Friction and Wear Characteristics of Indegenous 'EPDM' Rubber Under Dry Sliding Condition

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Abstract - Ethylene Propylene Diene Monomer (EPDM) rubber emerges as a dominant elastomeric compound for major engineering applications like automobiles, constructions, electric and electronic industries and many more. The major engineering properties of EPDM are its outstanding heat, ozone and weather resistance ability. The resistance to polar substances and steam are also good. EPDM rubber has a common use as seals in automobiles.

In the present work friction and sliding wear behaviors of indigenously developed ethylene propylene diene monomer rubber (EPDM) of different hardness have been studied against steel counterpart in dry condition. Different hardness of EPDM have been achieved by adding different proportion (parts per hundred) of carbon black (CB) with the main ingredients of EPDM. Tribo-testing has been carried out in a multi tribo tester TR-25 (Ducom, India). Experiments have been conducted at a constant load of 25N with different speeds and times. The frictional force, coefficient of friction (COF), mass loss and wear of EPDM rubbers have been determined from the test data and concluded accordingly.

Present experimental work attempts to highlight some important tribo-characteristics of EPDM rubber as well as to shed light on various possible areas of further research works including the study of worn surface morphology using scanning electron microscope (SEM).

Keywords: EPDM, plate on roller tribo-test rig, COF, Wear.

I. INTRODUCTION

In the recent time rubber of various grades has emerged as very useful and suitable material for wider varieties engineering and other applications. Rubber possesses large elasticity compared to metals, has good damping capability and can accumulate energy to a greater extent than that of steels. Internal friction of rubber is also very high. During the deformation of rubber by compressive load, internal damping of rubber leads to energy dissipation. This is the cause of hysteretic friction of rubber. Friction of rubber has a great practical importance and advantage in the use of tires of automobiles, wiper blades, rubber seals, conveyor belts and so on. However, large friction is not desirable in various other applications. During rubber forming operation 'pancaking' or 'barreling' is developed due to the interfacial friction of rubber and the mating die halves [1, 2]. This is particularly true during upsetting operations [3, 4, 5]. Friction of rubber is also undesirable as this may lead to wear and abrasion. Automobile tires, rubber bushes, gasket, rubber spring insulated buildings, dock fenders, automobile door and window seals, bearings, sealants and sluices are some common examples of engineering applications of rubber. Rubber may also be used in the areas like water proof attires, bungee jump cords, high speed racing car tires and other sports accessories [6].

Rubber-metal springs are conveniently used in road and railway transport vehicles. Over metal springs they have the advantage like reduced weight, reduced cost, improved absorbing and damping capacity of shocks and overloads [7]. In railway vehicles rubber-metal springs are used as primary and secondary suspensions, elastic supports of aggregates, buffers and draw gear applications [8].

Rubber to metal contact is also found in different applications like vibration control, power transmission systems, automobile seals and rubber pad forming processes [9]. In rubber forming process, one of the dies is made up of rubber. This process has the advantage like low cost of tooling, ease of operation, reduced damage of the work material. This process is also suitable for the production of complex geometrical shapes [1].

It is thus clear that rubbers of different kind have wide industrial and other application potentials. The property development of rubber is also gaining importance in this juncture of renewed interest of application of rubber in different industrial applications. As a result, researchers in different parts of the globe aim at developing various property of rubber. Reinforcing rubber with organophilic clay, carbon nanofibres, carbon nanotubes, fly ash, addition of white rice husk ash (WRHA), silica, carbon black in different quantities are some examples in this regard [10, 11, 12].

Characterization of rubber is important to forecast the behavior during actual working of the same. Fundamental studies on the properties of rubber are not new. Though it is not out of place to mention that the properties of any viscoelastic material like rubber are very complicated and there is hardly any model which can define such behavior in an unique way. In tribological state tests friction and wear characteristics are of great importance. Friction behavior of rubber, at the same time, is also very complex and the viscoelastic characteristics greatly influence the friction of rubber [13].

