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RESEARCH

Some Tribological Characterization of "EPDM" Rubber

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A B S T R A C T

Ethylene Propylene Diene Monomer (EPDM) rubber emerges as a dominant elastomer for major engineering applications. The major properties of EPDM are its outstanding heat, ozone and weather resistance ability. It has a good resistance to polar substances and steam condition too.

In automobiles EPDM rubber has a common use as seals. This includes door seals, window seals, trunk seals and sometimes hood seals. Frequently these seals are the source of noise due to the movement of the door versus the car body. This is due to friction between the EPDM rubber parts and the mating surfaces. Thus, the contact iteration between the rubber sealing and the indenting object must be known to optimize the performance of rubber sealing. However, it is need less to mention that the behaviour of any viscoelastic material is very difficult to be predicted.

In the present work various tribo-characteristics of EPDM rubber of different hardness have been evaluated utilizing the available laboratory test facilities in the Jadavpur University, Kolkata, India. Compression tests have been carried out using 'Instron' to determine the flow behaviour of EPDM rubber of different hardness both in dry as well as under different conditions of lubrication. The flow behaviour like load -vs.- elongation curves, true stress -vs.- elongation curves and true stress -vs.- true strain curves have been drawn from the experimental data. Abrasive wear behaviour has been evaluated using a two-body abrasion tester and the pattern abrasion has been appraised through SEM/EDAX study.

Experimental results reveal that the hardness of EPDM rubber has significant effect on the flow behaviour and wear characteristics. The hardness, again, depends on the proportion of carbon black (CB) content. Thus it can be stated that the flow behaviour can be governed by controlling the CB concentration in the EPDM rubber.

Based on the experimental results conclusion has been drawn accordingly. Some of the important tribo-characteristics of EPDM have been highlighted. Light has also been shed on various possible areas of further researches those should be undertaken in the future to come.

1. INTRODUCTION

In the recent time, being fuelled by several new researches and development in the field of viscoelastic materials as well as due to various property requirements of rubber for several engineering, domestic, sports and other applications, the performance evaluation of rubber is becoming very demanding and gaining renewed research interest in different parts of the globe.

The friction and wear data base of rubbers are also not very promising due to the fact that the rubbers used in such tribotests are not characterized adequately [1,19]. Test configurations, parameter selections, experimental conditions are all important factors which need to be standardized before comparing the tribotest data generated by various agencies or researchers. All these necessitate further and continued study and iteration of tribotest data for rubber to find its suitability as engineering or other materials.

Property prediction is another driving force [2,17]. It means that the property of engineering and other materials should be predictable and there should have some authentic model in that regard. It is not out of place to mention in this regard that various researches on tribological properties of composites are also going on in the recent time [2,21,22]. It is, however, needless to be mentioned that the property of any viscoelastic material, like rubber, is very hard to be predicted.

Ethylene Propylene Diene Monomer (EPDM) rubber is widely used as seals in automobile door, window, hood and other parts. They are subjected to wear and tear due to pressure, vibration, friction and exposure to extreme conditions of atmosphere. Though EPDM has outstanding heat, ozone, weather resistance ability and resistance to any polar substance as well as steam is also very good, still some realistic tribological data are yet to be developed. This is particularly true for any indigenous development of EPDM.

In the present work flow behaviours of EPDM rubber of different hardness have been evaluated. EPDM specimens have been compressed in between flat MS platens and stress-strain relationship, specific energy and loss factors have been computed subsequently. Similarly wear characteristics have been studied in a two-body abrasion tester. The worn surface morphology has been studied by SEM/EDAX method to appraise the pattern abrasion.

2. EXPERIMENTAL WORK

The EPDM rubber specimens for the tests have been prepared indigenously in the laboratory of National Engineering Limited (Rubber Division), Kolkata. It is needless to mention that the actual proportions of various ingredients are trade secret and strictly a ‘not-disclosed grade’. The following table indicates a very close approximation of various chemical constituents of EPDM as prepared in the laboratory:

Table 1. The chemical compositions of EPDM of different hardness.

