properties. The hard particles such as Al2O3, SiC, TiC, etc., in the matrices of composite materials reduce the wear loss. The aluminum/polymer composites become effective materials for a wide range of industrial applications due to the combination of properties such as low density, corrosion resistance, thermal stability, and ease of fabrication. But little study has been conducted with aluminum as hard particle in the epoxy/ rubber composites. A. P. Sannino. et.al [19] and R. K. Uyyuru.et.al [20] indicated that the wear rate of Al2O3 reinforced composites decreases as the particle size increases from 5 μm to142 μm at a fixed volume fraction. S. Suresha.et.al [21], M. Gupta.et.al [22] and S. Venkatprasad et.al [23] suggest that hybrid reinforcements enhance the properties of the composite than a single reinforcement.Asif et.al [24] also observed that the wear rate of the hybrid composite was lower than that of the binary composite.H.J. Kim.et.al [25] studied that the polymer and its composites are improved by the surface treatment of aluminum powders. From the above studies it is concluded that the addition of aluminum particles to the rubber epoxy composite is to be studied further to develop the tribological properties of the composite. H.B. Takallou & M.B. Takallou [26] and N, N. Eldin [27] studied that the use of crumb rubber, obtained from scrap tires is used to form composite material with asphalt, concrete etc. and thereby reducing the problem of storing the scrap tire. Hence it may be used in the composite instead of natural rubber to reduce the cost as well as to control the pollution due to storing.

Therefore, the present study is to investigate the effect of aluminum particle in the composite on the wear and coefficient of friction due to reciprocating force under the parameters of reciprocating time, reciprocating frequency, normal load and percentage of aluminum.

II. EXPERIMENTAL WORKS

A. Material

Crumb rubber having mesh size 20-22 is used with Al particle of diameter 75µm.The matrix is composed of epoxy resin (ARALDITE CY 205 IN) having density 1.27 gm/cc and curing hardener (HY 951).Both are supplied by Huntsman Advanced Material (India) Pvt. Ltd.

B. Fabrication of Composite

Crumb rubber has been reinforced in epoxy resin based matrix system. Crumb rubber, aluminum and epoxy resin composite is fabricated in the following steps.

The quantity of epoxy is calculated on the basis of the mould volume so as to ascertain the constant weight of the fabricated composite. The ratio of the crumb rubber and epoxy resin remains the same, but the ratio of aluminum particles varies for different composites.220gms of Crumb rubber is taken in a tray.

In the 1st sample aluminum particle is not taken. The ratio of constituents in the 2nd Sample, Crumb rubber: Epoxy: Aluminum =10:10:1, in the 3nd Sample, Crumb rubber: Epoxy: Aluminum =10:10:2. In the 4th Sample, Crumb rubber: Epoxy: Aluminum =10:10:3.

The required quantity of aluminum particle is mixed with the crumb rubber. The required quantity of epoxy resin (ARALDITE CY 205 IN) having density 1.27gm/cc is taken in a glass container. Hardener (HY 951) is added to the epoxy in the ratio by weight (epoxy resin: hardener=10:1) and the mixture is starred for about ten minutes to ensure proper mixing and exothermic reaction is just to start. The epoxy resin, hardener mixture is added to the crumb rubber, aluminum particle mixture and starred mechanically to obtained homogeneous mixture. The high speed steel mould is fabricated according to the requirement to avoid bending during the compression. The dimension of mould is 150mmx100mmx3mm.A very thin scratch free plastic film of few microns is cut according to the inner dimension of the mould and stick to both the inner top and bottom parts of the mould. This film is used instead of releasing agent in order to prevent the possibility of infusion of releasing agent to the homogeneous mixture. The homogeneous mixture is then taken to the mould and the cover plate is placed on it. Then the mould is compressed by a hydraulic press at a pressure of 1.0MPa and is kept for 48 hours at room temperature. Due to compression, entrapped air bubbles are removed completely with the homogeneous mixture. After removing from the mould, post curing is done at room temperature for next 48 hours to complete the composite fabrication. Four different samples are formed in the same way.

