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Dry Sliding Wear Behavior of Epoxy-Rubber Dust Composites

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***Abstract*—**Composite pins of rubber dust collected from tyre retreading centres of trucks, cars and buses etc.and epoxy with weight percentages of 10. 15, and 20 % of rubber (weight fractions of 9, 13 and 17 % respectively) have been prepared in house with the help of a split wooden mould. The pins were tested in a pin-on-disc wear monitor to determine the co-efficient of friction and weight losses with varying speeds, loads and time. The wear volume and wear rates have also been found out for all these three specimens.. It is observed that all the specimens have exhibited very low coefficient of friction and low wear rates under dry sliding condition. Out of the above three samples tested, the specimen with 10 % rubber dust by weight has shown lowest wear rates. However a peculiar result i.e decreasing trend has been obtained with 20% reinforcement of rubber in epoxy while rubbed against steel at varying speeds. This might have occurred due to high surface finish of the disc and formation of a thin transfer layer from the composite

***Keywords*—**epoxy, rubber dust, composites, weight fractions, pin-on-disc wear tests, wear volume and wear rate calculations.

I. INTRODUCTION

AMONG the waste materials, in highly industrialized regions, the waste automotive material represents one of the most problematic area to be addressed. This is due to the increasing demand of new products and the shortness in the life of many components, such as the tyres or the brake pads. Therefore, by only considering the waste coming from the short-lived component of cars, trucks or buses etc., it is possible to have an idea of how large this problem is. The grinding of brake pads to obtain the desired thickness, for instance, gives rise to an enormous amount of an expensive waste material. On the other hand, grinding is a fundamental step in the production of brake pads. Therefore investigation is going on in the possibility of using a waste brake-pad powder or tyre retreaded dust as fillers in a polyester matrix to enable the production of low cost composites. The recycling of this dust can lead to a decrease in environmental pollution. Moreover, the resulting composite can be considered an inexpensive structural material or a low performance friction material for bike brake pads or friction elements of small engines.

In this investigation an attempt has been made to develop a composite material using throw away tyre (cars, trucks and buses etc.) rubber dust with epoxy resin (the rubber dust is used as a reinforcement material and epoxy resin as matrix material). Rubber, because of its elasticity is in many respects a unique material, involving properties markedly different from those of low – molecular– weight solids. Epoxy resin is used to make articles with better mechanical strength. The frictional analysis of this new product will give the characteristics & the efficient usable properties of the composite in engineering field. It is clear that there are many literatures dealing with the composite materials but limited literatures investigated the rubber composites prepared as stated above. Therefore this paper is concentrated on studying the friction and wear behavior of rubber -epoxy composites. It is recognized that rubber has many excellent mechanical properties in comparison to other materials. These include impact resistance, flexibility, abrasion resistance and resistance to degradation, properties that point to crumbed rubber (produced from discarded tyres) having the potential to be a great engineering material available abundantly from waste tyres. Applications of composites includes areas such as shoe soles, automotive components, tyres, non-pneumatic tyres, wheels, building products (roofing materials, insulating materials, window gaskets) coating/sealants, containers for hazardous waste, industrial products (enclosures, conveyor belts etc) and many more.

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II. REVIEW OF LITERATURE

Cardwell, B. J.,et al.[1] conducted three-point bend fracture toughness tests at various loading rates and temperatures on both rubber-modified and unmodified epoxy specimens. Using time-temperature superposition, apparent activation energy was determined by shifting the fracture toughness data along the rate axis for each temperature tested. Surprisingly, this apparent activation energy calculated for the rubber-modified epoxy was found to be within 2% of the value of the activation energy determined for the [beta] relaxation peak found from small strain d.m.a. measurements of the unmodified epoxy matrix. Since shear yielding is the primary mechanism by which this epoxy system is toughened, it can be hypothesized that the [beta] relaxation may significantly influence the kinetics of yielding and consequently the fracture toughness of the material.

The fracture toughness and uniaxial tensile yield strengths of unmodified and CTBN-rubber-modified epoxies were measured by Li, D., et al [2]. under hydrostatic pressure. The purpose of these experiments was to learn how suppressing cavitation in rubber particles affects the deformation mechanisms and the fracture toughness of rubber-modified epoxy. It was found that the cavitation of CTBN-rubber could be suppressed at a relatively low pressure (between 30 and 38 MPa). With cavitation suppressed, the rubber particles were unable to induce massive shear yielding in the epoxy matrix, and the fracture toughness of the rubber-modified epoxy was no higher than that of the unmodified epoxy in the pressure range studied.