Ingredient	Shore Hardness				
	55Å	60Å	70Å	80Å	85Å
EPDM	100	100	100	100	100
ZnO	5	5	5	5	5
St. Acid	1	1	1	1	1
PEG 4000	1.2	1.2	1.2	1.2	1.2
FEF 550	80	130	160	170	180
P Oil (2500)	130	110	100	90	80
Sulpher	1	1	1.2	1.2	1.2
HBS	1	1	1.5	1.5	1.5
ZDBS	1	1.5	1.2	1.2	1.2
TMT	1	0.7	0.7	0.7	0.7

Basic ingredients have been pre-mixed in a K4/2A-MK3 (Alfred Herbert) for 6 minutes at a ram pressure of 100 psi. Curatives have been added to the pre-mixed materials on a two roll laboratory mill (330 × 150) at room temperature. Curatives are required to enhance various properties. The mixing time in rollers was approximately 10 minutes. A constant friction ratio of 1:1.25 was maintained during rolling.

Processing characteristics including optimum cure time (t_{90}) and torque difference (Δm = Mh – M_l) have been determined with Oscillating Disc Rheometer equipped with computer assisted data acquisition system and supported by ‘Rheosoft’ software. Standard procedures as introduced by Sohail Khan et al. [5] and other researchers have been followed in this regard. However, the machine used for the purpose is Indian one and specific procedural steps for the said machine have been followed accordingly. ‘M_h’ and ‘M_l’ are high and low Mooney (torque) respectively. The torque has been monitored as a function of time and the optimum cure times have been recorded from the corresponding rheographs. One such graph is shown in Fig. 1.

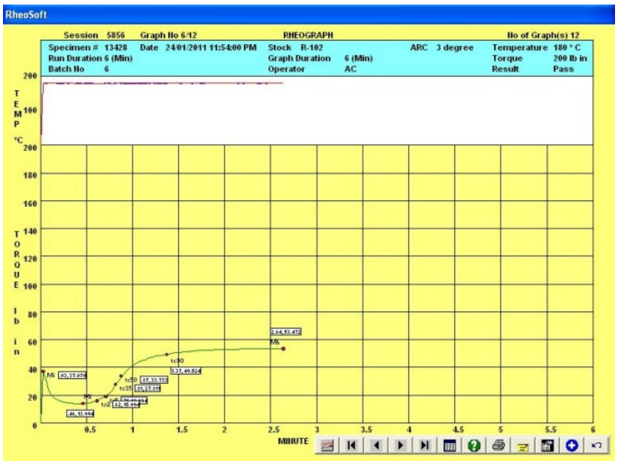

Fig. 1. Torque-vs.-Time rheograph of an EPDM specimen.

Based on the satisfactory results of rheometric analysis, the material has been considered 'ready' for molding operation. Short cylindrical specimen of diameter 'φ' (16.5±0.5) and height 'h' (12.5±0.5) have been prepared in the steam heated hydraulic press at a pressure of 3000 psi and temperature 150 ^{0}C. The material is compressed in the press for approximately 10 minutes. The molding operation has been carried out as per IS: 3400 (part-X) - 1977 specification. The extra projection of materials, if any, has been trimmed by scissor after molding to give the specimen proper shape. The dimension, specific gravity and shore hardness values of all the samples have been measured accordingly using appropriate measuring tools and instruments for the respective parameters.

2.1 Compression test

Each test specimen, that is the sample, has been placed axysymetrically in between two flat mild steel platens in such a way so as to ensure an even force distribution on both the faces of the specimen. The required compressive load has been provided by an Instron (model 8801; serial no. K 2342 with 'Dynacell' load cell, made in England. Maximum working pressure: 207 bar; dynamic load capacity: ± 100 KN). The machine, as shown in Fig. 2, is equipped with '8800: Instron SAX V9.3' software based data acquisition system. Only one fatigue cycle has been utilized at a frequency of 0.005 Hz for the application of compressive load on the specimen. The height of each cylindrical specimen has been reduced by 65 %. Each test has been replicated twice to observe the repeatability of the process. The compressive load followed by load relaxation data have been recorded and utilized later on for the plotting of the loading and unloading curves.

Fig. 2. 'Instron' equipped with data acquisition software.

