

The Wear Behaviour of Nylon-66 and its Composites Under Impact Loading

M.S.ZAAMOUT

*Mechanical Engineering Department, College of Engineering and
Islamic Architecture, Umm Al-Qura University, Makkah, Saudi Arabia,*
Email: zaamout2000@yahoo.com and zaamout@uqu.edu.sa

ABSTRACT. Due to their tribological properties coupled to their high strength – to – weight ratio and ease of manufacture, Polymeric materials are widely used in most of modern industries. They are replacing other materials in producing different machine elements of satisfactory properties. Gears, cams, bearings and bushes are good examples. During their working life, such machine elements are exposed to different causes of failure such as wear due to impact forces. The aim of this research is to investigate the impact wear behavior of Nylon66, and three of its composites, namely Glass Filled nylon66, Oil Filled nylon66, and Nylatron. All experiments are conducted under dry condition. Preliminary results show that the presence of impact forces has significant effects on the wear behaviour of all examined polymers. Such effects vary from one polymer to another.

KEY WORDS: Impact wear, Wear of polymers, Composite materials.

1. Introduction

The external variables that affect the tribological properties are many, among which are applied loads, sliding distance, running speed, counter-surface topography, working temperature, and many other physico-mechanical properties of the counterparts [1-5]. Studying the effects of such parameters is of a continued and common interest [6-12].

However, in spite of the considerable attention spent on the tribological behaviors of materials in general, the share of polymers was somewhat less. Among the very poor attendant parameters that affect the tribological properties of polymers is the impact force. The phenomenon of impact as a collision of two moving bodies where we have active and reactive forces of large magnitude is commonly encountered in machines such as automobiles, construction machinery and equipment, and many others [13]. In spite of the importance of such forces, limited efforts were spent to study its effects on the wear of polymers. Literature and published work are rare. This research is a preliminary step in the task of filling this gap.

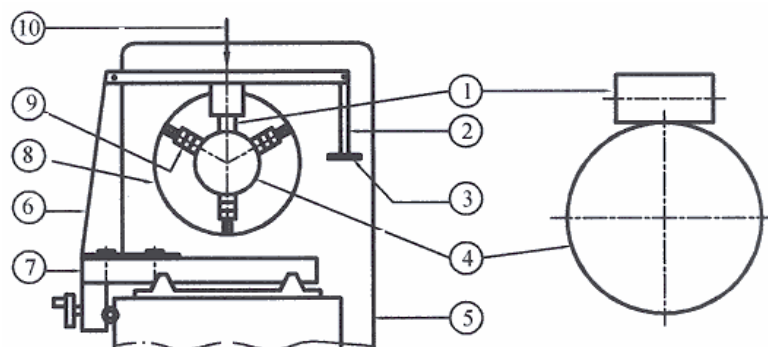
The experimental work of this research was conducted in the tribological laboratory at the department of mechanical engineering under controlled environment of 25 °C temperature and 40% humidity.

2. Experimental

2.1 Wear test machine

A center lathe was modified to a crossed – cylinder tribotester shown in Fig.1. Relative motion between stationary pin and cylindrical counterpart was provided by an electrical motor and gearbox system of variable speed.

This machine was used throughout this course of research to conduct all the wear experiments. Full description of the machine and attachments is presented in reference [14].



1- Pin, 2-Load hager, 3- Applied load, 4- Disc, 5- Speed box,
6- Supports, 7- Carriage, 8- Disc holder, 9- Jaws, 10- Impact force.

Fig.1: Crossed cylinder wear testing machine

2.2 Balance

Precision electrical balance type (Toledo – AB104) supplied by (Mettler Company of Denmark) was used in this research to derive the material losses of the specimen, hence evaluating the wear volume for run. The balance accuracy is (± 0.1) mg as indicated by the manufacturer and checked by the author.

2.3 Microscope

Microscope type (FEROX, 051594) manufactured and supplied by (CETI of Belgium) was also used in this research. It is used mainly to examine the surface of the contact area on the polymeric specimens before and after run.

2.4 Counterpart material and preparation

Steel - 66 cylinder was used on the wear machine as a counterpart to the polymeric specimens. It is supplied by the (SANYO Special Steel Co. Ltd. of Japan). The cylindrical surface was first machined on a center lathe, and then prepared on grinding machine to the required (Ra) surface roughness.