Mechanical performance of different kinds of vulcanizates had been studied by many researchers. Thermal conductivity, stress-strain relationship, tensile stress, dynamic mechanical properties, elasticity, strength and so on are some few to be mentioned [6].

In the present paper the study of friction and wear behavior of an indigenous EPDM rubber of different hardness in dry working condition have been made. This has been done by evaluating the tribological characteristics of EPDM rubber in a multi tribo tester TR-25 of DUCOM, India. Plate-on-roller configuration of the tribo tester has been used, which is also not found in any of the research papers on tribological characterization of EPDM Rubber, filled or unfilled.

II. THEORETICAL FRAMEWORK

EPDM rubber is considered as a potential wear resistant material for door and window sealing in automobiles. EPDM rubber has an unique low friction characteristics. But due to its smooth molecular morphology, it suffers from high wear rate [14]. To minimize this effect it is reinforced with various compounds. In this paper, work has been done with an indigenously developed EPDM rubber filled with different portions of carbon black as filler material (parts per hundred). Adhesion and hysteresis are considered as the main mechanisms of rubber friction and wear [6]. Hysteresis is a bulk phenomenon of rubber and adhesion creates stick-slip action between Rubber and counter surface [15]. Persson B.N.J (2001) stated that friction is a bulk property of rubber and adhesion is important in case of clean and relatively smooyh surfaces [16]. Depending on the surface condition of the counter surface, there are various wear mechaism like abrasive wear, fatigue wear, wear by roll formation etc. The study of abrasive wear in a two body abrasive wear tester has been made by the present author and concluded accordingly [17]. Similarly, hysteresis effects have been discussed in references [4, 7]. In the present paper attempts have been made to shed light on the wear mechanism of EPDM Rubber by roll formation.

Rubbing of soft, smooth elastomer against a smooth counter part will lead to adhesion where the wear will be accomplished by roll formation. However, friction and wear of viscoelastic materials like Rubber is a complicated process and can't be explained in a simple manner as stated. Beside the experimental condition like temperature, duration, load, speed etc., viscoelastic behavior results in a spatial distribution of real contact area which varies both locally and temporally during cyclic loading [14, 15]. The main mechanisms of friction and wear of any viscoelastic material are as follows:

(i) breaking off the adhesive bonds or boundary layers (ii) plastic deformation of the contact area

(iii) plowing due to rough, portruded parts and wear debris

(iv) elastic hysteresis

These are shown schematically in Figure 1.

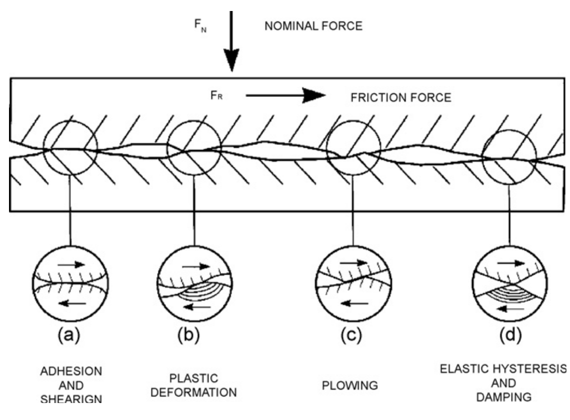

Fig. 1 Friction and wear mechanism of rubber sliding against a solid metal body [ref.14].

III. MATERIALS AND TEST CONDITIONS

3.1 Material preparation

Ethylene Propylene Diene Monomer rubber specimens have been prepared in the laboratory of NEL(Rubber), Kolkata, using laboratory intermix and open mill in two steps. Theoretical proportions of the ingredients of EPDM rubber is as follows:

EPDM - 100 parts, ZnO - 5 parts, N - cyclohexyl - 2 - benzothiazole sulfonamide – 0.6 part, 2 – mercapto benzothiazole – 0.6 part, Zn- dicyanatodiamine – 0.6 part, Zn- dibenzyl dithiocarbamate – 1.5 parts, Carbon Black (CB) – in different proportions depending on the hardness requirement like 0,30,45,60 parts and so on. This is only indicative. Actual proportions, however, is a trade secret and 'not disclosed grade'.