Compressions of the samples have been carried out in five different ways. One in dry condition, one under fixed contact and three with different lubricants like, talc, water and grease. Work metal tends to spread over the die surface to increase its diameter during compression in between two die halves. However, frictional force opposes the outward flow of metal near the mating zone of work piece and die halves. But the material at the mid height of the specimen is absolutely free to flow in an out ward direction. This leads to the development of an undesirable phenomenon known as 'barreling' or 'pan caking' [3]. Barreling of one EPDM sample during compression under fixed contact, using sand paper, is shown in Fig. 3. Undesirable frictional force may be reduced to a greater extent with the application of some suitable lubricant. The effect of compressive load on EPDM specimen of different hardness in dry working condition has been appraised by the present author [4]. Suitable solid, liquid or gaseous substances may be used in between two mating and interacting surfaces to reduce friction as well as wear. These are considered as lubricants [6]. The flow characteristics of EPDM rubber of different hardness under compressive load in the presence of some lubricants have been studied by the present author [7]. Selection of proper lubricant(s) depends on several considerations and should be judicious [8]. In the present experimental work some lubricants have been selected based on the literature survey and considering the practical work environment [9-12]. The mechanical characteristics of EPDM rubber, like stress-strain relationships, specific energy and loss factors have been studied.

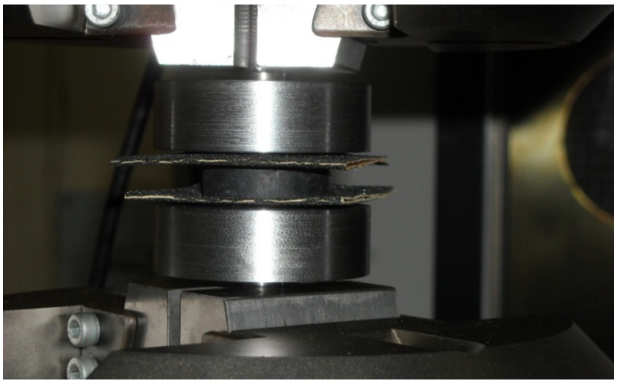

Fig. 3. Compression of EPDM specimen using fixed contact.

2.2 Abrasion test

Specimen of sizes 70 mm x 30 mm x 2 mm have been cut from vulcanized rubber sheets of 150 mm x 150 mm x 2 mm for abrasion tests. EPDM rubber of three different shore hardness values has been selected for this purpose. These are 55 Å, 70 Å and 80 Å respectively. Abrasion tests have been carried out using a two body abrasion tester TR-605 (Ducom) as shown in Fig. 4. The machine is equipped with a stepper motor drive (makes –My Com, 24 V DC, and 40 W, model no. IMS-200-220 AL) and requires an electricity of 230 V x 1 φ x 50 Hz and 100 W power. The wheel of the abrasive wear tester is made up of stainless steel having a diameter of 50mm and width of 12 mm. Silicon Carbide (SiC) water proof paper (Carborundam Universal) of grades ER 240, ER 220 and ER 180 have been pasted on the top surface of the wheel for the purpose of abrasion. Each abrasive paper has been cut into appropriate size. It is then pasted on the top surface of the wheel using an adhesive (Feviquick). Rubber specimens have been placed in the desired position on the machine table and clamped properly. The specimens have been subjected to normal load using a dead weight. The leverage action obtained in the machine is 1:2, that is, a counter weight of 2 N will apply 1 N of normal load on the job. Then the specimens have been abraded against the abrasive paper under simulated abrasive wear condition. The standard followed as per ASTM D 6037 (Test method B) ISO 8251 in this regard.

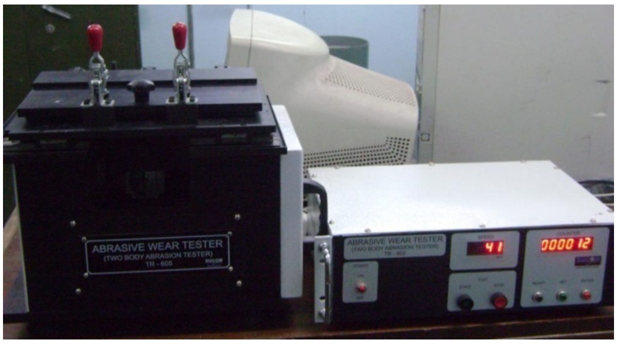

Fig. 4. Laboratory set up of a two-body abrasion tester.

Four different factors like hardness of EPDM rubber, abrasive grade, load on job and cycle have been considered at three different levels like low, medium and high respectively for this laboratory experimentation. It is needless to mention that if a full factorial experimentation were to be conducted with the four factors each at three levels then a total of 81 experiments would have to be done and the number would have been multiplied accordingly for replication. In the present study, based on Taguchi's experimental design technique [13], an L_9-orthogonal array has been selected and thus only 9 experiments have been conducted. The combinations of different factors and levels as well as the specific wear rate corresponding to each combination are shown in Table 2.

