

## Experimental determination of the contribution of early running stages in the wear of polymeric moving elements

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### تقدير تجريبي لمساهمة المراحل الأولى للحركة في تآكل العناصر اللدانية المتحركة

يعتبر التآكل أحد أهم العيوب التي تقيد استعمالات اللدائن، ولا تزال الأبحاث تتوالى للحد من هذه الظاهرة أو التحكم بها. ولقد أشار الباحثون إلى عدة آليات لتآكل المواد المتلامسة في مناطق تلامسها. وبناء على هذه الدراسات أيضا فعند توقف حركة العناصر الميكانيكية المتحركة على بعضها فإن مناطق التلامس الحقيقي تتحمل كافة الأحمال مما يؤدي إلى تالاصق قممها. وعند إعادة الحركة تنكسر هذه القمم المتالصة مما يؤدي لتآكل العناصر باليتين هما (بالتلصق، والعنصر الثالث أو الحبيبات الناتجة عن تكسر القمم المتالصة). هذا البحث جزء من جهود الباحثين للتعرف على آليات تآكل العناصر المتلامسة في مرحلة بدء الحركة، وبالتالي تقييم مساهمة هذه المرحلة في تآكل بعض المواد اللدنة. تم اختبار تسع لدائن هي: نايلون ٦٦، النايلون المخلوط بنسبة (٣٠%) ألياف زجاجية، ألياف الفينول، (بي تي إف إي)، بولي بروبيلين، (بي في سي)، كوبوليمر، هومبوليمر، بولي إيثيلين. كما تم إجراء التجارب في حالتي الجفاف والتزليق. وقد استخدمت المياه المقطرة ومياه البحر كعنصري تزليق. وتمت دراسة تأثيرات عاملي الحمل وزمن الحركة. وللقيام بذلك اعتمد زمن (٣٠ ثانية) حدا أقصى لنهاية مرحلة الحركة الابتدائية. قبل بداية كل تجربة تحمل العينات المختبرة وتترك متلامسة مع سطح الاختبار المصنوع من الفولاذ المقاومة للصدأ ومن دون حركة لفترة زمنية كافية لتشكل التالاصق. أجريت التجارب في وسط ذي درجة حرارة (٢٣) و رطوبة (٤٠%). بينت النتائج وجود ثلاث آليات للتآكل هي (التلصق، والحت، والعنصر الثالث). كما بينت أن المواد المختبرة تسلك في تأكلها سبلا مختلفة عن بعضها.

#### Abstract

Wear is one of the great disadvantages of polymers which restricts their use. Studies to control this phenomenon are continuously conducted. Accordingly, researchers stated several mechanisms of wear that may take place at the area of contact of resting or moving parts. However, when moving parts rest on each other, the real area of contact supports all loads, hence adhesion at the tips takes place. Restarting the motion causes breakage of the welds, hence generating abrasive and third body wear. This work is a part of continuous effort of the author to determine the possible wear mechanisms that take place at the starting stage of motion, hence, to determine the contribution of this stage in the wear of some polymers. Nine polymers were examined: Nylon66, 30% GFNylon66, Phenolic-fabric, Polytetrafluoroethylene (PTFE), Polypropylene (PP), Polyvinylchloride (PVC), Copolymer, Homopolymer, and Polyethylene (PE). The trials were conducted under dry and lubricated conditions. Distilled and sea waters were used as lubricants. The effects of applied load and running time (sliding distance) were examined. Running each trial, from rest state up to 30 seconds was considered the time limit for the starting stage. However, before starting each trial, the specimen was rested for (30 min.) on the stainless steel counterpart. The work was conducted under controlled environment of temperature (23 °C) and humidity (40%). Results show evidence of adhesive, abrasive, and third body wear occurrence. It also shows various behaviors of wear rates.

**Key words:** Dry and lubricated wear of polymers; self lubricated materials, wear mechanisms; lubricants and lubrication.

## INTRODUCTION

As one of the three basic types of materials, polymers are the latest and at the same time the oldest known to mankind. In spite of the negative side of their properties such as low strength, low modulus of elasticity, limited service temperature, and degradation when they are subjected to sun light, polymeric materials are the prime mover in replacing many engineering materials over most industries. This is related to the positive side of their properties such as high strength/weight ratio, low friction coefficient, self lubrication, ease and cost effective manufacturing, and machinability. Coupling that with the growing industrial demands for self lubricated components has recently moved the researchers to improve on, and learn more about the properties of this new generation of engineering materials. Selected examples are Kempthorn, 1993; Brydson, 1993; Bhushan and Gubpta, 1991, BSviridyonok, 1991; Sheldon, 1982; Richardson, 1977; Dowson, *et al*, 1976, Lancaster, 1973; and others. However, the published research work on the mechanical and tribological properties of the polymers and composites is still cursory.

One of the many tribological properties of polymers that have attracted the attention of researchers has been the wear resistance. As a phenomenon that depends on many factors such as load, sliding speed and distance, initial temperature, thermal, mechanical, and chemical properties, [wear] has been defined as a progressive damage, involving material loss, which occurs on the surfaces of a component as a result of its motion relative to the adjacent working parts Williams 1994. However, wear is of a significant importance to the functions of many moving engineering parts. It is suggested that there are many possible physical mechanisms of wear, such as adhesion, abrasion, erosion, third body, fatigue, etc. Generally, more than one mechanism occurs at a time Zhang, *et al*, 2003; Lee, *et al*, 2002. However, wear of polymeric materials are still ill-understood and, consequently, monumental progress has been made to avoid the unwanted results of it Trevoort *et al*, 2002.

The study of the wear of polymers was conducted under dry and lubricated conditions. Different lubricants (solids, semi solids, liquids, and gases) were used to lubricate the area of contact between the parts in relative motion. Many parameters that could affect the wear behavior were examined. Among the selected examples of published works on dry wear are Zaamout, 2006, Zaamout, 2004; Palabiyik, and Bahadure, 2002; Hayashi *et al*, 1999; Indumathi *et al*, 1999; Zaamout & Makhadmi, 1997; Yen *et al*, 1996; Rhee & Ludma, 1976, and on lubricated wear are Zaamout & Makhadmi, 1999, 1997; Zaamout, 1995; Dwyer-Joyce & Sales, 1993; Evans 1976; Abouelwafa, *et al*, 1976. Overcoming or complete controlling of the wear problem is still beyond reach. This research [carries on] the author's and colleagues' effort on the subject Zaamout, 2004.

## EXPERIMENTAL WORK

### Wear machine

A pin-on-disc wear testing machine of crossed cylinders configuration shown in Figure 1, was employed during this research to provide the needed relative motion between the examined polymeric cylindrical samples (pins) and the cylindrical stainless steel counterpart (disc).

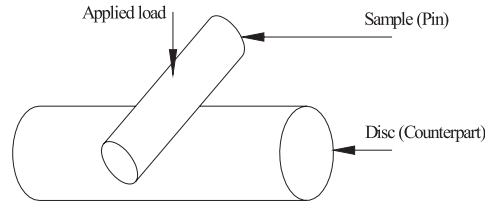


Figure 1. Crossed cylinders configuration.