3.2 Preparation of the specimens

The basic ingredients, as mentioned in 3.1 have been pre-mixed in a laboratory inter mix [type K4/2A-MK3, made by Alfred Herbert, net volume capacity 45 liters and approximate fill factor of 0.6 to 0.75] for 6 minutes at a mixing temperature of $120^{\circ}C$-$130^{\circ}C$ and at a ram pressure of 100 psi (7 kg/cm^2). Curatives have been added to the pre-mixed materials on a two-roll laboratory mill ($\varphi 330 \times \varphi 150$) at room temperature. The external surfaces of both the rolls are plated with hard chrome. A constant friction ratio of 1: 1.25 has been maintained between the rolls. Total mixing time was approximately 10 minutes.

3.3 Rheometric analysis

Processing characteristics like optimum cure time (t_{90}) and difference in torque ($\Delta M = M_h - M_l$) have been determined with the help of a rubber process analyzer. High and low Mooney (torque) M_h and M_l respectively, scorch time and optimum cure time (t_{90}) have been noted using a Oscillating Disc Rheometre (Future Foundation, India made) being equipped with computer based data acquisition system and 'Rheosoft' software. Approximately 10gm of circular shaped sample has been punched out from the uncured materials and placed between two rotating discs of the Rheometre at a constant temperature of 180^0C and at an arc of 3° for 6 minutes for the measurement such parameters. The torque has been monitored as a function of time. The time corresponding to the development of 90% of the maximum torque, that is, the optimum cure time (t_{90}) has been measured from the corresponding rheographs.

3.4 Curing or hot pressing

After satisfactory rheometric analysis the material has been placed in the molding press, which is a steam heated hydraulic press, made by Hydromech and Pneumatics Pvt. Ltd., India. Molding of the samples have been carried out in a die of approximate size of 150mm × 150mm × 2mm at a pressure of 3000psi and temperature 150^0C for 10 minutes as per IS: 3400 (part X)-1977. Silicon emulsion may have to be used in case the molten material sticks to the molding plates. Ultimate aim of such curing is to produce a smooth and comparable surface of the specimens.

3.5 Hardness measurement

The hardness of the specimens have been measured as per IS:3400 (Part II) -1980 standard using a Shore (A) Durometer. TSE-Rubber Hardness Tester, SHR – Mark III –A, sr.no.15718, made by Testing Machine, India, has been used for this purpose. The machine has been calibrated accordingly by Techno India. Indentations have been made at several points on the upper surface of each specimen and the average value has been taken as a measure of hardness.

3.6 Sample preparation for wear test

The samples have been prepared for the wear test as per the requirement of the sample holder of multi tribo tester 'TR-25'. 20mm × 20mm × 6mm mild steel blocks have been prepared following various machining operations. Blocks of 20mm × 20mm × 2mm EPDM rubber have been cut from the larger sheets of EPDM. The smaller sheets have been pasted on the top of the mild steel blocks using Fevi Kwik adhesive. Thus, samples of size 20mm × 20mm × 8mm have been prepared to be accommodated in the holder of the multi tribo tester. The substrate of each sample is 6mm thick mild steel and the abrading surface is a 2m thick EPDM rubber.