Specimens of required dimensions are cut by a cutter in a specially designed machine. Samples of final dimension are obtained by hacksaw, flat file and sand paper.

C. *Test procedure*

Reciprocating test of the sample is carried out in a friction tester, TR-282, DUCUM, to determine the friction behavior in dry condition at different frequencies and loads. The test duration, normal load and reciprocating frequency are selected during the experiment.

A circular sample of 10mm diameter and 3mm thickness was prepared from fabricated material as per specification of the sample. The flat surface of the sample comes in contact with the steel ball as counter face. The surface of both the sample and the steel ball are cleaned with the soft paper soaked with acetone before the test. The test samples are weighed before test using Electronic balance (0.1mg accuracy).The weighted sample are placed in the specified position of the test machine. The normal load is applied to the ball. The ball having 6mm diameter, material: AISIE-52100 steel, hardness 58-66 HR_c, $R_a < 0.05$mm, is kept on the test sample in such a way so as to ensure point contact.

The test was carried out with normal loads (0.4Kg, 0.7Kg and 1.0Kg) with duration of test 20minutes at frequencies 10Hz, 25Hz, and 40Hz, with a fixed reciprocating stroke length of 1mm.The test is stopped after 20 minutes using the timer mechanism of the testing machine. The weight of the sample after completion of the test is taken in the same balance after cleaning with soft paper. The difference between the initial and final weights measures the reciprocating wear loss. At least four trials were conducted at each condition of test. The friction force, coefficient of friction between the ball and specimen was recorded in the computer. The reciprocating friction in dry condition at different normal loads and frequencies gives the information about the material properties. This arrangement reduces the topography modification effect due to polymer transfer, keeping the steel-polymer interface almost unchanged.

III. RESULTS AND DISCUSSION

A. *Effect of reciprocating duration on coefficient of friction*

In this work, variation of coefficient of friction with reciprocating time at constant reciprocating frequency for different loads and percentage of aluminum has been studied. The coefficient of friction varies with reciprocating time for different normal loads 0.4Kg, 0.7Kg and 1.0Kg at a constant frequency of 25Hz for different percentage of Al in the Fig.1 (a), Fig.1 (b), Fig.1(c) respectively.

From Fig.1 (a), it is observed that the coefficient of friction goes on increasing and reaches a maximum value after a few minutes and then goes on decreasing for few minutes and becomes stable till the end of the operation. The use of different compositions causes the composites to have a micro structural homogeneity, a greater porosity and a poor interfacial bonding between the matrix and the aluminum particles[28]Fig.1(b) shows the variation of coefficient of friction with respect to reciprocating time at different loads with increased percentage of aluminum. The same trend is observed as before.Fig.1(c) shows the same trend as observed for 10%Al and 20%Al. From Fig.1 (a), Fig.1 (b), Fig.1(c), it is observed that with the increase of normal loads, the coefficient of friction for all percentage of aluminum and for the loads 0.7Kg and 1.0Kg, the coefficient of friction becomes stable after few minutes of decreasing the of coefficient of friction i.e. less time is required to become stable for all the samples. K.M.Shorowodi, A.S.M.A. Haseeb indicates a reduction in the value of the friction coefficient for the metal matrix composites when aluminum particles are incorporated owing to a higher hardness of aluminum particles [29].