Figure 2 shows a schematic diagram of the wear machine. The stationary sample 1, is held in seat 3, by screw 2. The seat is attached to arm 4 hinged to column 5 stationed on carriages 6. Load 8 is applied to hanger 7, which in turn is hinged to the other end of arm 4. The rotating disc (counterpart) 9 is held in position by the headstock 10. The rotational speed of the machine is provided by box 11. (Full description of this machine is provided in Zaamout and Makhadmi, 1997.

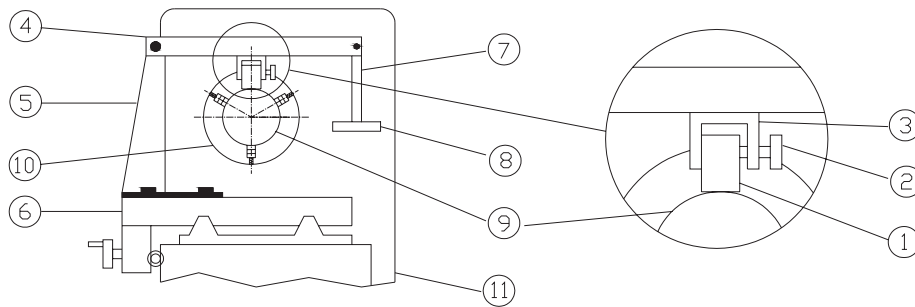


Figure 2: Schematic diagram of pin-on-disc wear test machine.

- 1- Sample (stationary pin), 2- Tightening screw, 3- Sample seat, 4- Arm, 5- Column, 6- Carriage,  
7- Load hanger, 8- load, 9- rotating disc (counterpart), 10- Headstock, 11- Speed box

### Timer

The electrical timer was employed to record the running time of each experiment. To ensure a simultaneous start and stop for both machine and timer, they are connected to the same start and stop buttons.

### Balance

Electrical balance type (Toledo – AB104) supplied by (Mettler of Denmark) was employed to derive the material loss by wear, hence evaluating the wear volume and consequently, the wear rate for each run. The balance accuracy is ( $\pm 0.1$  mg) as indicated by the manufacturer. This was checked by the author before use.

### Microscopy and camera

A microscope type (Ferox, 051594), supplied by the (CETI of Belgium) was also employed in this research work. It was used to examine the area of contact on both polymeric specimens and stainless steel counterpart. This examination was carried out before and after each run. In addition, a (Kodak Easy Share V610) digital camera, supplied by (Eastman Kodak Company – USA), was attached to the microscope and computer. Some relevant photos were shot.

### Counterpart (Disc) and talysurf

A (60 mm) diameter cylinder was used as counterpart to the polymeric specimens. It is stainless steel alloy grade (AISI 304) supplied by (SANYO Special steel Co. Ltd, Japan). To ensure the same surface roughness for all tests, the surface was first prepared on grinding machine for once, then by abrasive paper grade (600) before each run. The surface roughness [was] then checked by Talysurf apparatus type (Surtronic -3).

### Materials of wear samples

Nine polymers, supplied as rounded rods by (RS Company, England), were examined in the as-received condition in this work; namely: Nylon66 (N66), GFNylon66 (GFN), Phenolic-fabric (PF), Polytetrafluoroethylene (PTFE), Polypropylene (PP), Polyvinylchloride (PVC), Copolymer (CP), Homopolymer (HP), and Polyethylene (PE). Manufacturer properties are tabulated in Table 1. They were selected due to their wide use in different industries to produce engineering parts such as gears, bushes, bearings, wheels, rollers, cams[, etc.] The examined samples were cut to size of (20–25 mm) diameter and 40 mm length, from the supplied rods.

### Lubricants and lubrication

Distilled water type (Al-hadara), manufactured and supplied by (Al-hadara Factory, Riyadh, Saudi Arabia), and sea water brought from the red sea at about 3 km off Jeddah shore, were both used to lubricate the area of contact between the examined samples and counterpart surface.

The lubricant was poured, by gravity action, at the borders of the area of contact before run and continue[d] to the end of each lubricated run. The lubricant was then dragged into the area of contact under the hydrodynamic action.

### Wear calculation

The wear volume for each run was obtained from the difference in sample weights before and after the run, and the density of the examined material. Assuming  $V$  is the wear volume,  $F$  normal applied load,  $S$  sliding distance, and  $k$  the specific wear rate SWR, the wear rate [was] then calculated by the Archard equation [Archard, 1953]:

$$V = k F S \quad \Rightarrow \quad k = V / F S$$



## EXPERIMENTAL PROCEDURES

Experimental procedures were devised by the author and strictly followed during the courses of all the experiments. To avoid any spurious or unwanted results, all non-related parameters were kept at constant values.

### Procedure steps for dry condition

The effects of applied load and sliding distance (sliding time) were examined. During the course of this study all [non-related] parameters were kept constants at: sliding speed (1.4 m/s), counterpart surface roughness (5  $\mu$ m), laboratory temperature (23°) and humidity (40%). For accuracy purposes, each run was repeated at least three times and average values were derived.

### The effect of applied load:

In addition to the above constant parameters, the sliding distance/ sliding time was also kept at constant value of (42 m/30 s). The applied load was varied in the range of (10-110 N) at an interval of (10 or 20 N) each time.

The steps of each trail were:

- 1- Prior to each run, the disc was polished, washed by acetone and dried.
- 2- The sample (pin) was also washed by warm water, cleaned by a cloth, left (30 minute) to dry; then was weighed.
- 3- The pin was firmly seated in place, the holder system was lowered on counterpart and contact was established.
- 4- The load was applied to load hanger.
- 5- The timer was zeroed and the machine started.
- 6- At the end of the trial, the machine was stopped; the specimen removed, cleaned off loose debris and/or worn polymeric fibrils, then left for a period of (2) hours to acclimatize.
- 7- After acclimatization, the specimen was weighed again and the weight was recorded.
- 8- On-restarting the test, the counterpart was prepared again; the specimen was replaced by an identical fresh one.

### The effect of sliding distance (running time):

The applied load was kept at constant value of (50 N), whereas the sliding distance was varied in the range of (7.5 to 60 m) at an interval of (7.5 m). The other constant parameters were kept at the same values indicated above. The same steps of applied load were followed.

### Procedure steps for lubricated conditions

The above steps were followed. The lubricant was continuously and gently pumped at the area of contact.

## RESULTS AND DISCUSSIONS

### Applied load

#### Dry condition:

Figure 3 shows the variation of the specific wear rate with the normally applied load for the nine polymers. Except for the PTFE, where the specific wear rate SWR is always decreasing with an increasing load, the results illustrate that SWR for all polymers decreases with increasing the load up to 50 N, then it changes the trend and starts to increase as the applied load increases.