3.7 Wear test

Wear test has been carried out in a multi tribo tester 'TR-25' of DUCOM, India. The machine is also equipped with 'Winducom 2006' data acquisition and analysis software. Plate-on-Roller configuration has been utilized for this purpose. The rubber surfaces of the samples have been slid against an EN-8 steel roller of diameter 50mm and hardness of 55 HR_C. It is not out of place to mention here that several researchers have conducted the wear test using either pin-on-disk, roller-on-plate (for abrasive wear), fretting wear, pin-on-cylinder type of tribometers [12, 18]. However, the use of plate-on-roller configuration has not been found in the literatures. The test parameters have been selected judiciously considering the data base as found in research papers. In the present study, five rotational speeds of the wheel namely 50 rpm, 75 rpm, 100 rpm, 125 rpm and 150 rpm have been selected against a constant load and time of 25 N and 900 sec respectively. The coefficient of friction, wear and mass loss of the samples have been recorded for each test. The samples have been cleaned thoroughly with acetone before and after the tests to remove any trace of dirt, oil or grease, wear debris etc. The initial and final weights have been measured in an electronic analytical and precession balance (Sartorius BSA 223S, Germany. Maximum range = 220 gm with a readability of 0.001 gm). The schematic arrangement of the testing procedure has been indicated by line diagram in Figure 2.

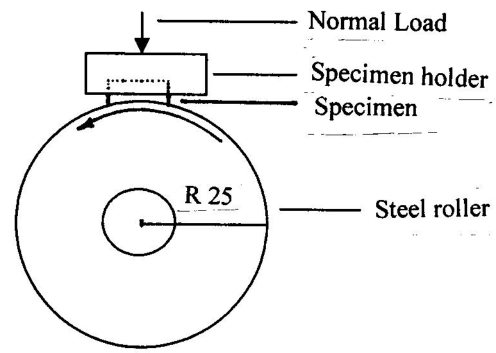

Fig. 2: Schematic diagram of tribo-tester.

IV. RESULTS AND DISCUSSIONS

Three types of EPDM rubber have been selected for the wear test based on the proportions of carbon black as filler material. Hardness of the material depends on the carbon black content (parts per hundred). Accordingly, three hardness values 55 Å, 70 Å and 85 Å have been obtained.
The coefficient of friction (COF) and wear (in micron) data of different EPDM at different rpm and times are shown in Table 1 (a) to (e) below:

TABLE 1 (A) COF AND WEAR DATA AT 50 RPM.

Time (sec)	EPDM Hardness					
	55Å		70Å		85Å	
	COF	Wear	COF	Wear	COF	Wear
180	2.87	78.4	2.91	29.4	1.85	8.6
360	2.43	77.7	2.86	19.4	1.65	8.5
540	2.49	73.1	2.51	13.1	1.58	5.9
720	2.39	68.8	2.66	9.8	1.54	5.5
900	2.11	65.9	2.46	5.6	1.56	6.4

(b) COF and wear data at 75 rpm.

Time (sec)	EPDM Hardness					
	55Å		70Å		85Å	
	COF	Wear	COF	Wear	COF	Wear
180	2.27	136.7	2.53	96.5	1.80	41.3
360	2.05	125.8	2.29	90.7	1.65	44.8
540	1.89	119.6	2.21	83.9	1.62	39.1
720	1.92	115.7	2.26	79.4	1.56	37.3
900	1.89	111.3	2.33	76.9	1.55	35.6

(c) COF and wear data at 100 rpm.

Time (sec)	EPDM Hardness					
	55Å		70Å		85Å	
	COF	Wear	COF	Wear	COF	Wear
180	2.76	264.2	2.14	87.5	1.49	24.8
360	2.44	315.1	1.86	76.6	1.39	24.2
540	2.42	332.3	1.86	67.7	1.42	20.6
720	2.23	334.2	1.88	55.0	1.36	15.8
900	2.29	339.3	1.78	55.5	1.37	15.6

(d) COF and wear data at 125 rpm.

Time (sec)	EPDM Hardness					
	55Å		70Å		85Å	
	COF	Wear	COF	Wear	COF	Wear
180	2.33	87.3	2.09	47.2	1.13	36.4
360	2.24	84.7	1.91	39.7	0.963	35.5
540	2.20	71.5	1.99	31.4	0.954	33.8
720	2.09	61.1	1.82	23.8	0.836	33.4
900	2.17	53.3	1.91	17.0	0.926	31.8

(e) COF and wear data at 150 rpm.