The influence of sliding velocity and nominal pressure on the tribological behaviour of epoxy resin-inox steel couples is analyzed by Bassani et al.[3] in dry sliding conditions, on a pin-disc configuration. The patterns observed for the friction coefficient, wear coefficient and estimated surface temperature have been correlated to the surface morphology of both pin and disc as results from SEM analysis and profilometric traces, and a preliminary explanation of the contact process is proposed. Fatigue wear (the prevalent mechanism) and adhesive wear appear strongly influenced by the combined action of sliding velocity (affecting interface dynamics and deformation mode) and nominal pressure (which controls interfacial stress). Differences in the action of the two variables apparently result from the particular thermal state induced in the polymer, as well as from the quantity and the morphology of wear debris.

The influence of polysulfide and carboxylated butadine rubbers on the mechanical characteristics of epoxy-rubber adhesives was studied by Yu.S. Kochergin, et al. [4]. The optimal concentration of rubber was determined and the technology of compounding carboxylated rubbers and an epoxy oligomer was described. The character of changes in stress-strain characteristics for bulk specimens and films prepared on the basis of modified and unmodified epoxy oligomers was determined. The properties of a new cold-setting epoxy-rubber adhesive with an improved self life , good stress-strain and dielectric characteristics were presented

An investigation on the effect of epoxidation and maleated natural rubber (MNR) on fatigue and rubber-filler interaction properties of paper sludge filled natural rubber composites was elucidated by Ismail, H.,et al.[5]. Paper sludge loading was varied from 0 to 40 phr and conventional vulcanisation system was used while compounding was carried out on a laboratory sized two roll mill. Two different types of natural rubber, SMR L and ENR 50 having 0 and 50 mole% of epoxidation were used in order to investigate the effect of epoxidation on the composites. Results indicate that, at a fixed filler loading, ENR 50 vulcanizates exhibit higher fatigue life than SMR L vulcanizates especially at filler loading below 20 phr which might be associated with better rubber-filler interaction. In the case of composites with the addition of maleated natural rubber (MNR), a higher fatigue life was observed due to presence of physical and/or chemical linkages, which increases the interfacial adhesion.

Oil palm fibres were used Sreekala, M.S., et al.[6]. as reinforcement in phenol formaldehyde resin. In order to improve the interfacial properties, the fibres were subjected to different chemical modifications such as mercerisation, acrylonitrile grafting, acrylation, latex coating, permanganate treatment, acetylation, and peroxide treatment. The effect of fibre coating on the interface properties has also been investigated. Morphological and structural changes of the fibres were investigated using scanning electron microscopy and IR spectroscopy. The incorporation of the modified fibres resulted in composites having excellent impact resistance. Fibre coating enhanced the impact strength of untreated composite by a factor of four.

Polymeric matrix composites were prepared by Lucignano et al. [7].by mixing a tribological dust in a polyester resin. The dust resulted from the fabrication process of friction products and was initially destined for disposal. Composite specimens were fabricated with different dust content (up to 70 wt%) and cured in an oven at 808 ^{0}C for 30 min. Flexure tests and dynamic mechanical analysis (DMA) were carried out together with pin-on-disc tests to quantify mechanical and tribological performances. Flexural modulus and strength generally increased by increasing the filler content as well as the friction coefficient. At the highest values (60–70 wt%), mechanical and tribological properties were damaged by the dust clustering during mixing.

Ganguly and George [8] have synthesized an asbestos free friction material composite for brake linings containing fibrous reinforcing constituents, friction imparting and controlling additives, elastomeric additives, fire retarding components and a thermosetting resin. The composite shows exemplary friction characteristics and has great resistance to wear and shows good temperature stability.

