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Comparison of Wear Behaviour of Commercial Tire and Bearing Pad Rubber under Dry Sliding Condition

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ABSTRACT. *The consequence of load and sliding distance on the performance tribology of commercially used tire and bearing pad rubber was evaluated using a pin-on-disc method. The test was carried out under ambient dry sliding conditions with load of 2.5N, at sliding velocity of 0.369 ms*$^{-1}$ *and with varying sliding distance ranging from 110m-2650m. The results showed that the sliding distance at the fixed load affects the wear rate of the rubbers and the weight loss increased with increasing the distance for both the rubbers. Wear rate also increases almost linearly to a maximum then attain a plateau with increasing sliding distance. The tire rubber showed the higher wear and coefficient of friction due to presence of natural rubber. The worn surface was characterized by optical microscope and SEM. The results show surface with shallow grooves width and depth increased as the distance increases. Oxidative wear was found to be the predominant mechanisms in the dry sliding.*

Keywords: Rubber, wear, friction, surface, SEM

1. INTRODUCTION

Natural and synthetic rubbers are two types of polymers with excellent properties that are widely used in many industrial and household applications. Each rubber type has its own chemical and physical properties depending on the nature of the monomer and chemical structure of the rubber [1]. Applications for natural rubber include tires, hoses, conveyor belts, rubber linings, gaskets, seals, rubber rolls, rubberized fabric, bridge bearings, footwear and septums. Natural rubber is used in some products only because it has certain properties that cannot be matched by any other rubber. Applications for neoprene include adhesives, v-belts, timing belts, blown sponge gaskets for door, deck, and trunk, spark plug boots, power brake bellows, radiator hoses, steering and suspension joints, tire sidewalls, ignition wire jackets, gaskets, seals, track mounting, air brake hose, pipeline "pigs", coated fabrics, wire and cable jackets, appliance cords and shoe soles. The main difference between natural rubber and synthetic rubber is that natural rubber is a natural biosynthesis polymer obtained from a plant called Hevea brasiliensis, whereas synthetic rubber are man-made polymers under controlled conditions [2, 3].

Natural rubber is the main raw material used in manufacturing tires, although synthetic rubber is also used. In order to develop the proper characteristics of strength, resiliency, and wear-resistance, however, the rubber must be treated with a variety of chemicals and then heated. Neoprene bearing pads or polychloroprene is a family of synthetic rubbers that are produced by polymerization of chloroprene. Neoprene exhibits good chemical stability and maintains flexibility over a wide temperature range [4, 5]. Wear of rubber and its components is of great importance because rubber parts are widely used in different applications [6]. Their use is limited by incomplete understanding of their abrasion wear resistance and the means by which this can be controlled and improved. A number of studies on polymer matrix composites subjected to sliding and abrasive wear indicate that wear resistance depends on the detailed properties of the material as well as the external wear conditions such as applied pressure and contact velocity [7-10]. On the other hand, the right combination of polymers, rubber chemicals and reinforcing filler systems affect their performance [11]. Most of the rubber fillers used today offer some functional benefit that contributes to the process ability or utility of the rubber product. The characteristics which determine the properties of the filler and impart to a rubber compound are particle size, particle shape, surface area and surface activity. Surface activity relates to the compatibility of the filler with a specific elastomer and the ability of the elastomer to adhere to the filler [12-14]. Polymer structures and their mechanical behaviors are specific and thus they are very sensitive under conditions of mechanical stresses, temperature and chemical reactions. It is though infeasible to go through the rigorous classification of wear modes but most common type of wear is abrasive, adhesive and fatigue [15].

The aim of the present investigation is to observe the structure and dry sliding wear behaviour of the commercially used tire and bearing pad rubber so that specific recommendation can be put forward towards the tribological use of the rubber for local automobile spare parts manufacturers.