Since the mechanical properties of polymers, (tensile, impact, flexural, shear strengths and hardness; Table 1), are load and time dependent, such behavior could be related to the following: (a) the simple theory of wear, which suggests that wear of a material increases with increasing certain parameters such as load, sliding distance, and temperature of the area of contact. However, the results also indicate that the increase in wear with applied load is non linear. The wear for loads up to 60 N is mild, whereas it is severe for greater values of load; (b) due to the time given to the sample to rest on its counterpart before the run, some polymeric fibrils adhere to the protuberance of counterpart. Starting the run causes detachment of these fibrils from the bulk, hence increasing the wear and consequently increasing SWR; (c) high loads increase the adhesion of polymer, the penetration of counterpart protuberances into the polymeric bulk, and the temperature at the area of contact, hence increasing SWR; (d) as a result of increasing the temperature at the contact area, the mechanical properties decrease. This again, eases the detachment of polymeric fibrils from its bulk and [adheres] it to the counterpart surface since it is colder than the sample due to heat dissipation into the stainless steel (photos 1-3); (e) as a result of polymer low thermal conductivity, the adhesion of the worn fibrils to the counterpart surface causes heat concentration at the area of contact, hence softening the material and easing the detachment of the fibrils from the bulk and increasing SWR; (f) as for PTFE; since it is an anti-adhesion polymer only abrasion and third body wear occur (Photos 4-6), and the SWR keeps decreasing with increasing load.

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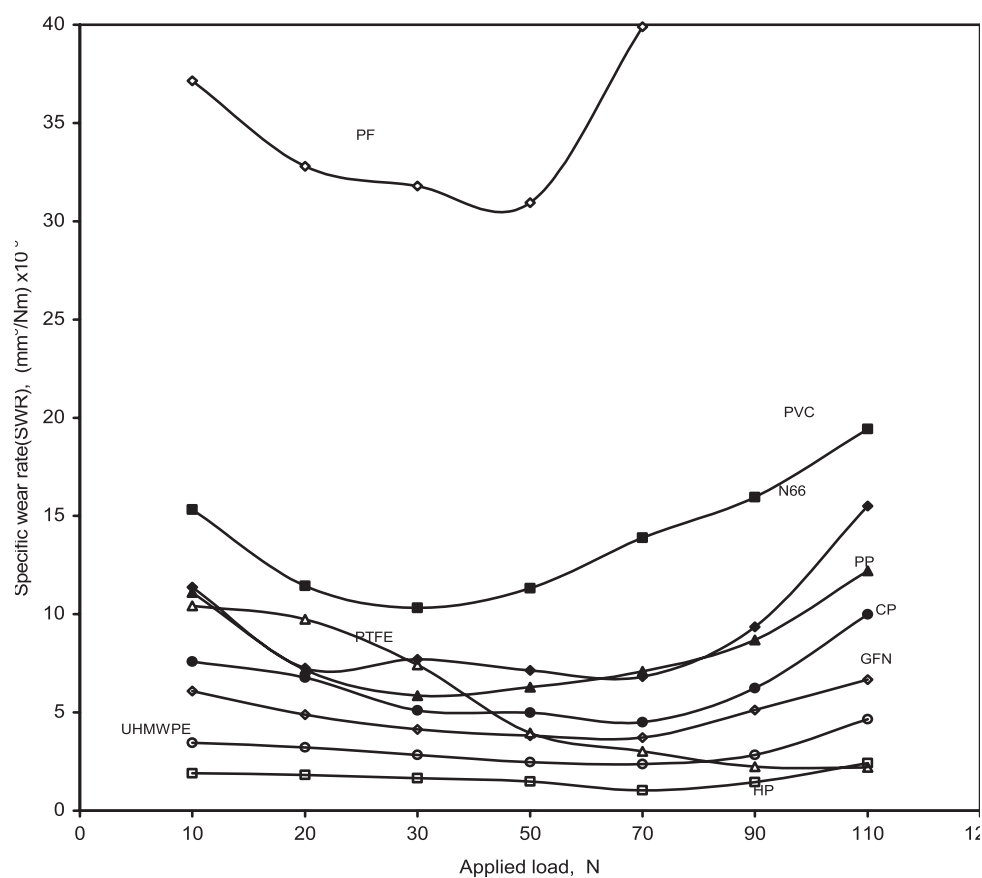


Figure 3: Variation of SWR with load – dry

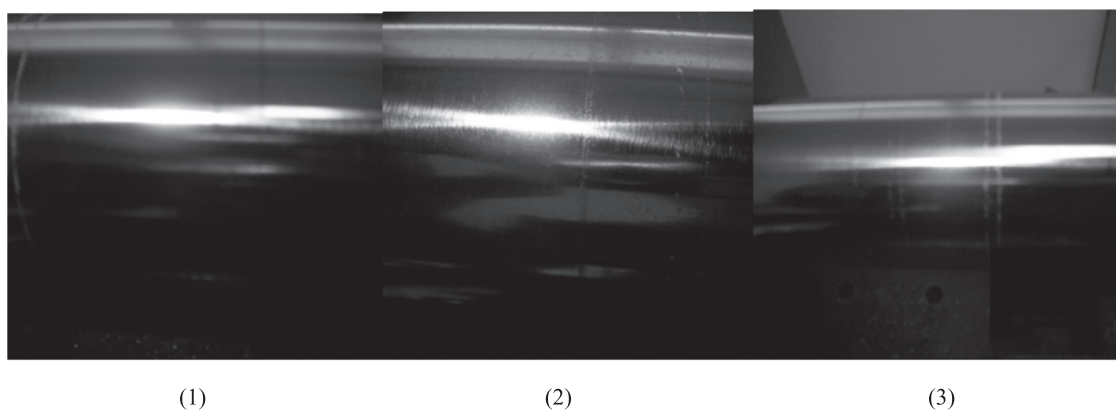
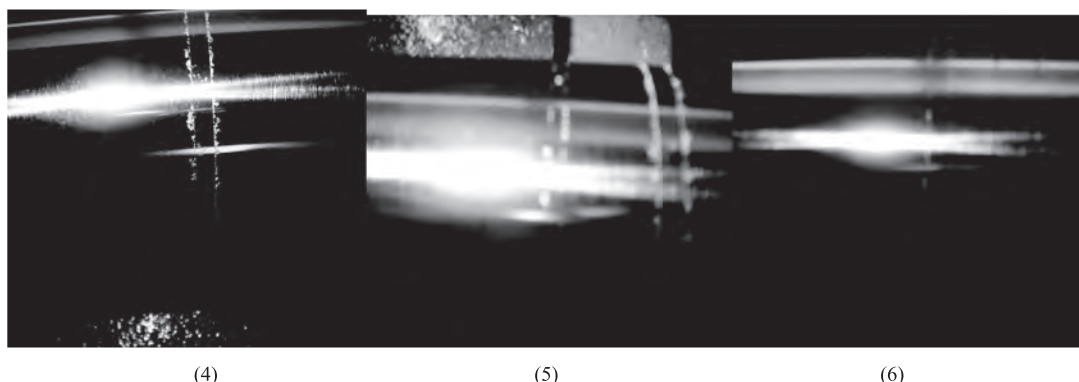


