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SOME TRIBOLOGY STATE TESTS OF "EPDM" RUBBER BASED ON LABORATORY EXPERIMENTATIONS

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Abstract: *Rubber is very useful and suitable material for a wide variety of engineering and other applications. Use of rubber as engineering material is not new. However, in the recent time, its application is gaining importance due to several other reasons. Recent and renewed researches on rubber material reveal its suitability for varied engineering applications. Several researches are also going on to enhance the property requirements of rubber for different applications.*

Rubber possesses large elasticity compared to metals, has greater damping capability, high internal friction and can accumulate energy greater than that of steel or other metals. During the deformation of rubber material, e.g., by compressive force, internal damping of the material leads to energy dissipation. This is the cause of hysteretic friction of rubber. Friction of rubber is of great practical importance at the same time it has many disadvantages too.

Amongst various rubber Ethylene Propylene Diene Monomer (EPDM) rubber emerges as a dominant elastomer for major engineering applications in automobiles, constructions, electric and electronic industries etc. The major properties of EPDM are its outstanding heat, ozone and weather resistance ability. The resistance to polar substances and steam are also good.

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. It I, however, need less to mention that the behavior of any viscoelastic material is very difficult to be predicted.

In the present work various tribo-characteristics of EPDM rubber of different hardness are evaluated utilizing the laboratory test facilities available in the frame work of the mechanical engineering department, production engineering department and other specialization of the Jadavpur University, Kolkata. Compression tests have been carried out using 'Instron' to determine the flow behavior of EPDM rubber of different hardness values in dry as well as in different lubricated conditions. The flow behavior like load - elongation curves, true stress - elongation curves true stress - true strain curves have been drawn from the experimental data. Abrasive wear behavior has been evaluated using a two-body abrasion tester and the pattern abrasion has been appraised through SEM/EDAX study. It has been proposed to study further the wear loss using a pin-on-plate (POP) type tribometer and conduct fretting wear test on the same material, that is, EPDM.

Experimental results revealed that the hardness values of EPDM rubber had significant effect on the flow behavior and wear characteristics. The hardness, again, depends on the carbon black (CB) concentration. Thus it can be stated that the flow behavior can be governed by controlling the CB concentration in the EPDM rubber. The results of different tests followed by comparative analysis have been furnished in the 'result and discussion' section of this paper.

Conclusion has been drawn accordingly, highlighting some of the important tribo-characteristics of EPDM rubber as well as shedding light on various possible areas of further researches those should be undertaken in the future to come.

Keywords: *EPDM, compression, flow behavior, abrasion, SEM/EDAX.*

1. INTRODUCTION

Tribological studies of rubber like materials are not new. However, in this 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.

Property prediction is the other driving force [2,17]. It means that the property of engineering and other materials should be predictable and there should have some useable model in that regard. It is, however, needless to be mentioned that the property of any viscoelastic material, like rubber, is very hard to be predicted. 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].Test configurations, parameter selections, experimental conditions are all important factors which should be standardized before comparing the tribotest data generated by various agencies or researchers. All these necessitate further study and iteration of tribotest data for rubber to be used as engineering or other materials.

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 tribotest data are yet to be developed.

In the present work flow behaviors 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 for this purpose. Similarly wear characteristics have been studied in a two-body abrasion testing machine. SEM/EDAX studies have also been made to appraise the pattern abrasion, immediately after two-body abrasion testing.

2. EXPERIMENTAL

The EPDM rubber specimen for the tribo tests in this work were prepared in the laboratory of National Engineering Limited (Rubber Division), Kolkata, following the recipe code as mentioned in Table 1.

Table 1. The recipe code of different hardness of EPDM.