2. MATERIALS AND METHODS

The materials used in the current study were commercial tire and bearing pad rubber. The chemical composition of the rubbers is given in Table 1. The sample of 12 mm length and 5 mm diameter were machined from the tire and bearing pad rubber for wear study. Mild steel discs were used as the counter-body material. The hardness of the discs was around RC 50. One of the surfaces of the disc was grinded by surface grinding machine and cleaned with cotton. The surface roughness of the disc surface was 0.31µm. The frictional and wear behaviors of the rubbers were investigated in a pin-on disc type wear apparatus by following ASTM Standard G99-05. During the wear tests, the end surface of the pin samples were pressed against horizontal rotating mild steel disc. Applied load of 2.5 N was used throughout the test, which yielded nominal contact pressures of 0.13 MPa. The tests were conducted at the sliding speed of 0.369 ms-1 with varying sliding distances ranging from 110m-2650m. All the tests were carried out in ambient air (humidity 72%) under dry sliding condition (without lubrication). After completion of wear tests, samples were cleaned with acetone. At least four tests were done for each type of material. Wear rates were calculated from average values of weight-loss measurements. Wear rate was estimated by measuring the mass loss (ΔW) after each test. Cares have been given after each test to avoid entrapment of wear debris. It is calculated that ΔW to sliding distance (S.D) using:

$$W.R = \frac{\Delta W}{S.D \times L} \qquad (1)$$

Here,
$W.R$ = Wear Rate
ΔW = Weight Loss
$S.D$ = Sliding Distance
L = Load

Hardness of rubber samples at various states was measured in Durometer Hardness tester. Tensile testing was carried out in an Instron testing machine, using cross head speed to maintain the strain rate of 10-2/s. Density of the rubbers were calculate from the volume and weight. Microstructural observation of the worn specimens were done carefully by using OPTIKA Microscope with a CCD camera (Model: OPTIKA) attached to PC at different magnifications and some selected photomicrographs were taken. The SEM investigation was conducted by using a JEOL scanning electron microscope (Model: Link AN - 10000). Some photograph of the sample prepared, counter body used and the experimental setup are shown in Fig-1.

Fig -1: Experimental tire and bearing pad, wear samples, MS counter disc and Wear testing machine.

Table -1: Chemical composition of the tire and bearing pad rubber (wt %)

Composition	Tire rubber	Bearing pad rubber
Natural Rubber	27	-
Synthetic Rubber	13	58
Carbon Black	27	30
Steel	15	-
Magnesium oxide	-	5
Zinc oxide	2	2
Fillers, oils	16	-
Accelerator (TMT)	-	1.5
MBT (curing agent)	-	1.5
Sulfur	-	1.5
Aromatic Oil	-	0.5

3. RESULTS AND DISCUSSION

3.1 Physical and mechanical properties

Fig-2 shows the physical and mechanical properties of commercially available tire rubber and bearing pad rubber obtained at room temperature. The hardness of tire rubber 59DH is higher than the bearing pad rubber 51DH but the density is lower for tire rubber 1217 Kg/m3 than that of bearing pad rubber 1564 Kg/m3. In case of tensile property the strength of bearing pad rubber is three times and the elongation about five time higher than that of tire rubber respectively. From the table 1 it is shown that the bearing pad rubber contents about 58% of synthetic rubber and 30% of carbon black. Tire rubber achieved higher hardness at room temperature due to presents of steel particles and other filler materials. Higher percentages of synthetic rubber keep on causes the higher density of bearing pad rubber. Atomic weight of synthetic rubber is higher than natural tire rubber thus the higher molecular weight provides greater density to bearing pad rubber rather than tire rubber. Bearing pad rubber also has high tensile strength because it is produced by the polymerization that is linking together of single molecules into giant, multiple-unit molecules of chloroprene.

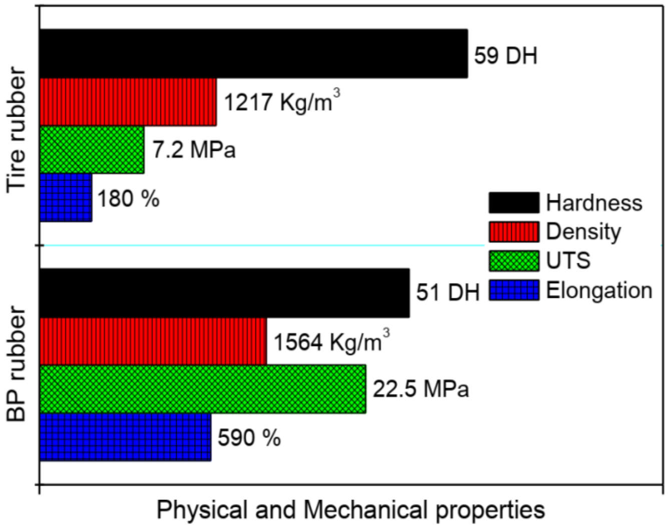

Fig -2: Experimental result of physical and mechanical properties of tire rubber and bearing pad rubber