2.5 Surface roughness measurements

The surface roughness of the steel counterpart cylinder was measured using talysurf apparatus type (Surtronic – 3P). The results are presented as centerline average (Ra) values in μm . Several readings were taken after each preparation of the counterpart surface. The value of roughness was kept at an average value of (20 μm).

2.6 Specimen materials and preparation

Specimens were turned into a cylindrical shape and cut to size from the supplied solid bars. Four nylon – 66 base polymeric materials were examined, namely: Nylon – 66, Nyloil, Glass Filled Nylon – 66, and Nylatron - GS. They are all supplied from commercial stock by the (RS Company of England) and tested in the as - received condition. Their manufacturer properties are tabulated in Table 1.

3. Wear measurements

3.1 Wear volume

To derive the wear volume for each test, the examined specimen is weighed before and after each run, then the wear volume was obtained from the

difference in weights and density:

$$V = \frac{W_1 - W_2}{\rho} \quad (1)$$

Table 1: Manufacturer Properties of Examined materials

Property	Units	Nylon66	Nyloil	GFNylon66	NylatronGS
Color	-	Yellow	Green	Black	Silver Gray
Specific gravity	-	1.14-1.15	-	1.36	1.14-1.18
Water absorption	%	7.9	0.2 (in 24hr)	5.5	6.8
Tensile strength	N/mm ²	62/83	810 kgf/cm ²	190	69/96
Tensile modulus	N/mm ²	1733/2744	-	10000	3130/4160
Impact strength	Kgf/cm ²	-	7 kgf/cm ² notch	13-17 KJ/m ²	-
Elongation	%	20-200	-	3	5-150
Flexural strength	N/mm ²	86-97	-	270	110-130
Flexural modulus	N/mm ²	1207-2827	-	-	2758-3448
Hardness	Rockwell	112-120	118	M100	R110-125
	Shore D	80-85	-	-	80-90
Melt point	°C	260	-	255	260
Max. service temp. in air:					
- For short period (1)	°C	160	200	145	160
- Continuous 20000hr (2)	°C	80		120	90
- Minimum service temp.	°C	-40		-20	- 40
Linear thermal exp. Coef.	K ⁻¹ x10 ⁴	10	5x10 ⁴ mm/°C	4.5	6.3
Thermal conductivity	W/K.m	0.24	-	0.24	0.3
Flammability	-	Self exting.	-	-	Self exting.
Volume resistivity	Ohm.cm	> 10 ¹³	-	>10 ¹⁵	>10 ¹³
Dielectric strength (3)	KV/mm	> 12	-	45	>20
Outside – Uv resistance	-	C	-	A	C
Acids – strong (PH<3)	-	D	-	C	D
Alkalis – strong (PH<11)	-	C	-	A	C
Chlorinated hydrocarbons	-	A	-	B	A
Hot water	-	C	-	B	C

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

(2) After those periods mechanical properties reduced by approx. 50%. Service temperatures are load and time dependent.

(3) Test specimen 1.6-mm thickness.

A: No attack.

B: Mold attack by absorption

C: Dimensional change due to absorption

D: Decomposition in short times.

Where V is the wear volume, W_1 specimen weight before run, W_2 specimen weight after run, and ρ specimen density.

3.2 Wear rate

Specific wear rate was calculated for each test using Archard equation [15]:

$$k = \frac{V}{FS} \quad (2)$$

Where k is specific wear rate, V wear volume, F normally applied load, and S the sliding distance.

4. Experimental Procedure

Steps of procedure were devised by the author and strictly followed throughout the course of this research. All non-related parameters such as: sliding distance, sliding speed, counter-surface roughness, laboratory temperature and humidity were kept constant at: 960 m, 1.32 m/s, 20 μm , 20 $^{\circ}\text{C}$, and 45% respectively.

4.1 Test Procedure

4.1.1 Varied statically applied load - no impact forces

After preparing the counterpart cylindrical surface to the required roughness and texture, the cylinder and wear specimen were thoroughly washed by (Acetone) before run. Then specimen was weighed, placed in the seat of specimen holder and carefully lowered over the cylindrical surface of the counterpart in crossed-cylinder configuration. The normal static load was then applied to the load hanger and the machine was started. At the end of each run, the machine was stopped, the specimen was released from the holder, cleaned and weighed again, and the weight loss was recorded.