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

However it is needless to mention that the actual proportions of various ingredients are trade secret and strictly a ‘not-disclosed grade’. The above table is thus only a closely indicative one.
Basic ingredients were pre-mixed in a K4/2A-MK3 (Alfred Herbert) for 6 minutes at a ram pressure of 100 psi. Curatives were then 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 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 ($\Delta m = Mh - M_l$) were determined with Oscillating Disc Rheometer equipped with computer assisted data acquisition system and supported by ‘Rheosoft’ software. Standard procedure as is observed in [5] and others were followed in that regard but the machine used for the purpose is Indian one and specific procedural steps for the said machine were followed accordingly. M_h and M_l are high and low Mooney (torque) respectively. The torque was monitored as a function of time and the optimum cure times were recorded from the corresponding rheographs, one such graph is shown in Figure 1.

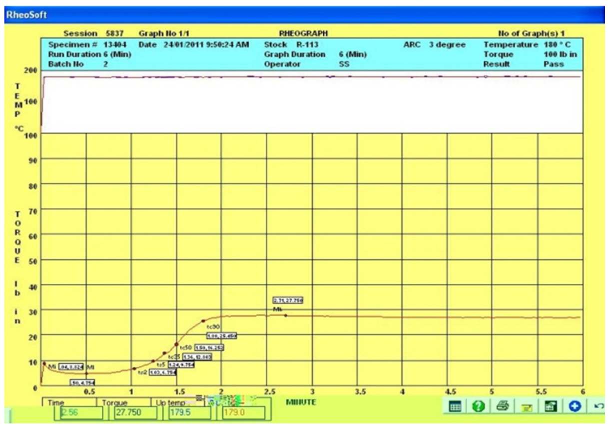


Figure 1. Torque-vs.-Time rheograph of an EPDM specimen.

The material after qualifying the rheometric analysis was ready for molding operation. Short cylindrical specimen of diameter φ (16.5±0.5) and height h (12.5±0.5) were then prepared in the steam heated hydraulic press at a pressure of 3000 psi and temperature 150^0C. 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 spew of materials have 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 was placed axysymetrically in between two flat mild steel platens. Much care had been taken in such placement to ensure an even force distribution on both the faces of the specimen. The required compressive load was 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 Figure 2, is equipped with '8800: Instron SAX V9.3' software based data acquisition system. Only one fatigue cycle had been utilized at a frequency of 0.005 Hz for the application of compressive load on the specimen. The height of each cylindrical specimen was reduced by 65%. Each test had been replicated twice to observe the repeatability of the process. The compressive load followed by load relaxation data had been recorded and later utilized to plot the loading and unloading curves.

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

Five different states of test had been applied during compression. One in dry condition, one under fixed contact and three with different lubricants like, talc, water and grease. Increased friction, during compression, in between the die and work piece mating surfaces leads to the development of an undesirable phenomenon known as 'barreling' or 'pan caking'. The metal spreads over the die surface to increase its diameter when it is compressed in between two die halves. 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 is the basic explanation of barreling [3]. One such barreling during compression under fixed contact, using sand paper, is shown in Figure 3. This undesirable frictional force may be reduced by using some suitable lubricant. The effect of compressive load on EPDM specimen of different hardness in dry working condition, that is, without any lubricant, was appraised by the present author [4]. Similarly, the flow characteristics of EPDM rubber of different hardness under compressive load in the presence of some lubricants were studied by the present author [6]. It is not out of place to mention here that to reduce friction and wear between two mating and interacting surfaces some film of solid, liquid or gas is applied which is considered as lubricant[7]. Selection of proper lubricant(s) depends on several considerations and should be judicious [8]. In this experimental work some lubricants were selected based on the literature survey and considering the practical work environment [9-12]. The characteristics studied for this purpose includes stress-strain relationships, specific energy and loss factors.