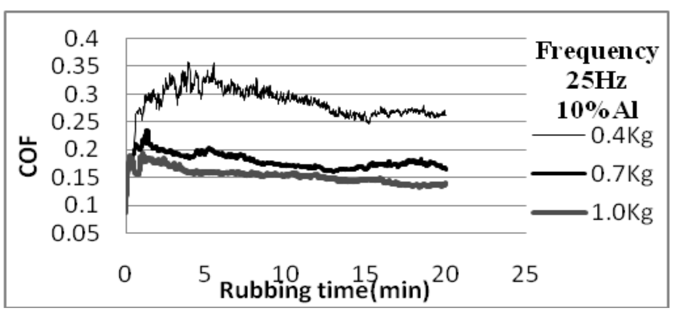

Fig.1(a)

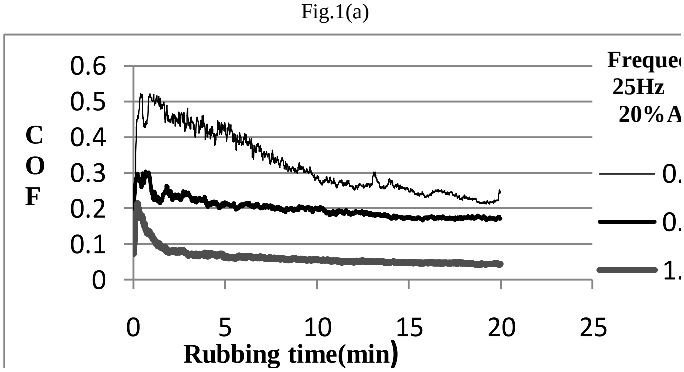

Fig.1(b)

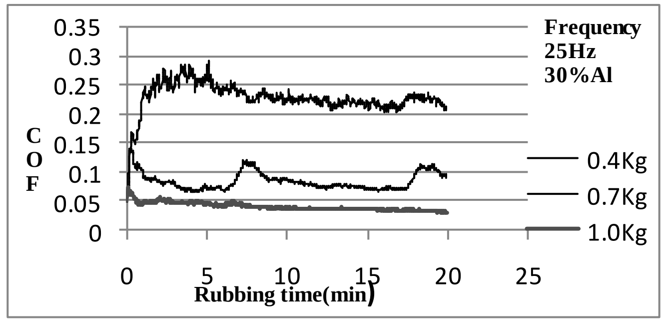

Fig.1(c)

Fig.1 Coefficient of friction as a function of reciprocating time at different loads and constant reciprocating frequency 25Hz (a)10%Aluminum,(b) 20% Aluminum and (c) 30%Aluminum.

B. *Effect of reciprocating frequency on coefficient of friction and wear*

The variation of coefficient of friction and wear loss with reciprocating frequency at constant normal load but different percentage of aluminum has been studied in this section. Fig.2 (a) shows the variation of coefficient of friction with reciprocating frequency at different percentage of aluminum at constant normal load.D.M.Nuruzzaman et.al,and Y.M.Pan et.al observed that coefficient of friction increases with increases of reciprocating frequency, after that it goes on decreasing [30] [31].H.Unal,U.sen and A.Mimaroglu studied that with the increase of reciprocating frequency, heat is generated at the contact surface and thereby increased adhesion with the steel ball[32].Coefficient of friction is minimum for 30%Al and maximum for 10%Al.From Fig.2(b) it is observed that variation of wear with reciprocating frequency at constant load is different for different percentage of aluminum. With the increase of reciprocating frequency wear loss increases for composites having 10% Al and 30%Al.and then decreases linearly. But wear decreases slowly for the composite having 20% Al. The higher wear rate at the initial stage was due to the adhesive nature of the sample during reciprocating motion and S.K.Chaudhury et.al also studied that phenomena [28].The probable reason for reducing the wear rate with the increase of reciprocating frequency is that the surface of the composite smoothens after 25Hz.