Fig-3 shows the hardness of tire and bearing pad rubber which decreases with real temperature. But the rate of decreasing is higher for tire rubber than bearing pad rubber. The reason for this dilemma is that the typical molecular structure of this historic material. Natural rubber is a highly ordered long chain molecular structure guarantees its excellent flexibility, but the unsaturated bonds of the polymer main chain to make it easier in case of ozone, oxygen decomposition, or a case of free radicals, ultraviolet light and heat gradually occurrence of secondary cross linking reaction. Due to its high structural regularity, natural rubber tends to crystallize spontaneously at low temperatures. Low temperature crystallization causes stiffening, but is easily reversed by warming [16]. The high structural regularity of neoprene allows the strain-induced crystallization those results, as for natural rubber, in high tensile strength. The 2-chloro substituent, instead of natural rubber's 2- methyl, results in a higher freezing point (poorer low temperature resistance) and alters vulcanization requirements. Neoprenes are generally cured with zinc oxide and magnesium oxide, or lead oxide for enhanced water resistance. The presence of chlorine in the polymer structure improves resistance to oil, weathering, ozone and heat. The improved oxidation resistance is due to the reduced activity of the double bonds caused by the chlorine. Except for low temperature resistance and price, neoprene would be considered nearly as versatile as natural rubber [17].

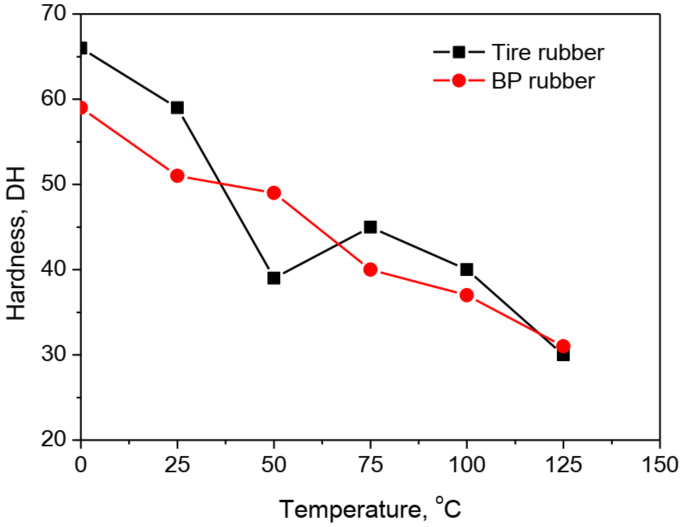

Fig -3: Variation of hardness with real temperature for tire rubber and bearing pad rubber

3.2 Thermogravimetric analysis

TGA analysis curves of tire rubber and bearing pad rubber are presented in Fig-4. It can be clearly seen that there is 0.33% and 0.15% weight loss for tire rubber and bearing pad rubber respectively within 100ºC. The weight loss recesses 2.1% and 1.8% respectively at 200ºC. That means the weight loss at these stage is higher for tire rubber. It is clear that the bearing pad rubber exhibit relatively good thermal stability than that of tire rubber up to 200ºC. It is due to loss of residual organic solvent and water. On the other hand the 12% weight loss is recorded between 100ºC to 340ºC for tire rubber and the 10% weight loss was recorded between 100ºC to 315ºC and this is due to CO2 desorption representing the decomposition of carboxyl, lactone and lactol groups. The 50% weight loss for tire rubber is recorded between 340ºC to 475ºC and 43% weight loss for bearing pad rubber recorded between 313ºC to 400ºC signifying CO desorption corresponding to decomposition of carbonyl, ether, quinine and phenol groups on the carbon surface at higher temperatures. The result means that more CO was released from the decomposition process signifying the relative abundance of carbonyl and phenolic groups.