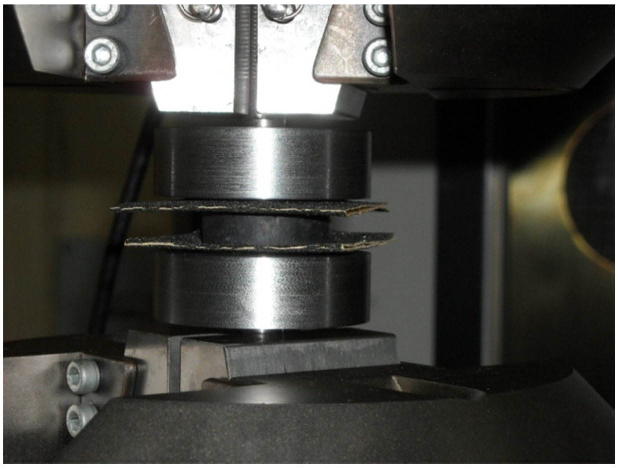


Figure 3. Compression of EPDM specimen using fixed contact.

2.2 Abrasion test

Specimen of sizes 70mm x 30mm x 2mm were cut from vulcanized rubber sheets of 150mm x 150mm x 2mm for conducting the abrasion tests. EPDM rubber of three different shore hardness values was selected for this purpose. These are 55 Å, 70 Å and 80 Å respectively. Abrasion tests were carried out using a two body abrasion tester TR-605 (Ducom) as shown in Figure 4. The machine is designed to conduct test as per ASTM D 6037 (Test method B) and/or ISO 8251 [18]. 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 of stainless steel having a diameter of 50mm and width of 12mm. Silicon Carbide (SiC) water proof paper (Carborundam Universal) of grades ER 240, ER 220 and ER 180 were pasted on the top surface of the wheel for the purpose of abrasion. Appropriate sizes of the abrasive papers were cut and pasted on the wheel using an adhesive (Feviquick). Rubber specimens were placed in the desired position on the machine table and clamped properly. The specimens were also subjected to normal load using a dead weight. The leverage action obtained in the machine in use is 1:2, that is, a counter weight of 2N will apply 1N of normal load on the job. Then the specimens were abraded against the abrasive paper under simulated abrasive wear condition.

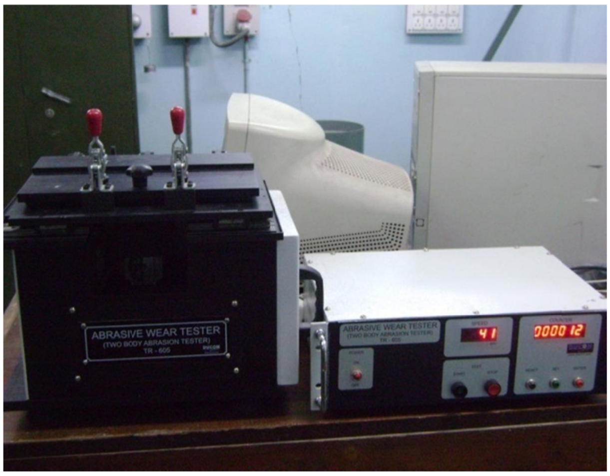
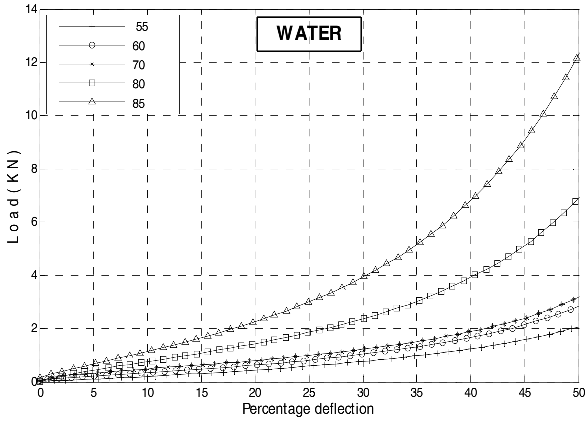


Figure 4. Laboratory set up of a two-body abrasion tester.