Time (sec)	EPDM Hardness					
	55Å		70Å		85Å	
	COF	Wear	COF	Wear	COF	Wear
180	1.84	72.3	1.76	52.9	1.34	19.7
360	1.64	66.7	1.70	41.4	1.21	16.3
540	1.49	57.8	1.89	29.7	1.08	9.9
720	1.58	54.7	1.74	20.4	1.16	4.8
900	1.57	43.9	1.76	13.0	1.26	3.1

Figure 3 indicates the comparative charts of coefficient of friction as a function of time for different hardness values of EPDM at a rotational speed of 50 rpm. This is generated by 'Winducom 2006' software. It is evident from the figures that the experimental data have strongly fluctuated from a high to low value. This is due to the effect of stick slip friction. However, for a better comparison, the average values of friction have been considered and the results have been depicted in Figure 4 to 7 for rotational speed of 75, 100, 125 and 150 rpm respectively.

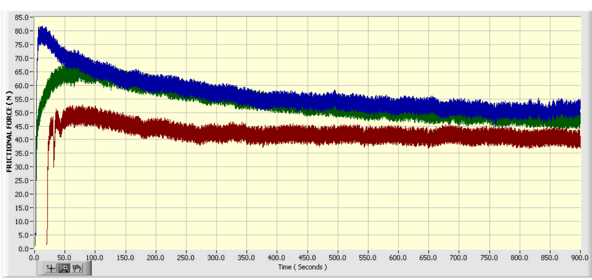

Fig. 3 Coefficient of friction as a function of time at 50 rpm. [Green: EPDM 55Å; Blue: EPDM 70Å; Maroon: EPDM 85Å].

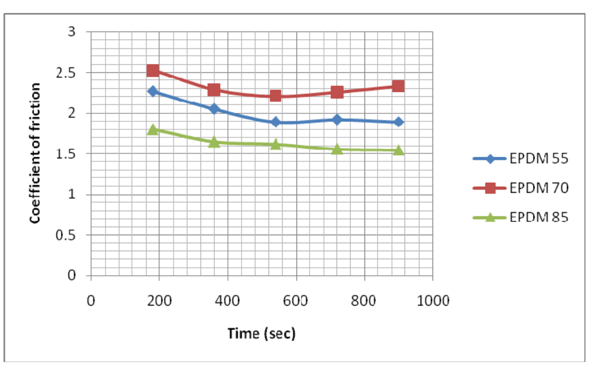

Fig. 4 Coefficient of friction as a function of time at 75 rpm

The regression equations of the curves are as follows:

y = ˜0 .000 x + 2.453; r^2 = 0.304 for EPDM 55Å

y = ˜0 .000 x + 2.271; r^2 = 0.747 for EPDM 70Å and

y = ˜0 .000 x + 1.813; r^2 = 0.859 for EPDM 85Å.

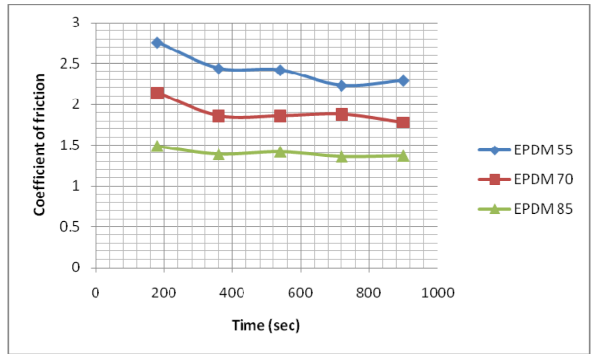

Fig. 5 Coefficient of friction as a function of time at 100 rpm.