The friction coefficient of rubber sliding against different types of flooring materials of different surface roughness was investigated by El-Sherbiny et al [9] under different sliding conditions: dry, water, water/detergent dilution, oil, water/oil dilution. The flooring materials are parquet, polyvinyl chloride (PVC), epoxy, marble, cement and ceramic. Based on the experiments, it was found out that at dry sliding, friction coefficient decreased with increasing surface roughness. Epoxy displayed relatively higher friction than parquet and PVC, while cement tiles gave the highest friction coefficient. Ceramic showed relatively lower friction values than marble and cement. In the presence of water on the sliding surface, friction coefficient slightly increased up to maximum then decreased with increasing surface roughness. Parquet displayed the highest friction coefficient followed by PVC and epoxy. At higher roughness marble tiles gave the highest friction. Ceramic showed the lowest friction among the tested floorings. Sliding of rubber against water/detergent wetted tiles caused drastic decrease of friction coefficient. Parquet displayed the highest friction values followed by cement and marble. PVC, epoxy and ceramic represented relatively lower friction values. At oil lubricated sliding of flooring materials, friction coefficient slightly increased up to maximum then decreased with increasing surface roughness of the flooring materials.

III. SCOPE

From the above review, it is clear that Rubber-epoxy composite development and its application in the field of automotives especially in the brake pad application is an ongoing process. Looking at its future prospects in above mentioned field it is decided to have an analysis of wear and friction characteristics satisfying the following conditions:

i. Developing a polymer composite of rubber dust with epoxy resin in various volume fractions.
ii. Proper manufacturing of the pin by moulding to be tested in pin-on-disc wear monitor.
iii. Different samples of specimens are to be tested in a pin-on-disc machine sliding against a mild steel friction disc and determining the wear characteristics by varying load, time, sliding speed and sliding distances etc.
iv. Finally selection of the best sample out of the results obtained.

IV. THEORETICAL CALCULATIONS

The composite is usually prepared based on calculation of weight fractions or Volume fractions. The density of the composite is found out by rule of mixtures.

Weight fraction of the reinforcement: $w_r = W_r / (W_r + W_m)$ *100, Weight fraction of the matrix:

$w_m = W_m/(W_r + W_m)$*100 where W_r = Weight of reinforcement, W_m = Weight of matrix,

Weight of the composite = $W_c = W_r + W_m$ Further as per rule of mixtures, the density of the composite is obtained by $\rho_c = \rho_m v_m + \rho_r v_r$ where ρ_c = Density of the composite, ρ_m = Density of the matrix, ρ_r = Density of the reinforcement, v_m = Volume fraction of the matrix, v_r = Volume fraction of the reinforcement .Further $v_m = V_m / (V_m + V_r + V_v)$*100, $v_r = V_r / (V_m + V_r + V_v)$*100

Volume of the composite = $V_c = V_m + V_r + V_v$, Where ,V_m = Volume of the matrix, V_r = Volume of the reinforcement and V_v = Volume of voids.

TABLE I PROPERTIES OF RUBBER

Properties	Value
Durometer range	40-100
Density	0.9×10^3 Kg/m^3
Specific gravity	0.94
Low temperature limit	0˚ to 50˚F
High temperature limit	158˚ to 225˚F

TABLE II PROPERTIES OF EPOXY

Properties	Value
Density	1.2×10^3 Kg/m^3
Specific gravity	1.18
Young's modulus	3.5 Gpa

TABLE III WEIGHT/VOLUME FRACTIONS OF COMPOSITE

Specimen	Weight fraction (%) of rubber dust	Volume fraction (%) of rubber dust	Density (gm/cm^3)
Specimen-1	9	12	1.164
Specimen-2	13	17	1.149
Specimen-3	17	21.4	1.128

Specimen-1- 10%, Specimen-2- 15% , Specimen-3- 20% rubber dust by weight percentages

V. EXPERIMENTAL INVESTIGATIONS

Specimen preparation:Tyre rubber dust of 600 micron size (Fig.1) was collected from nearby tyre re-treading centres. It was then washed to remove the dust particles and dried. A wooden split mould (Fig.2) was prepared in the carpentry section. It was designed as open from both the ends so that cast pins can be removed easily by pushing from any of the end. Mould was provided with two dowel pins for locating the mould.Composite material of rubber-epoxy was chosen as the pin in tribo tester. The rubber-epoxy composite was prepared by mixing rubber dust (at different wt. percentage of 10%, 15% and 20%- Weight fractions of 9, 13, and 17% respectively) with epoxy at room temperature and stirring slowly. After the complete mixing, the composite was poured into the split mould for manual casting process and allowed to solidify in 24 hours. After curing at room temperature the pins were ejected from the mould (Fig.3).