Photo 1-3: the adhered thin polymeric films to the counterpart surface



(4) (5) (6)  
Photos 4-6: abraded fibrils and wear trace on the counterpart surface

The results also classify the polymers according to SWR. Phenolic-fabric (PF) seems to have highest values, whereas Homopolymer (HP) has the lowest. Discussion of the reasons is beyond the scope of this work, however, detailed discussion is given by the author, (see Zaamout, 1997 – 2006). In summary, he related this behavior to the properties of polymers: (a) abrasion resistance, where PF is the poorest; (b) adhesion of polymeric fibrils to the counterpart surface changes the contact from polymer-to-steel, to polymer-to-polymer, this causes tragic increase in temperature at the contact area, hence increasing SWR. Nylon66 and GFnylon66 are examples; (c) thermal conductivity, where some polymers dissipate heat faster than others. PCV and UHMWPE are examples; (d) other mechanical properties such as hardness, compression, tensile, flexural, and impact strengths.

#### **Distilled water lubricated condition:**

Figure 4 shows the variation of SWR with load for distilled water condition. It illustrates that SWR decreases with increasing load for all polymers. However, as the load precedes the value of 50 N, the decrease in SWR becomes less drastic such behavior is thought to be related to the presence of water at contact area and around it.

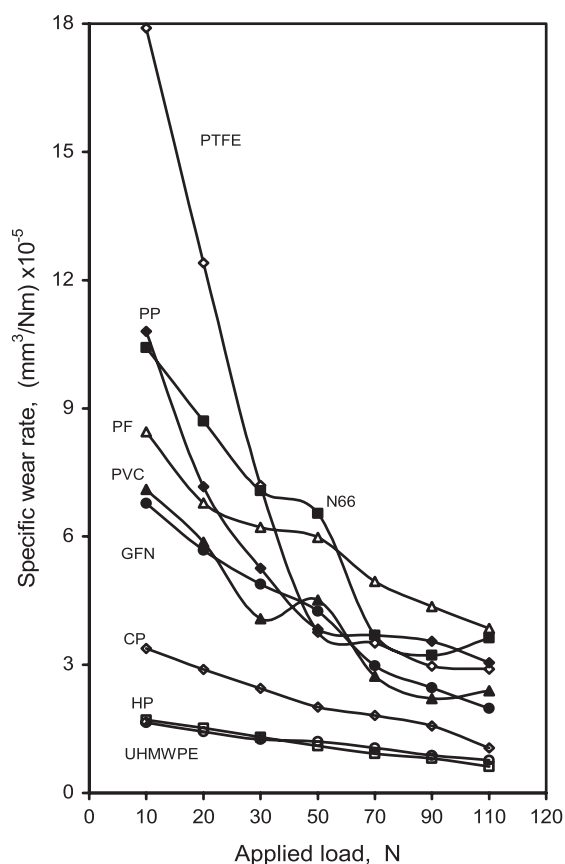


Figure 4: Variation of SWR with load - Dis. water

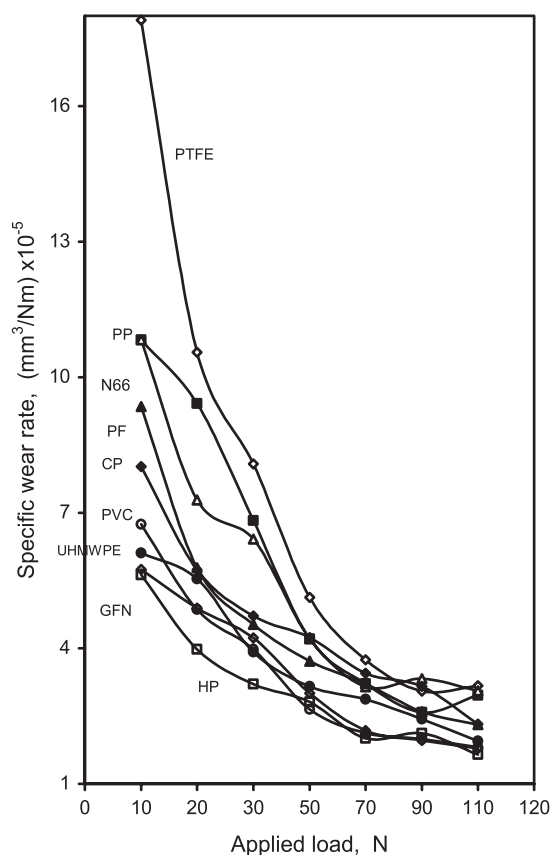


Figure 5: Variation of SWR with load - Sea. water

The water works in three ways: (a) as a coolant, preventing temperature rise at the contact area, which is the principal cause of wear problem under dry condition; (b) as a blowing agent, which blows the worn polymeric fibrils out of the contact area and from the counterpart surface, hence preventing any accumulation of polymer on the counterpart surface, therefore no photos could be shot for the worn scar on the counterpart; (c) as a lubricant, lubricating the area of contact. However, water is one of the less viscous and poorest lubricating agent. Furthermore, at high loads, the contact between the two cylinders (sample and counterpart) changes from point-on-point to area-on-area, hence dragging the lubricant (water) inside the area of contact by the hydrodynamic action. This tends to make the decrease in the SWR less drastic.

The results also classify the materials according to SWR. For loads less than 40 N, PTFE seems to have highest values of SWR, whereas UHMWPE and Homopolymer (HP) have the lowest. Discussion of the reasons is beyond the scope of this work[.] however, it is given by the author as indicated earlier, and it is similar to that of dry condition.