On restarting the test, the cylindrical counterpart is re-polished again to the same surface roughness, and then cleaned from all debris or polymeric fibrils; the wear specimen is replaced by a fresh new one and rested on the counterpart. Then all other described steps were repeated. For accuracy purposes, each experiment was repeated several times and average readings were recorded.

The static load was varied in the range of (20 – 120 N) at an increment of (20 N) at a time. The effects of this load on wear volume and specific wear rate were established.

4.1.2 Varied statically applied load – constant impact force

In addition to the above steps, a (6 N) constant impact force was introduced every (10 s) during all running time of the experiment. The effects of normally applied static load combined with this impact force on the wear volume and wear rate were also established.

4.1.3 Constant statically applied load, varied impact force

The static applied load was kept at a constant value of (80 N) over all experiments; the impact force was varied in the range of (2-10 N) at an increment of (2 N) at a time. Other steps of procedure were the same as those indicated for the case of varied statically applied load with no impact force. The effects of impact forces on the wear volume and specific wear rate of all examined materials were established.

5. Results

The effects of applied static, combined static and impact and impact load on the wear volume and specific wear rate of all examined polymers are drawn versus load.

6. Discussion

6.1 Varied applied static load

Figures (2 - 5) indicate that wear volume of Nylon66, Nyloil, GFNylon66, and NylatronGS increases in a non-linear trend as static applied load increases. Sever wear and sharp increase takes place as load exceeds certain value of (80 N) for Nylon66 and Nyloil, and even at less loads for the GFNylon66. This could be explained by the simple theories of wear, based on adhesion, which predict an increase in the wear volume with the increase in the values of some affecting parameters such as applied load. As indicated in table 1, all examined materials have low thermal conductivity factor. This tends to rise the temperature at the area of contact during motion, and hence contributes significantly to the sharp increase in the wear volume. Other mechanical properties such as elongation and brittleness have a contribution in reducing the limit of the applied load of sever wear for GFNylon66 and NylatronGS. This is also indicated clearly in Fig. 6 where the comparison of all examined materials

is shown. Figure 6 also shows that GFNylon66 is the lowest wear resistive. This is related to its higher brittleness and less ability of worn fibrils to adhere to counterpart area of contact, hence less transfer film thickness on the counter-surface.

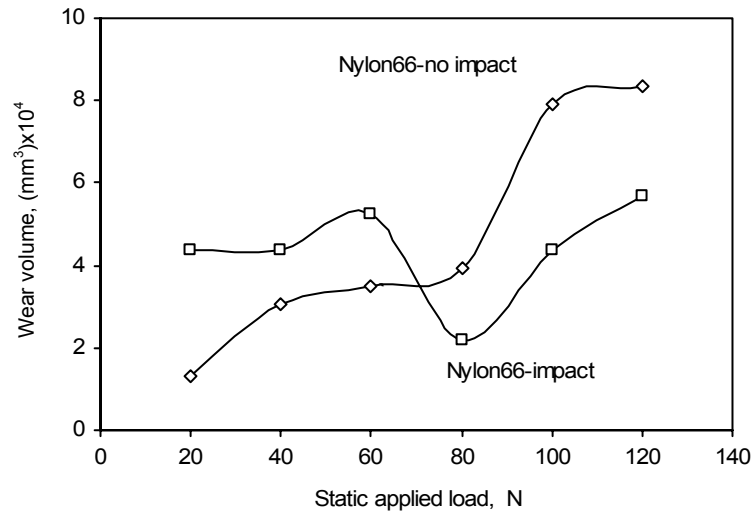


Fig. 2: Variation of Nylon66 wear volume with static load.