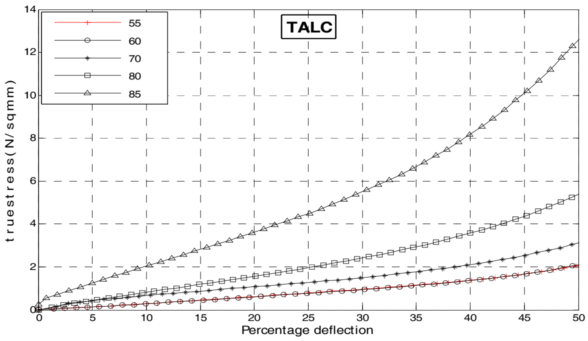
For this laboratory experimentation three different levels of four factors have been considered. The factors are hardness of EPDM rubber, abrasive grade, load on job and cycles and the levels are low, medium and high respectively. It is needless to mention that if a full factorial experimentation had been conducted with the four factors each at three levels, as mentioned, then a total of 81 experiments would have to be carried out and the number would have been multiplied accordingly for replication. In the present study, an L_9- orthogonal array has been selected based on Taguchi's experimental design technique [13] 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 3 in Appendix-I.

3. RESULTS AND DISCUSSIONS

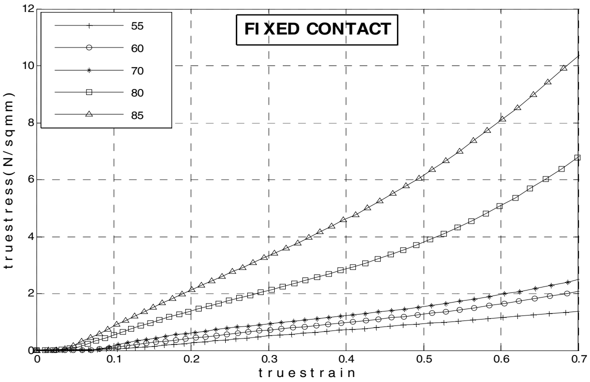
Table 2, in Appendix-I, indicates the flow characteristics of EPDM rubber under compressive load and in different working conditions, that is, with or without lubricants. The lubricants, as indicated in the table, are selected based primarily on the literature survey as well as from the real life experience. 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 in that regard. Some flow curves are shown in Figure 5 (a), (b) and (c) as samples.



(a)



(b)



(c)

Figure 5. Flow characteristic curves are shown in (a), (b) and (c) under different conditions as indicated in the curves.

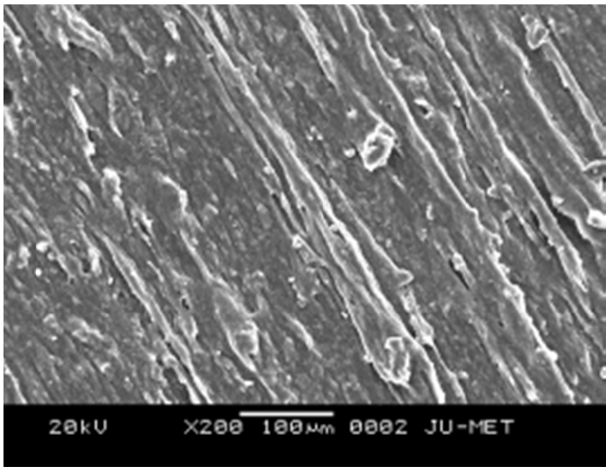
It has already been mentioned that four factors, each at three levels, have been selected to conduct the abrasion test. Table 3 indicates the said factor – level combinations and corresponding specific wear rate data which is obtained from the following formula [11]:

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

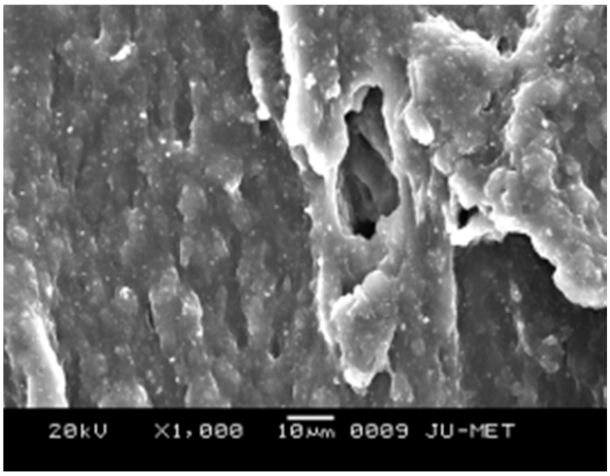
where, W_s = specific wear rate (mm^3/Nm)
Δm = mass loss recorded gravimetrically (gm)
ρ = specific gravity of EPDM (gm/cm^3)
F = the normal load on the job (N)
and, L = overall sliding distance (m)

The worn surface morphology had been studied for each sample immediately after the abrasion using a scanning electron microscope (SEM: JEOL, JSM-6360, model 75 82) to see the smallest detail of the pattern abrasion in the range of 4 – 5 nm (4 – 5 millionths of a millimeter). The test had been conducted immediately after the experiment, though it is reported by Pandey et.al. [14] that in their experiments fracture mode did not change within 72 hours of storage before conducting SEM studies and coating etc. The worn surfaces had been coated with a very thin layer of palladium (Pd) using ion sputtering machine (Auto Fine Coater: JEOL, JFC-1600) prior to SEM studies. It is not out of place to mention here that ion coating is done on non-conducting specimen (like biological specimen etc.) to be analyzed 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) had 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.

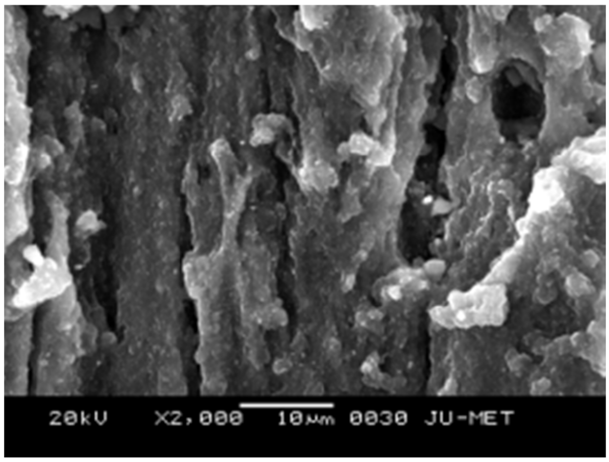
Figure 6 shows some typical pattern abrasion of EPDM as obtained from SEM studies. In figure 6(b) a chunk of rubber agglomerate has been separated leaving behind a groove (chunking and grooving). Figure 6(c) reveals the ridge formation which supports the concept of rubber wear by the process of plowing.



(a)



(b)



(c)

Figure 6. 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 Figure 7.

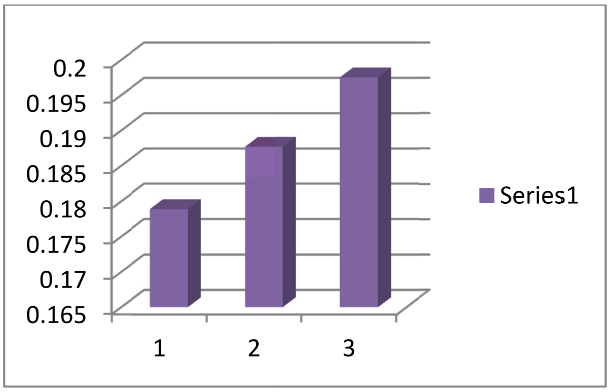


Figure 7. The specific wear rate of EPDM 55Å (1), 70Å (2) and 80Å (3).

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 is revealed that EPDM 70Å is better than others. The selection of material depends on the actual requirements in specific application area.

CONCLUSION

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

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APPENDIX – I

Table 2. 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]

Table 3. 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