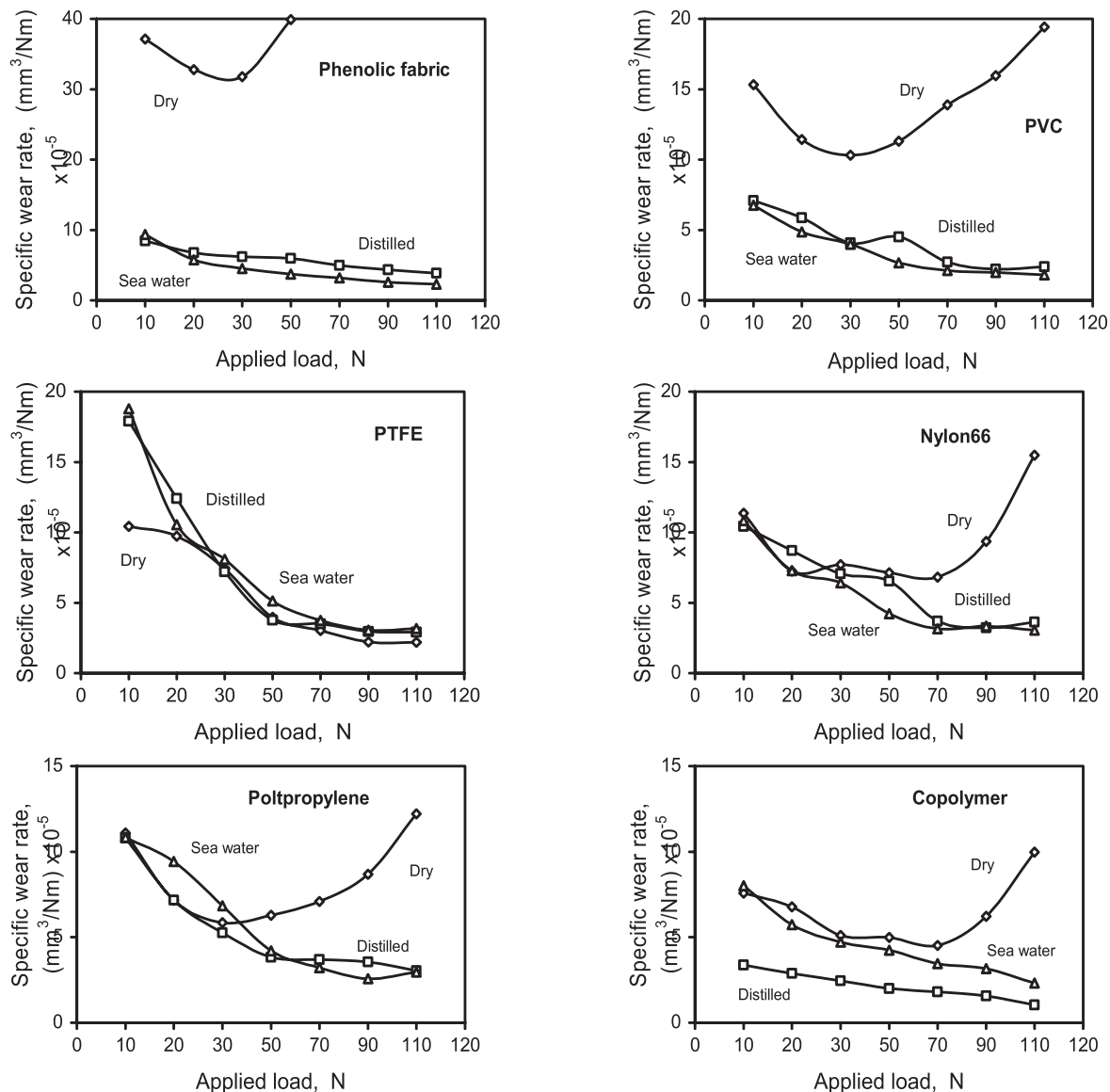
#### Sea water lubricated condition:

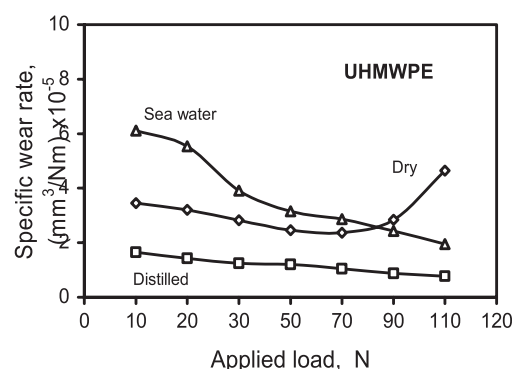
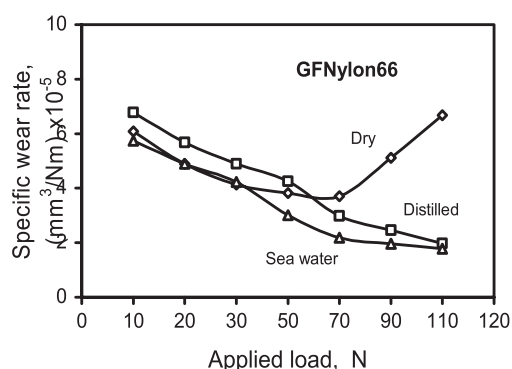
Figure 5 shows the variation of the specific wear rate with the normally applied load for sea water lubricated condition. Here again, the results show that the SWR is always decreasing with increasing load for all nine polymers. Interpretation is very similar to that introduced for the previous distilled water lubricated condition. In addition, the classification of the polymers according to the values of SWR is very closely the same.



### Comparison of results:

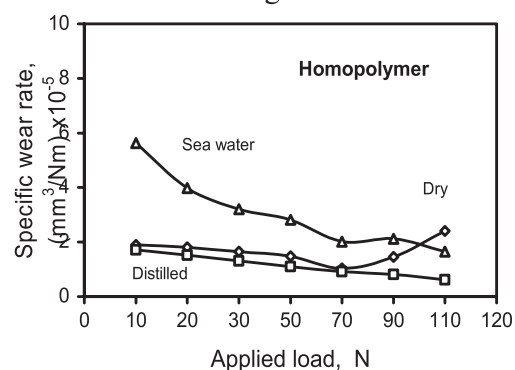
The figures below compare the results of the variation of SWR with load under dry and water lubricated conditions. Each figure shows one polymer. The results show that the use of water has drastic effects on the wear behavior of all examined polymers. The effects of water are illustrated as follows: (a) it reduces the level of SWR for all polymers. This is very drastic in the cases of Phenolic fabric and PVC. As stated in the previous discussion, this is mainly due to the cooling action of water rather than lubrication. (b) It changes the behavior of SWR from (decrease-increase) for dry condition to (always-decrease) with increasing load.





This is true for all examined polymers except PTFE and Homopolymer, where it is already (always-decrease) condition. Discussion of the reasons is presented earlier; (c) the use of sea water more effective than the distilled water for some polymers like Phenolic fabric, PVC, Nylon66, and GFNylon66, whereas, distilled water shows better results for PTFE, Polypropylene, copolymer, UHMWPE, and Homopolymer. The reasons for these results could be related to the action of water and its contaminants.

Distilled water works mainly as a coolant such chemicals and other contaminants could be responsible for this behavior. As for the UHMWPE, Homopolymer, and other similar materials, results show that the presence of sea water increases wear, and the levels of the SWR. The reason for this behavior is thought to be related to the decomposition of the materials with water and chemical contaminants.



## Sliding distance (Running time)

### Dry condition:

Figure 6 shows the variation of the SWR with the sliding distance (running time) for all nine polymers. Except for PF, where the specific wear rate SWR is always increasing with increasing distance, the results illustrate that SWR for the rest of polymers decreases with increasing the sliding distance. However, the increase in wear volume with sliding distance results in a non linear decrease in SWR. It has been stated above, that the mechanical properties of polymers are load and time (sliding distance) dependent. Accordingly, such behavior may be related to the very similar reasons indicated earlier for the effects of applied load condition: (a) the simple theory of wear; (b) the time given to the sample to rest on its counterpart before the run; (c) the temperature generated at the area of contact due to sliding; (d) the drastic reduction in the mechanical properties of the polymers due to the generated heat at area of contact.