Table 2. Factor-level combinations of the experiments as per Taguchi's L_9- orthogonal array and the abrasion loss data.

Trial No.	Hardness (Shore; Å)	Abrasive grade	Load on job (N)	Cycles	Specific wear rate (mm^3/Nm)		
					1st replication	2nd replication	3rd replication
1	55	Very Fine	5	200	0.1149	0.1038	0.1094
2	55	Fine	10	400	0.2641	0.1692	0.2952
3	55	Medium	15	600	0.2279	0.1507	0.1741
4	70	Very Fine	10	600	0.1930	0.1932	0.1921
5	70	Fine	15	200	0.1991	0.2234	0.1930
6	70	Medium	5	400	0.1640	0.1963	0.1353
7	80	Very Fine	15	400	0.1775	0.2142	0.1944
8	80	Fine	5	600	0.1782	0.2685	0.1848
9	80	Medium	10	200	0.1551	0.2098	0.1951

2.3 EPDM - EN 45 spring test

This has already been mentioned that rubber has various important industrial and other applications. Rubber-metal spring is one of such applications. M. Banic et al. had also demonstrated the tribological aspects of rubber shock absorbers [20]. Performance appraisal of an 'EPDM – EN 45' rubber-metal spring has been done by Mukhopadhyay Abhijit et al. and the results show better performance of the combined spring compared to the steel spring alone [18]. Figure 5 indicates a series combination of a disc spring.

Fig. 5. Series combination of 'EPDM-EN 45' disc spring.

3. RESULT AND DISCUSSIONS

Flow characteristics data of EPDM rubber under compressive load, with or without lubricants, have been tabulated in Table 3. The lubricants have been selected based primarily on the literature survey as well as from the real life experience. The compressive load imparted by Instron and corresponding height reduction data have been recorded through the data acquisition system of the machine and later on different flow characteristics like load-vs.-deflection, true stress-vs.-deflection and true stress-vs.-true stain have been calculated using the indigenously developed MATLAB code. Some flow curves have been shown in Fig. 6 (a), (b) and (c).

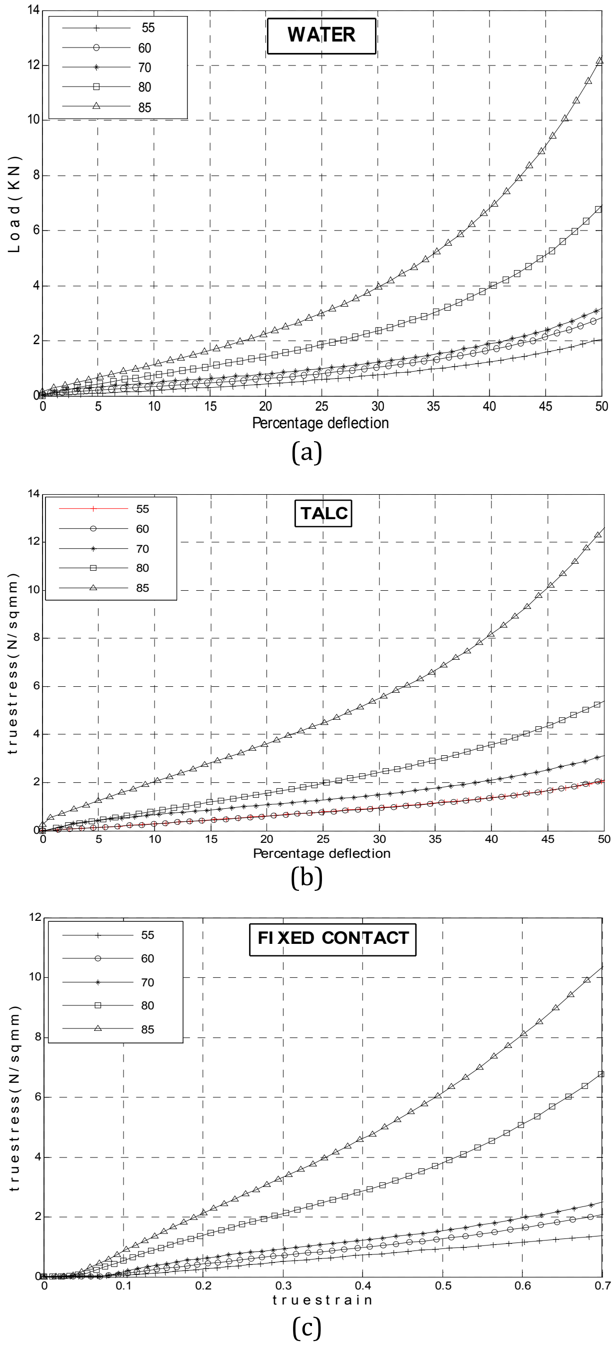

Fig. 6. Flow characteristic curves are shown in (a), (b) and (c) under different conditions as indicated in the curves.