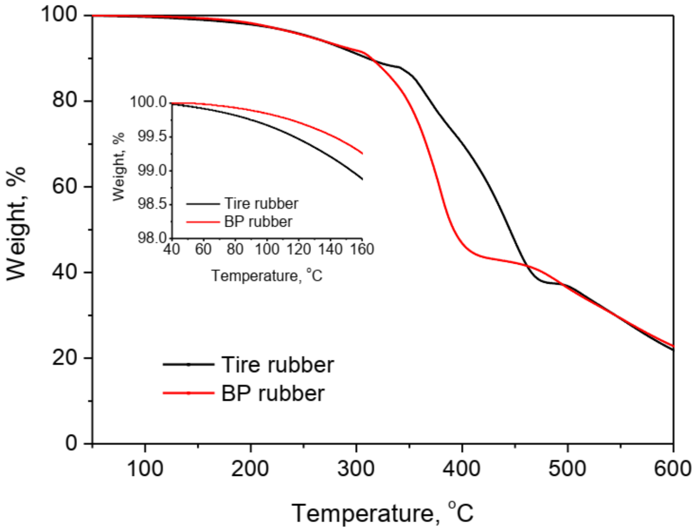

Fig -4: TGA analysis curves of tire rubber and bearing pad rubber

3.3 Wear study

Fig-5 shows the variation of weight loss against sliding distance varied from 110 to 2650m, at constant applied load and sliding velocity of 2.5N and 0.369 ms^{-1} respectively for both the tire rubber and bearing pad rubber. It is noticed from the Fig-5 that the sliding distance increases the weight loss also increases for both tire rubber and bearing pad rubber. The abrasion loss, that is, weight loss, is mainly due to the material removal of the test specimen as a result of the abrasive action of the rotating disk. Higher distance causes the higher weight loss of the two rubbers [18, 19]. The removal of material is estimated due to the tearing and chunking out of the material. In case of tire rubber the weight loss is more pronounced than bearing pad rubber.

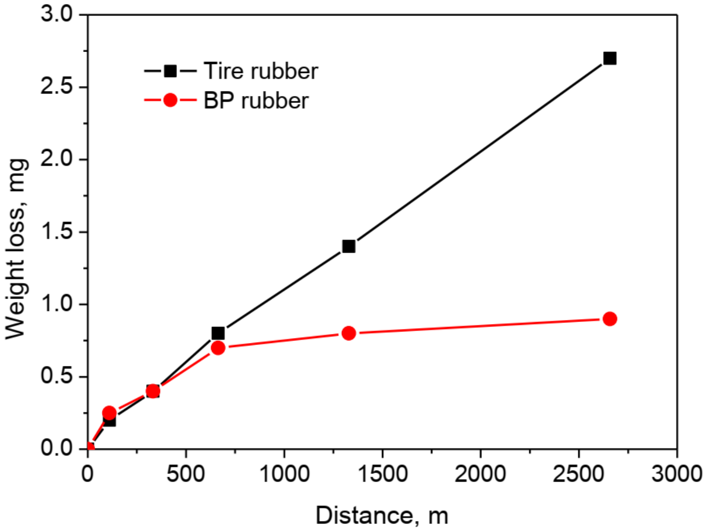

Fig-5: Variation of weight loss with the sliding distance for tire rubber and bearing pad rubber at applied pressure of 0.13MPa (Load = 2.5N)