As for PF, since it is anti-adhesion and has a very low abrasion resistance, the increase in wear volume with distance is very sharp; this allows the SWR to always increase with the increasing sliding distance.

The results also classify the polymers according to their SWR. Phenolic-fabric (PF) seems to have the highest values, whereas UHMWPE has the lowest. The reasons for this behavior are similar to those indicated earlier for load effects under dry condition.

#### Distilled water lubricated condition:

Figure 7 shows the variation of SWR with sliding distance for distilled water condition. The results illustrate that SWR decreases with increasing distance for all polymers. Interpretation is similar to that of applied load.

#### Sea water lubricated condition:

Figure 8 shows the variation of the specific wear rate SWR with the sliding distance (or running time) for sea water lubricated condition. Here again, the results illustrate that SWR decreases with increasing distance for all polymers. Interpretation is similar to that of applied load.

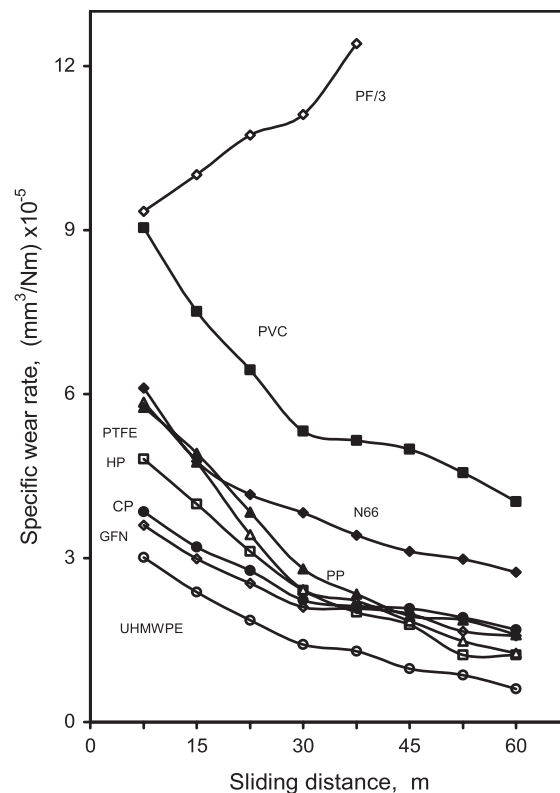


Figure 6: Variation of SWR with sliding distance – Dry.

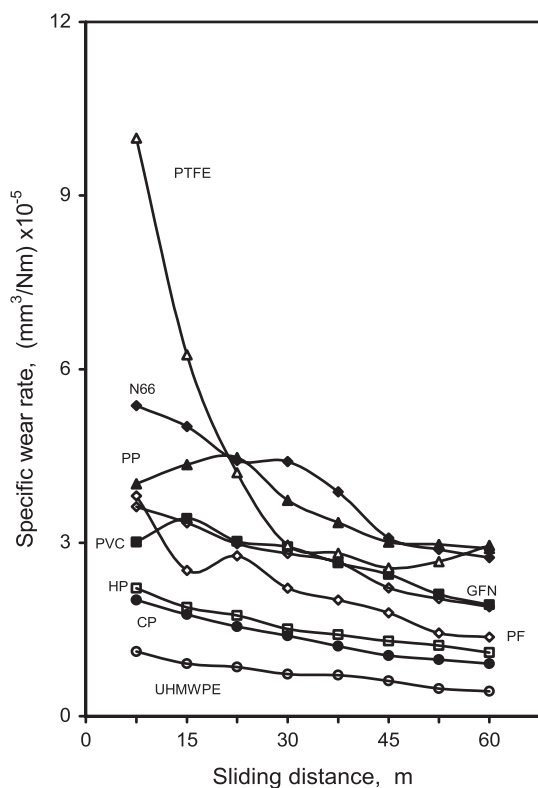


Figure 7: Variation of SWR with distance – Distilled Water.

#### Comparison of results:

The next nine figures compare the results of the variation of the specific wear rate SWR with the sliding distance (or running time) under dry, distilled water lubricated, and sea water lubricated conditions. Each figure belongs to one polymeric material, which is indicated on the figure. The results show that the use of both waters has drastic effects on the wear behavior of all nine examined polymers. The effects of water have been discussed for the case of the