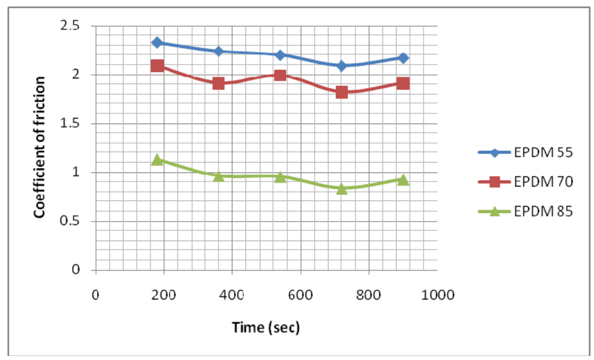

Fig. 6 Coefficient of friction as a function of time at 125 rpm.

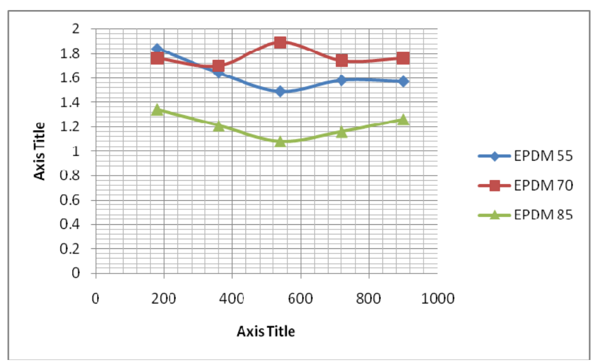

Fig. 7 Coefficient of friction as a function of time at 150 rpm.

The wear curves (in micron) of EPDM with different hardness values against different sliding speeds have been shown in Figures 8 to 13. Figures have been drawn separately using Excel worksheet.

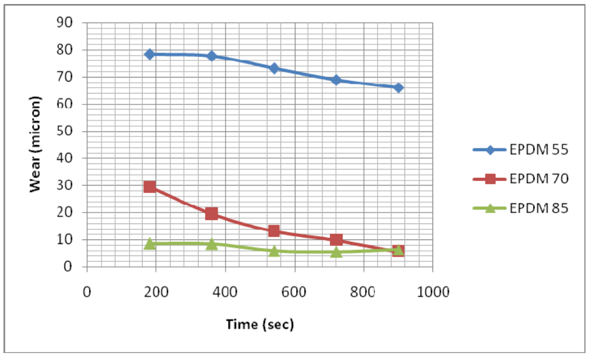

Fig. 8. Wear as a function of time at 50 rpm.