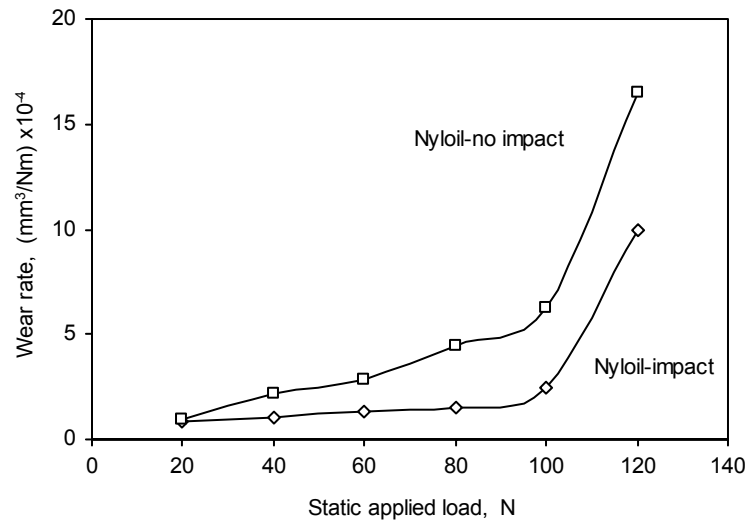


Fig. 3: Variation of Nyloil wear volume with static load.

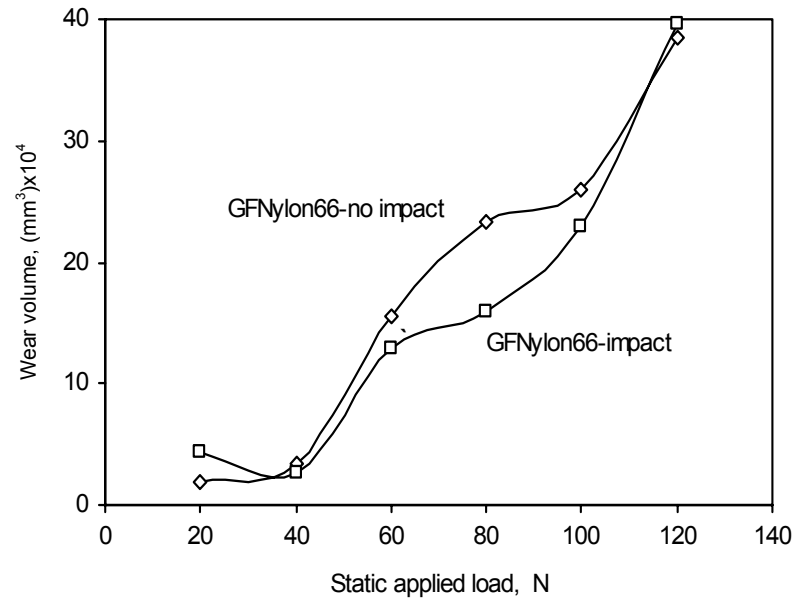


Fig. 4: Variation of GFNylon66 wear volume with static load.

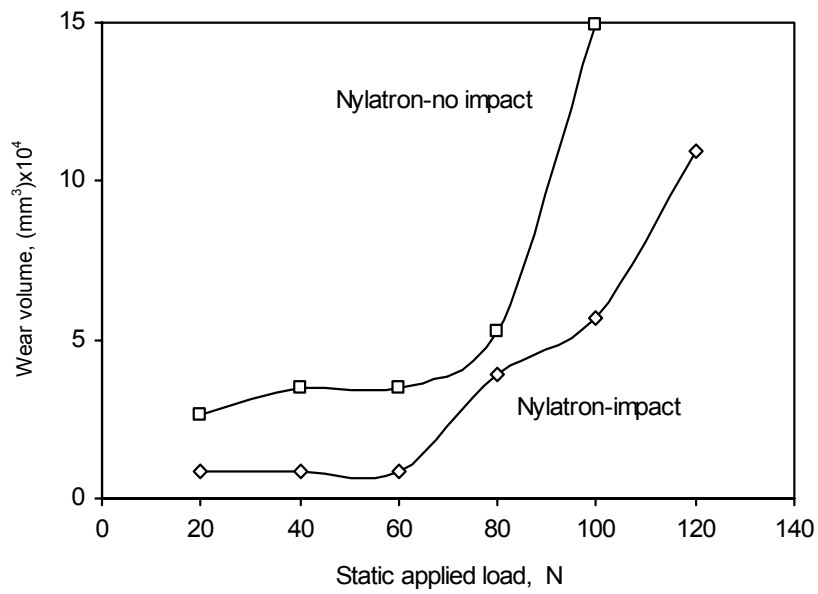


Fig. 5: Variation of NylatronGS wear volume with static load.