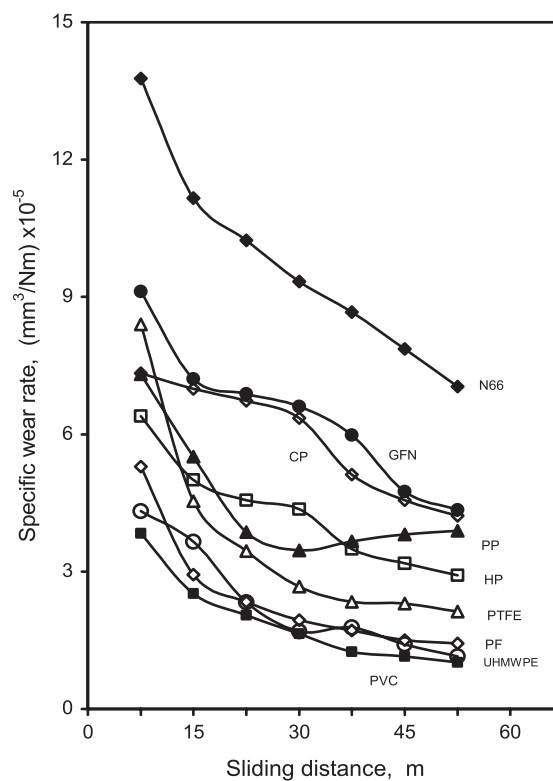
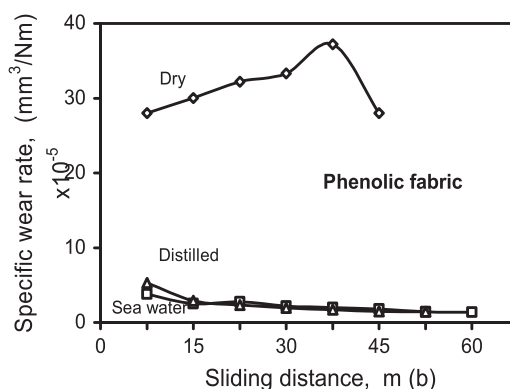
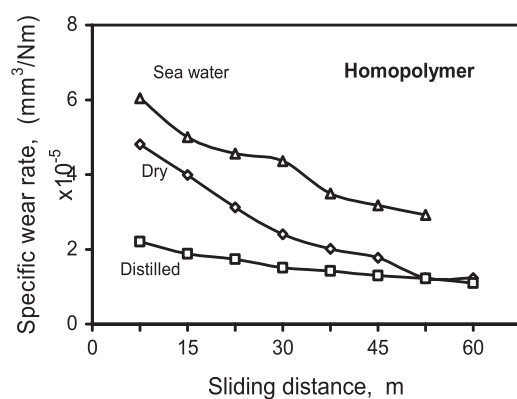
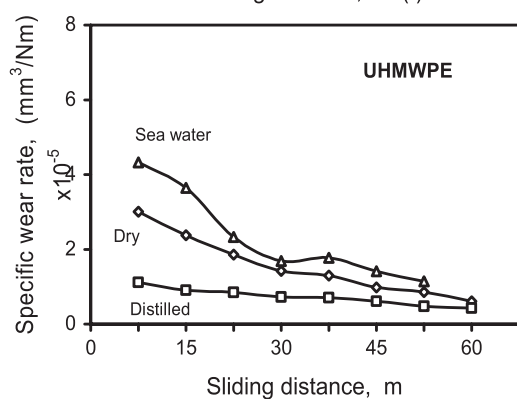
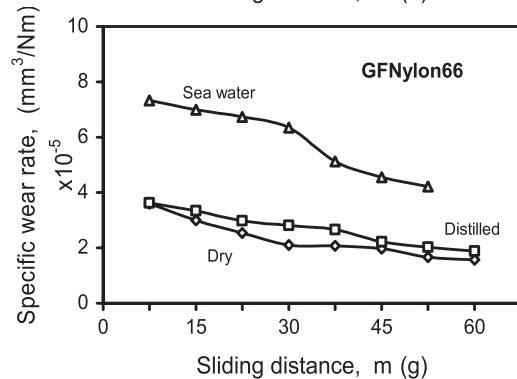
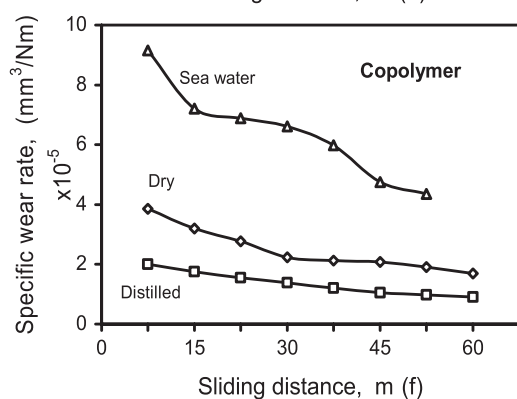
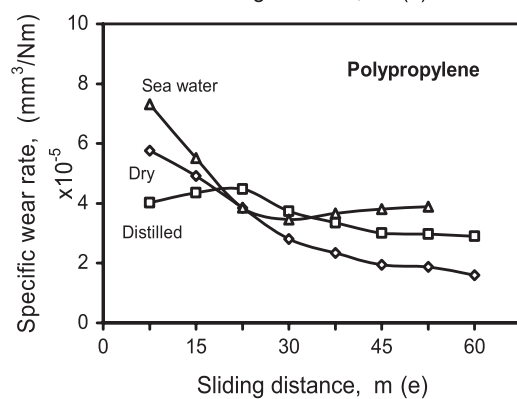
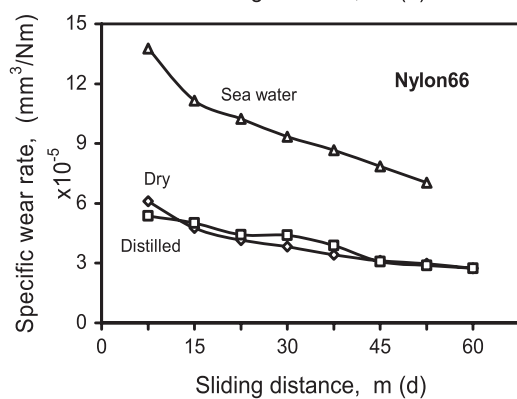
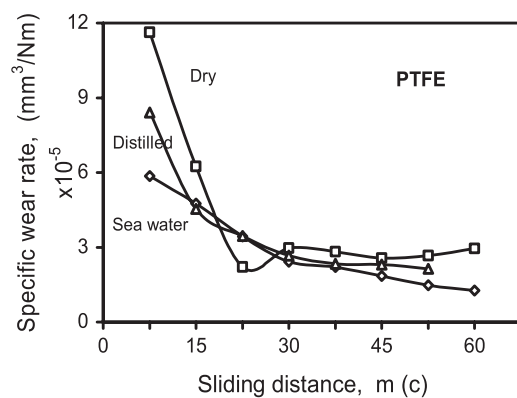
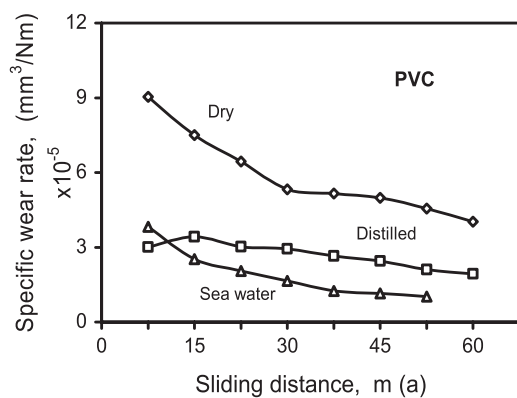


Figure 8: Variation of SWR with distance – Sea water.

applied load. Similar interpretation follows for these cases.







## CONCLUSIONS

Except for PTFE, the experiments show that the specific wear rate SWR for all polymers increases with increasing both applied load up to 50 N. However, for high values of load the SWR increases with increasing applied load. For the anti-adhesion PTFE, the SWR decreases with increasing applied load. Evidence of adhesion, abrasion, and third body wear take place at the start stage. As the motion continues, only abrasion and third body wear were noticed.

The experiments also show that the SWR always increase with increasing distance (running time) for all polymers except Phenolic-fabric (the low abrasion resistance) where it increases with increasing sliding distance. It is illustrated that the values of SWR at the beginning of motion could exceed 3 times its value for steady motion.

The addition of distilled water to the area of contact drastically reduces the level of SWR, whereas the addition of sea water reduces it for some polymers and increases it for others. The effect of water presence on the SWR depends on the type of water and its contaminants, and on the ability of the polymer to withstand the attack of such contaminants.

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**Table 1: Manufacturer properties of the examined polymers.**