Fig.1. Rubber dust (mesh size-600 mic)

Fig .2 Split wooden mould

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Fig.3. Composite specimens

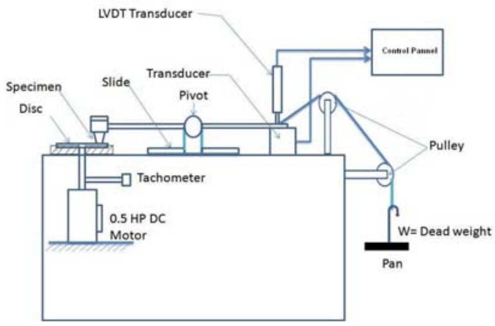

Fig.4. Schematic diagram of pin-on-disc machine

Fig. 5. Photograph of the set-up

Specifications of the set up; Make: Ducom Bangalore, India, Model: TR-20L, Power: 500 VA,Sliding Speed Range: 0.26 m/sec to 26m/sec, Disc Rotation Speed Range: 100~ 3500 rpm, Normal Load: 100 N Maximum, Pin size: 3mm to 12mm diameter, Disc size: 210mm diameter x 8mm thick, Mean wear diameter: 6mm to 76mm

Experimental Procedure:Wear test for the tyre rubber dust-epoxy resin composites have been conducted using pin-on-disc-testing machine model TR-20L supplied by M/S Ducom, Bangalore (India), (Fig.4&5) as per ASTMG99 standard. The tests were conducted in dry condition. Wear tests have been conducted using cylindrical samples that had flat surface in contact region and the rounded corner. The pin is held stationary against the counter face of a 210mm diameter rotating mild steel disc having a hardness of HRC65 and average surface roughness of 0.391 micron measured in Talysurf at Central Tool Room and Training Centre**,** Bhubaneswar.The tribological tests were performed at rotational speeds of 290 to 1200 rpm and contact pressure of 0.98MPa to 2.3 MPa along with varying time as required. The wear tests have been conducted under the normal loads 5, 8, 10 & 12 kg with varying sliding speed or sliding distances and time. Pin weight loss has been measured at the intervals of five minutes in digital electronic balance. The pin was removed from the holder after each run, properly cleaned using alcohol for taking the weights.

VI. RESULTS AND DISCUSSION

Out of the results obtained (Fig.6) it is observed that very low co-efficient of friction was obtained in case of 10% specimen and also for other specimens with higher percentage of rubbber reinforcement. Probably this phenomenon has occurred due to high surface finish of the steel disc which was of the order of 0.391 micron after regrinding. For specimen with 10% weight percentage the friction coefficient decreases with load where as for others it has shown an increase in the same. The order of coefficient of friction was within 0.0025 to 0.005.

For all the specimens the weight loss (Fig.7) has shown an increasing trend with varying speeds up to a level of 1000 rpm and then decreases. A peculiar behaviour of decrease in weight loss has been oberved with 20% rubber dust composites when slid against steel disc at varying speeds. This might have occurred due to adhesion or formation of transfer layer of composites after rubbed for certain period. Referring to Fig.8 the weight loss of each specimen has increased with respect to increase in loads. Similar trend has been observed with variation of time(Fig.9). Weight loss of 20 % composite being the maximum in both the cases. The graphs plotted for wear volume vrs sliding distance and wear rate vrs sliding velocity (Fig.10 & 11) show that there is increase in wear for all the specimens for higher sliding distances and velocities. After covering a distance of around 5 Km the wear volume seems to stabilise. Similar trends for all the specimens have been observed when wear rate is plotted against sliding velocity. The volume of material removed in all cases were found to be very less because of the high surface finish of the disc and low percentage of rubber dust.

VII. CONCLUSIONS

It is noted that with increase in percentage of rubber dust in the composite the density is decreasing making it more lighter. Where as from the wear tests carried out , it is clear that for all the composites the wear volume increases with increase in sliding distance and velocity. Similar situation prevails with increase in load. Out of the three composites so prepared it is observed that the composite with 10% weight percentage (Weight fraction 9%) exhibited excellent behaviour under sliding condition against steel. The composite with 15% rubber dust (Weight fraction of 13%) can also be considered as a good bearing material under similar circumstances. However the wear behaviour might have shown different results if sliding is done against higher roughness of the steel disc. Further wet sliding behaviour of such materials has not been studied in the present investigation which may be carried out later.