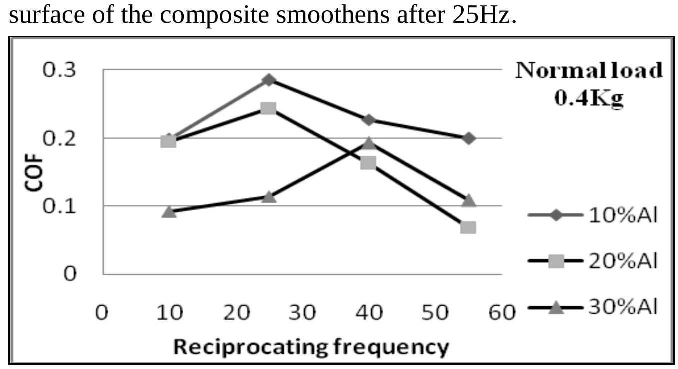

Fig.2 (a)

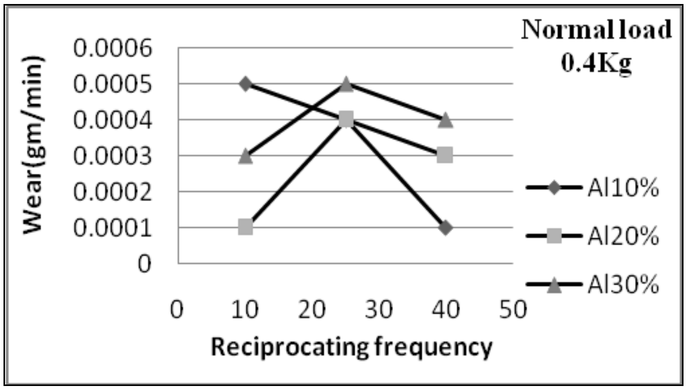

Fig.2 (b)

Fig.2 (a) Coefficient of friction as a function of reciprocating frequency at normal load 0.4Kg for different percentage of Al. (b) Wear as a function of reciprocating frequency at normal load 0.4Kg for different percentage of Al.

C. *Effect of normal load on coefficient of friction and wear*

The variation of coefficient of friction and wear with the normal load at constant frequency 25Hz for composites having different percentage of aluminum has been studied in this section.Fig.3(a) shows coefficient of friction decreases with increase of normal load at constant reciprocating frequency for all samples. The reason may be the formation of thin film due to plastic deformation of the matrix as an effect of heat generation due to increase of normal loads and P.V.Vasconccloset.al also studied that.[33].Fig.3(b) shows that wear rate decreases with the increasing of normal load at constant reciprocating frequency. The wear of the composites having 30% Al at 0.4Kg is more but it is less for 10%Al and 20%Al.The wear rate starts increasing at normal load of 0.7Kg.It is minimum at 0.7Kg.The reason is that the composite surface becomes hard due to the present of aluminum particles on the surface and are well dispersed which trends to form agglomerates and W. Brostow et.al also observed the same result. [34].The wears increase due to the adhesive nature of the composite. Wear rate is minimum for 10%Al.

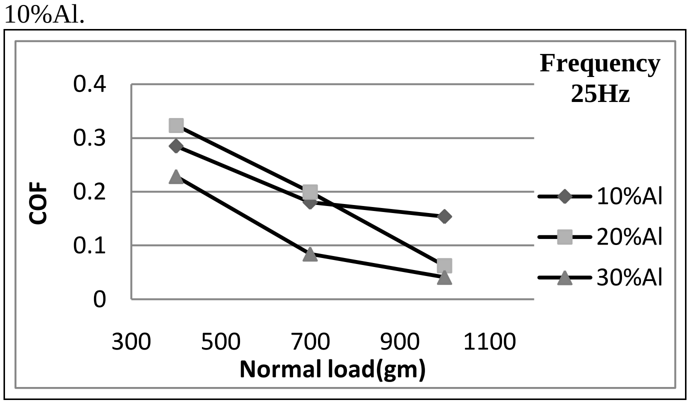

Fig.3 (a)