Property	Units	Nylon66	Polyp-ropylene	Phenolic Fabric	Copolymer	Homo polymer	GFNylon 66	UHMWPE	PVC	PTFE
Density	g/cm <sup>3</sup>	1.14/ 1.15	0.91	1.36	1.41	1.42	1.35	0.93	1.34	2.14-2.2
W. absorp.	%	7 / 9	< 0.3	0.6-0.8	0.8	0.9	5.5	Non absorb.	0.2	< 0.02
Tensile str.	N/mm <sup>2</sup>	62 / 83	27	42-56	62	70	191	40	48	12
Tensile mod.	N/mm <sup>2</sup>	1733/2744	--	6210/7590	2795	3105	10000	522/690	3500	340
Shear str.	N/mm <sup>2</sup>	66	--	105	53	66	--	24	--	--
Impact str.	KJ/m <sup>2</sup>	10	--	8.6	1.26	1.6	13 – 17	--	--	1.6
Elongation	%	20 – 200	10 – 15	1-4	> 60	> 30	3.5	> 350	120	>100/500
Flex. str.	N/mm <sup>2</sup>	86 – 97	-	69-97	90	98	270	--	125	--
Flex. modulus	N/mm <sup>2</sup>	1207/2827	1150	483/8970	2585	2620	--	517	--	552
Hardness	Rock. ShoreD	R112/120 80 / 85	R90-95 --	R105-115 --	R107 --	R110 --	R100 --	-- 65	R105 84	R58 50 – 65
Melt point	°C	260	260	Thermoset	165	175	255	130	80	327
Max service temp. in air: -short period <sup>(1)</sup> - continuous <sup>(2)</sup> Minimum	°C	160 80 - 40	110 -- --	130 120 --	80 -- - 40	145 90 -50	200 120 -20	80 60 - 100	70 -- -25	300 250 - 200
Thermal con.	W/K.m	0.24	--	0.3	0.23	0.23	0.3	0.42	0.14	0.25
Hot water	--	B	--	--	B	C	B	C	A	A

(1) Only few hours, with little or no load applied.

(2) For 20000 hr. After those periods, mechanical properties reduced by 50 %.

A: No Attack; B: Dimensional change due to absorption; C: Decomposition in short period.

**Table 2: variation of specific wear rate with applied load for various conditions (sliding distance 42 m).**

Specific wear rate SWR, (mm <sup>3</sup> /N.m) x 10 <sup>-5</sup>	Polymer	Condition	Applied load, N						
			10	20	30	50	70	90	110
	Phenolic fabric	Dry	37.15	32.8	31.79	30.94	39.99		
		Dis. Water	8.45	6.79	6.22	5.98	4.95	4.36	3.85
		Sea water	9.35	5.78	4.53	3.72	3.22	2.6	2.31
	PVC	Dry	15.32	11.44	10.32	11.32	13.89	15.96	19.42
		Dis. Water	7.10	5.87	4.08	4.51	2.73	2.21	2.39
		Sea water	6.75	4.86	3.98	2.67	2.13	1.99	1.81
	PTFE	Dry	10.42	9.74	7.42	3.95	3.02	2.23	2.2
		Dis. Water	17.91	12.4	7.2	3.76	3.51	2.97	2.9
		Sea water	18.78	10.55	8.08	5.13	3.75	3.05	3.17
Nylon66	Dry	11.37	7.26	7.71	7.14	6.82	9.36	15.5	
	Dis. Water	10.42	8.7	7.07	6.54	3.69	3.22	3.63	
	Sea water	10.83	7.28	6.42	4.22	3.15	3.33	3.06	
Poly-propylene	Dry	11.1	7.17	5.86	6.28	7.08	8.68	12.21	
	Dis. Water	10.8	7.17	5.26	3.83	3.69	3.55	3.05	
	Sea water	10.83	9.42	6.83	4.21	3.22	2.58	2.96	
Co- polymer	Dry	7.58	6.77	5.11	4.981	4.51	6.23	9.98	
	Dis. Water	3.38	2.89	2.45	2.01	1.81	1.57	1.05	
	Sea water	8.02	5.74	4.72	4.24	3.45	3.16	2.32	
GFNylon- 66	Dry	6.08	4.89	4.14	3.82	3.71	5.12	6.67	
	Dis. Water	6.78	5.68	4.89	4.25	2.98	2.46	1.98	
	Sea water	5.75	4.89	4.23	3.01	2.18	1.96	1.78	
UHMWPE	Dry	3.45	3.21	2.83	2.46	2.37	2.841	4.65	
	Dis. Water	1.65	1.43	1.25	1.2	1.05	0.88	0.77	
	Sea water	6.11	5.54	3.92	3.16	2.87	2.43	1.95	
Homo-polymer	Dry	1.90	1.81	1.65	1.48	1.03	1.45	2.41	
	Dis. Water	1.71	1.52	1.31	1.1	0.92	0.81	0.62	
	Sea water	5.63	3.98	3.21	2.81	2.01	2.12	1.65	

**Table 3: variation of specific wear rate with sliding distance for various conditions (applied load 50 N).**

Specific wear rate SWR, (mm <sup>3</sup> /N.m) x 10 <sup>-5</sup>	Polymer	Condition	Sliding distance, m							
			7.5	15	22.5	30	37.5	45	52.5	60
	Phenolic fabric	Dry	28.01	30.01	32.2	33.32	37.21	28.01		
		Dis. Water	3.81	2.52	2.77	2.21	2.01	1.79	1.44	1.37
		Sea water	5.29	2.93	2.34	1.94	1.71	1.50	1.43	
	PVC	Dry	9.04	7.51	6.44	5.32	5.15	4.99	4.56	4.03
		Dis. Water	3.01	3.42	3.02	2.93	2.65	2.45	2.11	1.93
		Sea water	3.83	2.52	2.05	1.64	1.25	1.15	1.02	
	PTFE	Dry	5.85	4.76	3.43	2.42	2.21	1.85	1.48	1.26
		Dis. Water	11.63	6.25	2.21	2.96	2.82	2.56	2.67	2.95
Sea water		8.40	4.54	3.45	2.67	2.34	2.30	2.13		
Nylon66	Dry	6.11	4.77	4.16	3.83	3.42	3.12	2.98	2.74	
	Dis. Water	5.37	5.01	4.42	4.40	3.88	3.08	2.88	2.74	
	Sea water	13.77	11.16	10.24	9.34	8.67	7.86	7.04		
Poly-propylene	Dry	5.76	4.92	3.84	2.80	2.34	1.94	1.87	1.60	
	Dis. Water	4.02	4.35	4.47	3.73	3.35	3.01	2.97	2.9	
	Sea water	7.31	5.51	3.86	3.46	3.66	3.81	3.89		
Co- polymer	Dry	3.85	3.20	2.77	2.23	2.12	2.08	1.91	1.69	
	Dis. Water	2.01	1.76	1.55	1.39	1.21	1.05	0.98	0.91	
	Sea water	9.12	7.21	6.88	6.61	5.98	4.75	4.35		
GFNylon- 66	Dry	3.60	2.99	2.54	2.10	2.08	1.98	1.66	1.58	
	Dis. Water	3.62	3.34	2.98	2.81	2.66	2.22	2.03	1.89	
	Sea water	7.33	6.99	6.73	6.35	5.12	4.56	4.22		
UHMWPE	Dry	3.01	2.38	1.86	1.42	1.30	0.98	0.86	0.61	
	Dis. Water	1.12	0.91	0.85	0.73	0.71	0.61	0.48	0.43	
	Sea water	٤,٣٢	٣,٦٥	٢,٣٣	١,٦٩	١,٧٨	١,٤١	١,١٥		
Homo-polymer	Dry	4.81	3.99	3.12	2.41	2.01	1.78	1.23	1.23	
	Dis. Water	2.21	1.88	1.74	1.51	1.42	1.30	1.22	1.10	
	Sea water	6.40	5.00	4.56	4.36	3.49	3.18	2.92		

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