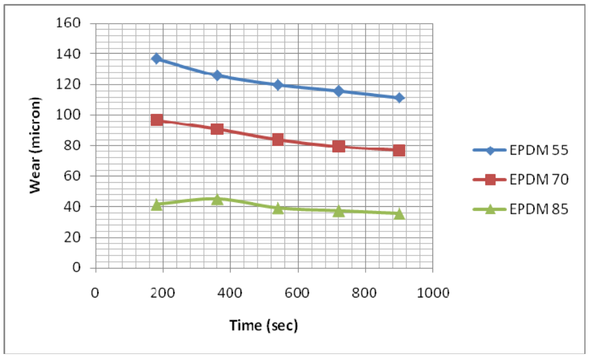

Fig. 9 Wear as a function of time at 75 rpm

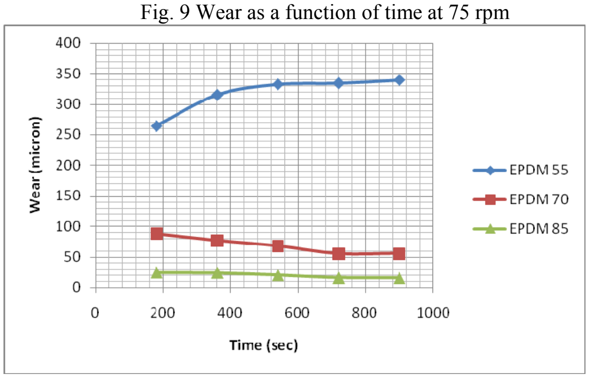

Fig. 10 Wear as a function of time at 100 rpm

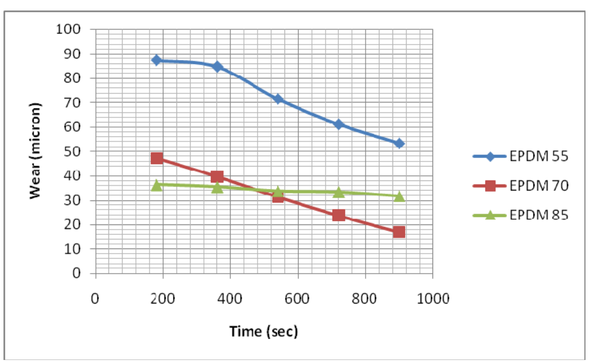

Fig. 11 Wear as a function of time at 125 rpm

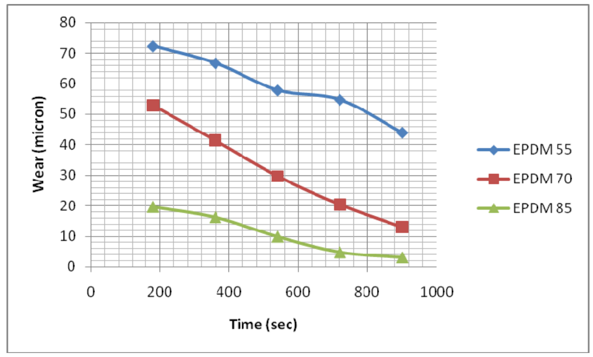

Fig. 12 Wear as a function of time at 150 rpm

Figure 13 indicates the wear curve as generated by 'Winducom 2006' software at a sliding speed of 150 rpm.

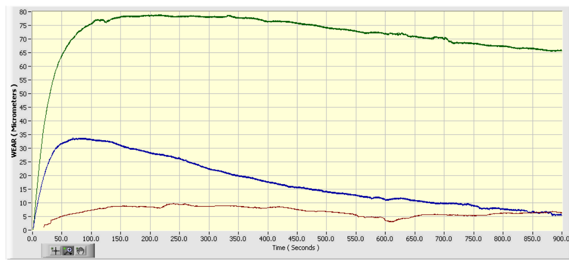

Fig. 13 Wear as a function of time at 150 rpm. [Green: EPDM 55Å; Blue:EPDM 70Å; Maroon: EPDM 85Å].

The mass loss data of the samples have also been recorded before and after the tribo testing using a precision balance as mentioned earlier. The weight loss data after 900 sec of sliding have been furnished in Table 2.

TABLE 2 WEIGHT LOSS OF SAMPLES AT DIFFERENT SPEEDS

rpm	**Weight Loss (gm) ($\Delta w=w_1-w_2$)**		
	55Å	**70Å**	**85Å**
50	0.003	0.001	0.003
75	0.003	0.006	0.003
100	0.003	0.004	0.002
125	0.004	0.003	0.002
150	0.007	0.004	0.002

From the test data and corresponding graphs in each case, it has been revealed that the friction coefficient values at the very inception of the test have a significant influence on the wear. From the wear curves it may be concluded, in general, that more the hardness of the EPDM rubber less the values of the wear. As carbon black content controls the hardness, hence, the wear may be controlled adjusting this parameter. EPDM 85Å shows a minimum wear under each and every test condition. The wear diminishes gradually after a high wear at the beginning and follows an almost straight line path. However, in case of 150 rpm, the wear is gradually diminishing after a comparatively high value of initial wear. This trend is different from those obtained in case of other rotational speeds. EPDM 55Å and EPDM 70Å however show different results. Unique conclusion can't be drawn from the trends of the graphs. As an example, wear of EPDM 55Å is always in the higher side than that of EPDM 70Å. However, the initial wears are very high with gradual reduction in wear at the later stage. Wear values of EPDM 70Å is in a mixed mode. The wear is in between the other two types of rubber. The wear at 900 sec is equal to that of EPDM 85 Å in case of 50 rpm and the value dips below than that of EPDM 85 Å in case of 125 rpm. In all the cases initial wear is very high for both the rubbers and the wear reduces gradually as the time proceeds. One of the causes of such behavior may be the accumulation of wear debris with time which stick or adhere to the surface of the steel roller and thus the gap in between the abrading rubber surface and the upper surface of the roller is diminishing. The linear transducer of the multi tribo tester 'TR-25' measures the gap in between specimen and the roller and this value is interpreted as the wear. As the counterpart, against whom the specimen is slid, is generally much harder than that of the specimen hence the gap is actually the measure of wear of the specimen surface. In the present study, effort has been made to clean continuously the steel roller. But as the measurement is in micron level, it is quite likely that the cleaning is not up to the mark. As the softer rubber worn to a greater extent than the harder, more sticking of wear debris is likely in case of the softer rubber.