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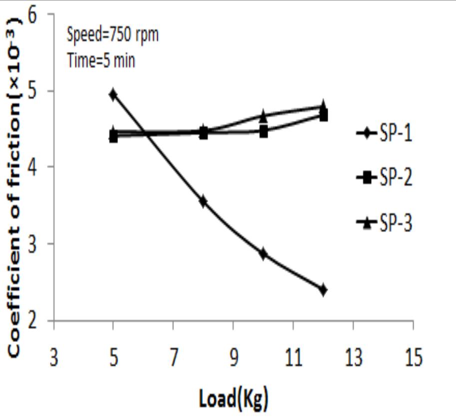

Fig 6: Variation of Coefficient of friction with load

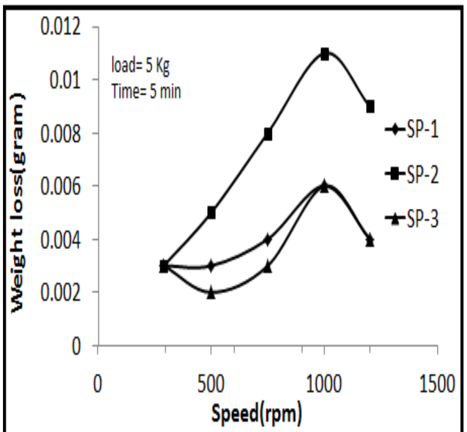

Fig 7: Variation of weight loss with speed

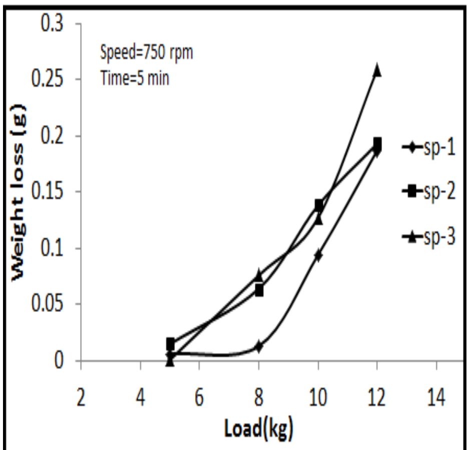

Fig 8: Variation of Weight loss with load

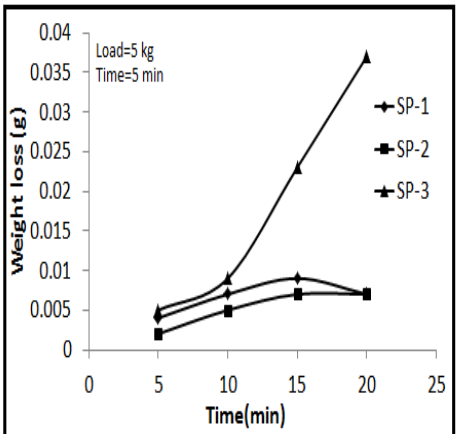

Fig 9: Variation of weight loss with time

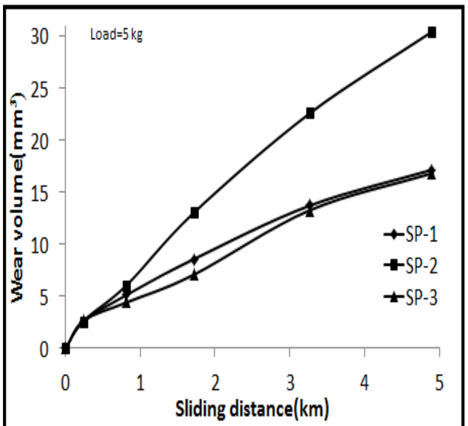

Fig 10: Variation of wear volume with sliding distance

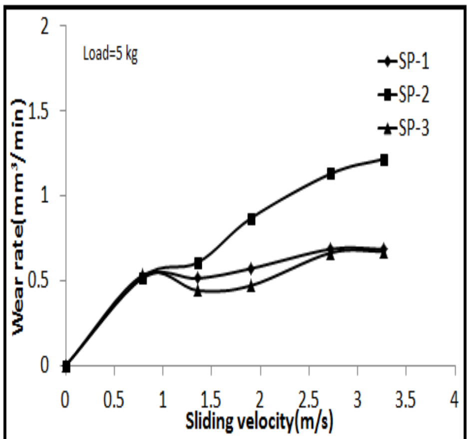

Fig 11: Variation of wear rate with sliding velocity

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