Table 3. Flow characteristics data of EPDM.

EPDM of different hardness	Lubricant														
	Dry			Fixed Contact			Talc			Water			Grease		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
55Å	2.71	2.08	2.16	1.77	1.34	9.90	2.71	2.04	2.05	1.99	1.52	1.52	1.66	1.34	1.25
60Å	3.35	2.41	2.53	2.65	2.01	6.78	2.64	2.05	2.04	2.72	2.05	2.05	2.36	1.75	1.79
70Å	4.05	3.15	3.47	3.18	2.40	2.40	3.95	3.17	3.03	3.09	2.34	2.34	2.52	2.62	1.91
80Å	9.03	5.95	6.75	8.36	6.38	2.01	7.88	6.29	5.24	6.78	5.05	4.83	6.94	3.91	5.24
85Å	16.57	10.00	12.53	13.03	9.90	1.34	16.32	12.29	12.29	11.76	9.33	8.87	-	-	-

[A: Load (KN) at 50 % deflection; B: True stress (N/mm^2) at 50 % deflection; C: True stress (N/mm^2 at a true strain of 0.7]

It has already been mentioned that four factors, each at three levels, have been selected to conduct the abrasion test. Table 3 indicates the 'factor – level' combinations as used in the experiments. Wear rate of the samples have been calculated and corresponding specific wear rate data have been tabulated. Specific wear rates have been calculated using the following formula [11]:

$$W_s = \frac{\Delta m}{\rho F L} \tag{1}$$

where: W_s = specific wear rate (mm^3/Nm); Δm = mass loss recorded gravimetrically (gm); ρ = specific gravity of EPDM (gm/cm^3); F = the normal load on the job (N) and L = overall sliding distance (m).

The worn surface morphology has been studied for each sample immediately after the abrasion using a scanning electron microscope (SEM: JEOL, JSM-6360, model 75 82) to observe the smallest detail of the pattern abrasion in the range of 4 – 5 nm (4 – 5 millionths of a millimetre). The test has been conducted immediately after the experiment. However, Pandey et al. [14] reported that fracture mode did not change within 72 hours of storage before conducting SEM studies and coating in their experiments. Prior to SEM studies the worn surfaces have been coated with a very thin layer of palladium (Pd) using ion sputtering machine (Auto Fine Coater: JEOL, JFC-1600). It is not out of place to mention here that ion coating is done on non-conducting specimen (like biological specimen etc.) to be analysed in SEM for quick and highly efficient results. This is done mainly to prevent charging of electrons at the sample [15]. For some samples energy dispersive X-ray spectroscopy (EDAX) have also been done in conjunction with SEM to find out the percentages of different elements in the sample. Elemental mapping with EDAX is helpful to get insight into the chemical changes on the surface and sub-surface of the sample [16]. As no chemical reaction is taking place in the present case hence EDAX has not done for all the specimens.

Figure 7 shows some typical pattern abrasion of EPDM as obtained from SEM studies. In figure 7(b) a chunk of rubber agglomerate has been separated leaving behind a groove (chunking and grooving). Figure 7(c) reveals the ridge formation which supports the concept of rubber wear by the process of plowing.