The coefficient of friction data have been tabulated in different tables [Table 1(a) to (e)]. For the analysis of friction results more closely, the tabulated data have been plotted in graphs [Figure 3 to 7]. In case of friction and wear studies viscoelastic materials like rubber, two components are considered to be important. One is adhesion and the other one is hysteresis. Adhesion is responsible for stick slip action whereas, hysteresis is the bulk phenomenon of rubber leading to internal damping. For relatively smooth specimen surface like EPDM rubber and very smooth counter surface like steel, the initial mechanism of friction is adhesion and wear is followed by the roll formation process. In the present study, both the surfaces are very smooth. Thus, initial frictions in all the cases are high compared to those at the later stages. After the detachment of the surface layer by the process of roll formation, comparatively rough texture of surface of EPDM appears. Thus, real contact area is reduced and reducing the coefficient of friction. In all the cases of the present study, a monotonous decrease of the friction coefficients after the high initial values has been noticed. But the behaviors of friction coefficient in case of 150 rpm for all the rubbers are peculiar. The author has no explanation at the present moment. It needs further investigations. The coefficients of frictions have been reduced to a greater extent with the addition of carbon black. The reduction in case of EPDM 55Å to EPDM 70Å is approximately 18% whereas in case of EPDM 55Å to EPDM 85Å is approximately 43%. Similarly, reduction in case of EPDM 70Å to EPDM 85Å is approximately 33%.

Weight loss (in gm) is minimum in case of EPDM 85Å at speed 75 rpm and above with a value of 0.002 gm. For EPDM 55Å, weight loss is 0.003gm up to speed of 100 rpm. At higher speed of 125 rpm, the weight loss is slightly more with a value of 0.004 gm and the value increases further at speed 150 rpm. Wear at this speed is 0.007 gm. No trend in weight loss has been established in case of EPDM 70 Å, may be due to inhomogenity in mixing of the ingredients or improper curing. However, it is desirable to have less weight loss of EPDM 70Å due to its improved hardness over EPDM 55Å.

V.CONCLUSION

The present experimental work has been devoted to study the friction and wear characteristics of EPDM rubber of different hardness in dry condition using plate on roller type of tribo tester against EN-8 steel counterpart. It is needless to mention that it is very difficult to harmonize the experimental conditions with real life applications and it is also very difficult to arrive at an unique conclusion in case of a viscoelastic material like rubber. In spite of the limitations as mentioned, the following conclusions have been drawn:

1. hardness of the rubber has been increased with increasing carbon black content (pph);
2. coefficient of friction decreases with increased hardness;
3. wear resistance of EPDM rubber has been improved by the addition of carbon black;
4. stick-slip effect of friction is prominent in case of two smooth sliding surfaces. In the present study, the friction curves reveal strong stick slip behavior.
5. wear is supposed to be accomplished by roll formation of the wear debris. This is supported by the gradual decreasing wear of the rubbers.
6. weight loss due to wear of the surface layer is minimum in case of harder EPDM compared to that of softer one. The weight loss, in general, is not too high in all the cases.
7. various other works must be carried out in future to understand more clearly the friction and wear mechanism of EPDM rubber.

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