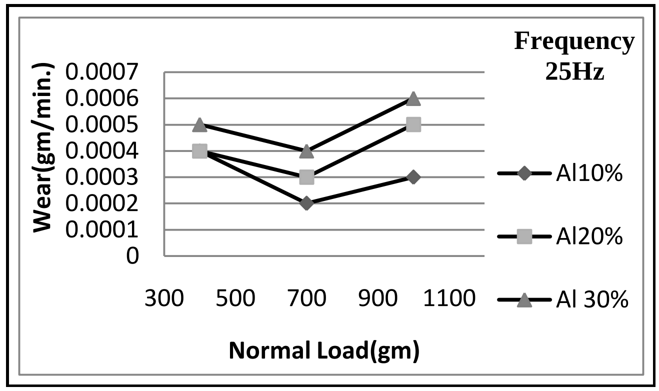

Fig.3 (b)

Fig.3 (a) Coefficient of friction as a function of normal load, for reciprocating frequency 25Hz and different percentage of Aluminum (b) Wear as a function of normal load, for reciprocating frequency 25Hz and different percentage of Aluminum.

D. *Effect of percentage of aluminum on wear rate at constant reciprocating frequency for different normal load*

From fig.4(a) andfig.4(b), the wear rate is maximum for the composite having 0%aluminum. With the addition of aluminum particles, the wear rate goes on decreasing up to 10%aluminum for different normal loads. After that it goes on increasing. Hence the wear rate decreases with the particulate reinforcement. The probable reason is the decrease of material integrity.

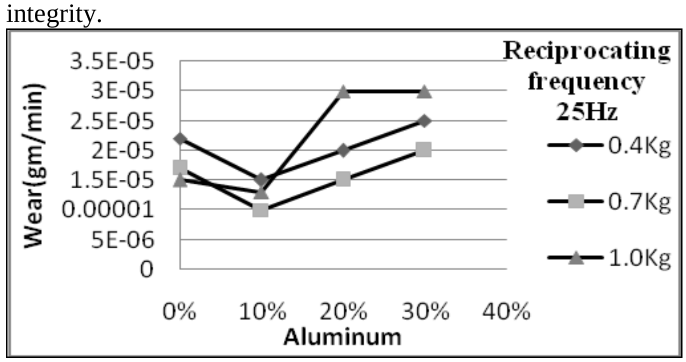

Fig.4 (a).

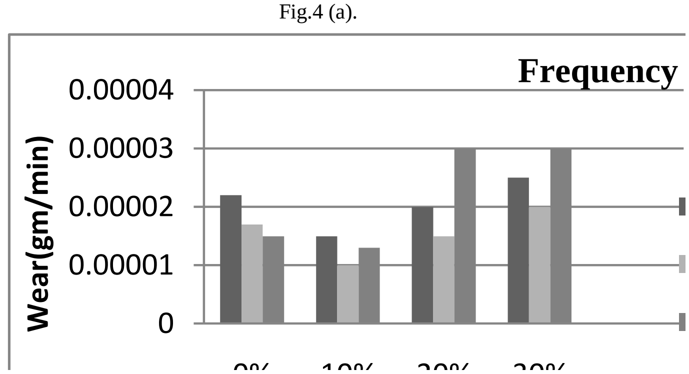

Fig 4(b)

Fig 4(a) and Fig 4(b): Wear as a function of percentage of aluminum, for reciprocating frequency 25Hz and different normal loads.

IV CONCLUSION

The following inferences are obtained from the above study:

- The coefficient of friction decreases with the reciprocating time for different normal loads and for different percentage of aluminum due to the higher hardness of the aluminum.
- The coefficient of friction and wear change with reciprocating frequency as the surface smoothens after 25Hz.
- The coefficient of friction and wear change with the normal loads. Wear is minimum for the composite having 10% aluminum and at 0.7Kg of normal load. Wear loss increases with more percentage of aluminum in the composite though composite becomes harder with the more percentage of hard aluminum particles.
- Wear is maximum at 0% Al and it decreases with the increase of aluminum particles. But wear is minimum at 10% aluminum for all normal loads. The probable reason is the decrease of material integrity. J. Marsh et.al observed that the cohesion depends basically on the aluminum/resign interface resistance [35].

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