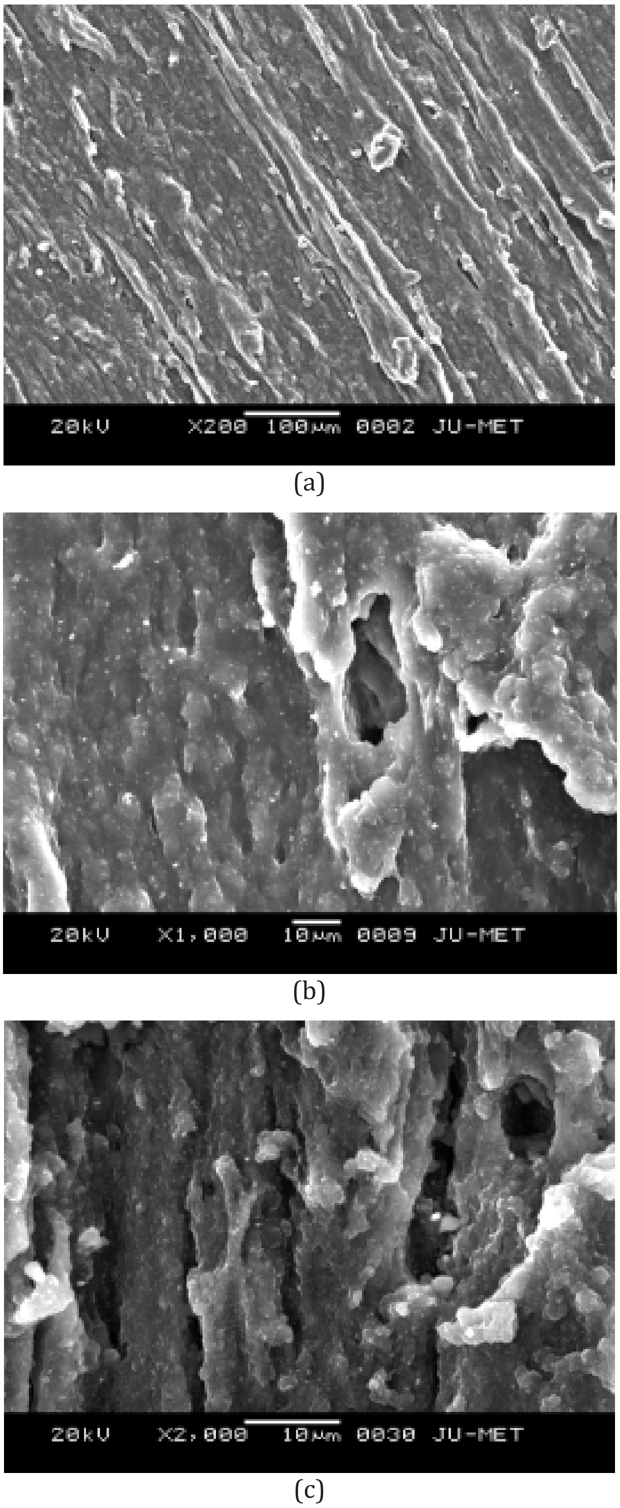

Fig. 7. Worn surface morphology of EPDM corresponding to trial no. 1 (×200), 2 (×1000) and 6 (×2000) as obtained from SEM studies.

The graph of the average specific wear rate is shown in Fig. 8.

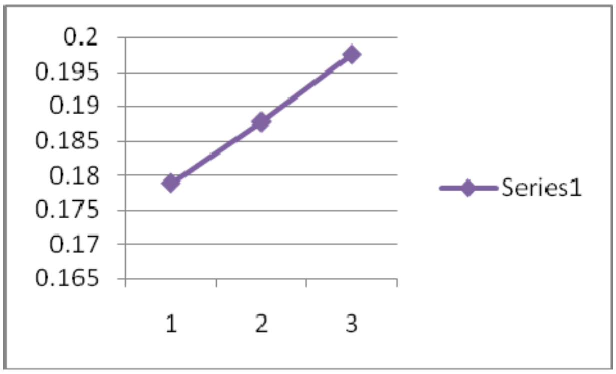

Fig. 8. The specific wear rate of EPDM 55Å (1), 70Å (2) and 80Å (3).

The curves reveal that the specific wear rate is smallest for the softer rubber, that is, EPDM 55Å. The specific gravity is also smaller in case of EPDM 55Å, which depends on the hardness and hardness again depends on the carbon black (CB) content of the rubber. However, in case of flow characteristics of EPDM it has been revealed that EPDM 70Å is better than others. The selection of material depends on the actual requirements in specific application area.

4. CONCLUSION

This experimental work is planned for the characterization of flow as well as wears of EPDM rubber of different hardness in different experimental conditions. The test conditions are very difficult to be harmonized but much care has been taken to obtain results as accurate as possible accepting the noise factors included in the experimentations. The obtained results have been tabulated, graphed and analyzed accordingly in the previous section. Future work has been proposed with different other lubricants as well as inclusion of complex operating environment, like extreme temperature and pressure conditions etc. It has also been proposed to conduct fretting wear test as well as measurement of abrasion loss using roller on plate type tribo-tester.

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