Fig-6 depicts the variation of wear rate with sliding distance for both the tire rubber and bearing pad rubber at applied pressure of 0.13MPa (Normal Load 2.5N). It can be observed that the value of wear rate increased quite significantly for both the rubbers but the tire rubber shows higher values than that of bearing pad rubber. Generally higher hardness causes the minimum wear rate but the tire rubber loss its hardness due to heat generation during sliding on disk. It has also minimum tensile properties as well as the minimum density cause the higher wear rate. Abrasion process involves removal of small particles leaving behind pits in the surface and then followed by removal of large particles. Detachment of small particles plays an important role in initiating the abrasion and this is related to either a structural unit or localized stresses in the rubber. Natural rubber softens and weakens at high temperatures, loses its strength and becomes tacky. These changes might occur due to reduced crosslink formation between the polymer chains of natural rubber [20]. Compared with natural rubber, synthetic rubbers have improved resistance to heat, gasoline, and chemicals and a higher useful temperature range. Neoprene bearing pads are synthetic rubber. They resist ozone attack better than natural rubber. Other benefits of neoprene bearing pads include high tensile strength, good weatherability, and resistance to heat and flame. However, neoprene bearing pads do not have the ability to remain as flexible as natural rubber in colder climates. Neoprene or polychloroprene is a family of synthetic rubbers that are produced by polymerization of chloroprene. Neoprene exhibits good chemical stability and maintains flexibility over a wide temperature range.

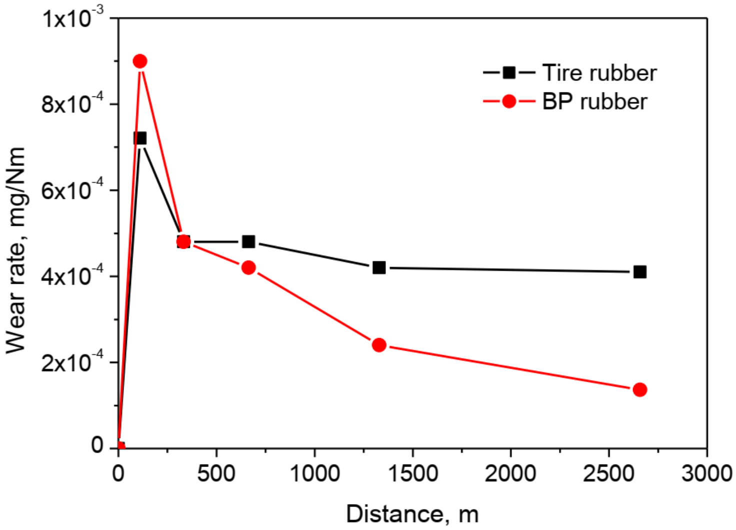

Fig -6: Variation of wear rate with the sliding distance for tire rubber and bearing pad rubber at applied pressure of 0.13MPa (Load = 2.5N)

The data for coefficients of friction of tire and bearing pad rubber have been plotted as a function of the sliding distance in Fig-7. It can be seen from the plot that the coefficient of friction of the tire rubber and bearing pad rubber reaches a steady state after showing a sharp increase during the initial sliding distance. This increase becomes relatively more pronounced for tire rubber. The increase of coefficient of friction is due to uneven contact between specimen pin and the counterpart disc. Once an ideal contact is achieved, then the result shows the steady state value [21]. In most cases, higher hardness is strongly associated with the reduction of coefficient of friction. With increase in sliding distance causes a rise in interface temperature results in thermal softening of the material. From the results obtained the softening rate of tire rubber is higher, so commercially tire rubber had a higher degree of COF followed by bearing pad rubber. The fine grained structures also responsible for higher wear resistance values as compared to the bearing pad rubber [22, 23].

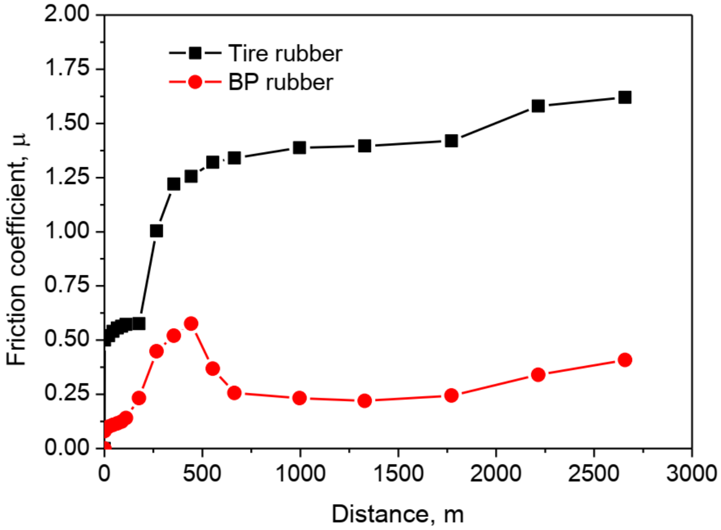

Fig -7: Variation of coefficients of friction with the sliding distance for tire rubber and bearing pad rubber at applied pressure of 0.13MPa (Load = 2.5N)

In Fig-8 the static friction force is plotted against the normal load for both the rubbers. The nominal load ranges from 1 to 7.5 N at sliding velocity of 0.369 ms-1. It can be noticed that in both cases the friction coefficient increases with normal load. It is due to the fact that when normal load increases the contact area also increases, therefore friction between rubber and contact surface increases. Some factors such as high ploughing, surface damage and breakage of reinforced materials are also responsible for higher friction with higher normal load [24]. Furthermore increases of load, the condition are changed. The co-efficient of friction decreases gradually. This clearly indicates that at high load conditions, the change of phase takes place and the material becomes more ductile.

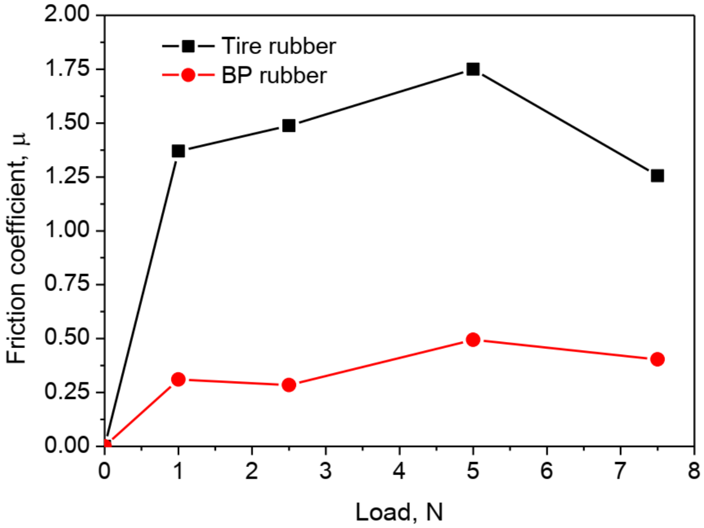

Fig -8: Variation of coefficients of friction with the load for tire rubber and bearing pad rubber

3.4 Optical microscopic observation

Fig-9 is presented the worn surfaces for both tire rubber and bearing pad rubber before wear, after wear at applied pressure of 0.13MPa for 5 min and 120 min respectively. Fig-8a and 8b show the smooth wear surface in comparison to other Fig- 9c-9f. There is no symptom of plastic deformation or drawing on the surfaces. After wear for 5 min the microstructures show significant plastic deformation and deep grooves parallel to the sliding direction (Fig. 9a and 9b). The worn surface was characterized with relatively deep wear grooves and rough surfaces as the sliding distance increases [25, 26]. It can be seen that the wear grooves and furrow marks caused by the micro-cutting and micro-ploughing of the counter face asperities were dominant on the worn surfaces.

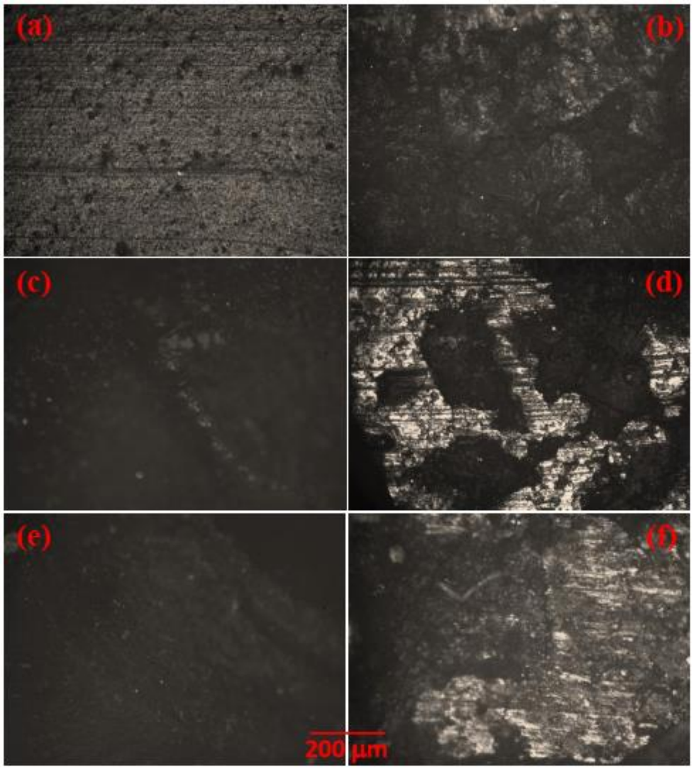

Fig -9: Optical micrograph of worn surfaces before wear a) tire rubber b) bearing pad rubber, after wear at applied pressure of 0.13MPa for 5 min c) tire rubber and d) bearing pad rubber after wear at applied pressure of 0.13MPa for 120 min e) tire rubber and f) bearing pad rubber

3.5 SEM Observation

The SEM micrographs of the worn surfaces of tire rubber and bearing pad rubber are shown in Fig-10a and 10b respectively. Tire rubber shows many domains. On the other hand bearing pad rubber does not show any large structures but small black domains. The significant differences in the micrographs of the two rubbers suggest that large domains may be composed of proteins in tire rubber and the small domains may be related to phospholipids and fatty acids in bearing pad rubber [27]. Fig-10c and 10d shows the failure surfaces of tire rubber and bearing pad after wear at applied pressure of 0.13MPa for 120 minutes respectively. It can be seen that voids or loose on the failure surface, indicating a weak matrix interaction. Voids can be attributed to the easy detachment of agglomerated from the matrix. The tire rubber clearly provides evidence for the poor tensile strength. The surface of bearing pad rubber displays better adhesion. The bearing pad rubber is well bonded with the matrix, meaning that strong interfacial adhesion [28]. Abrasion thus initiates the removal of small particles which generates pits in the surface followed by removal of larger particles in the form of chunks. The removal of material is estimated due to the tearing and chunking out of the material.

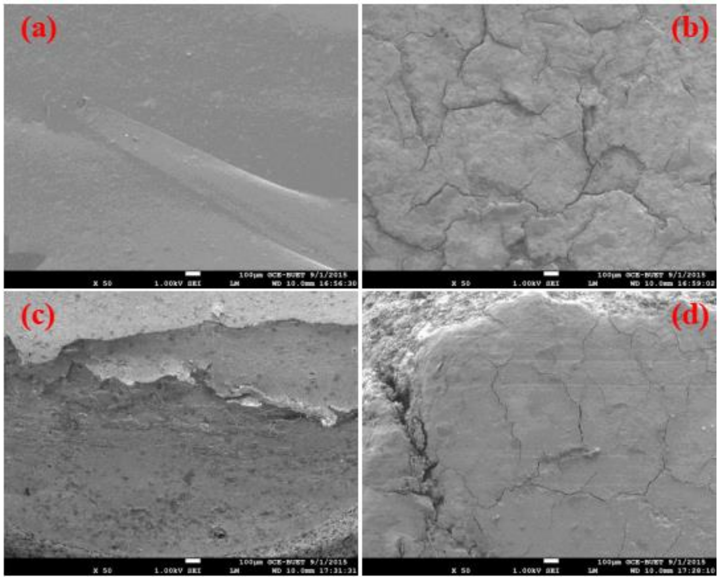

Fig -10: SEM micrographs of worn surfaces before wear a) tire rubber b) bearing pad rubber, after wear at applied pressure of 0.13MPa for 120 min c) tire rubber and d) bearing pad rubber

4. CONCLUSIONS

The load and the sliding distance affect the wear rate of the tire rubber and bearing pad rubber. The wear rate and coefficient of friction are always higher for tire rubber than bearing pad rubber. The tire rubber defeats its hardness due to heat generation during sliding on disk as compare to bearing pad rubber. The worn surface consists of shallow grooves at constant loads. At the same time the groove width and depth increased with the sliding distance increases. The surface of bearing pad rubber displays better adhesion because of rubber is well bonded with the matrix,

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