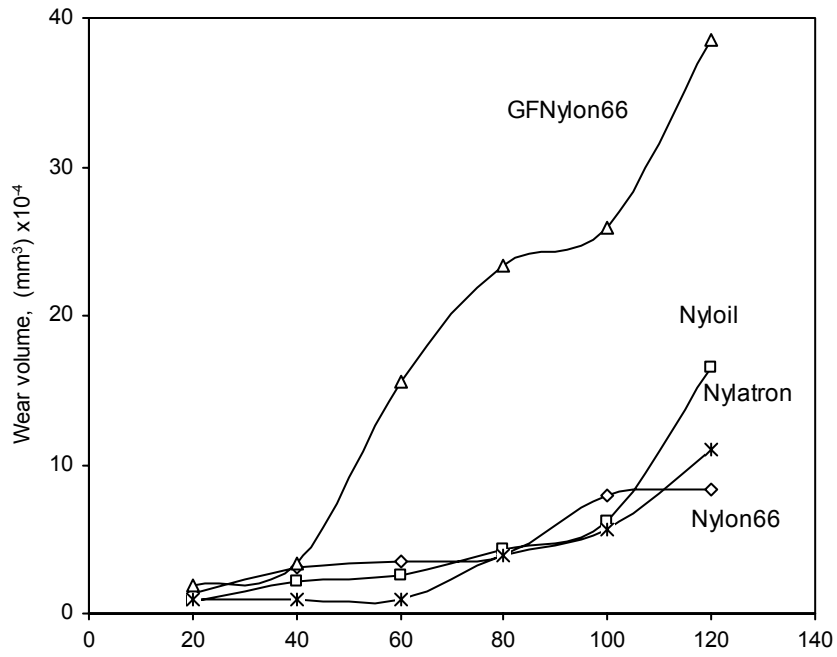


Fig. 6: Comparison of wear volume variation of all polymers with static load.

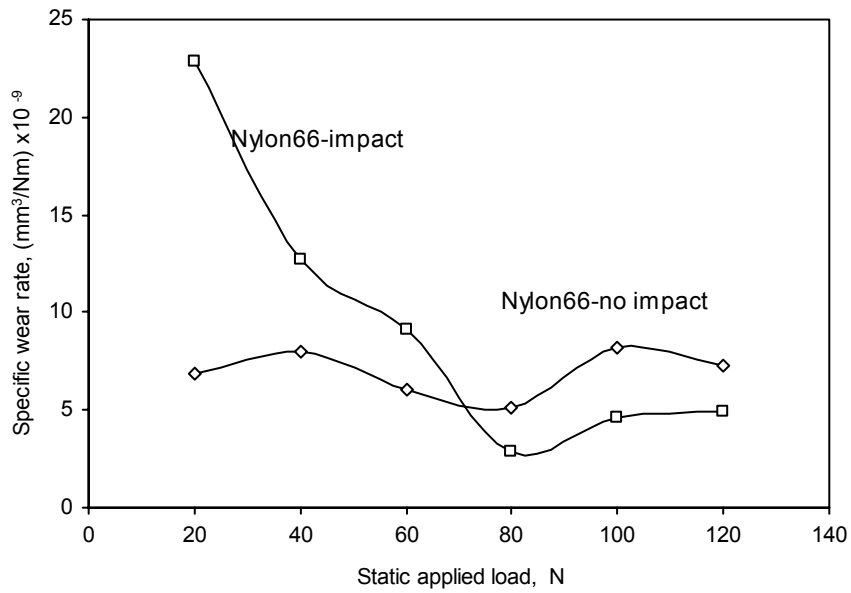


Fig. 7: Variation of Nylon66 specific wear rate with static load.

Figures (7 - 10) show the variation of specific wear rate for Nylon66, Nyloil, GFNylon66, and Nylatron with normally applied static load. Different behaviour for each polymer is illustrated. Fig. 7 shows the decreasing wear rate of Nylon66 with statically applied load. Figs. 8 and 10 show decreasing wear rate as static load increases up to 70 N, then the curve changes the trend and wear rate increases with increasing load. Fig. 9 shows increasing wear rate of GFNylon66 with increasing statically applied load. Fig. 11 compares the results of all polymers; it shows that GFNylon66 has the highest wear rate. This behaviour thought to be related to the same reasons indicated above for wear volume.

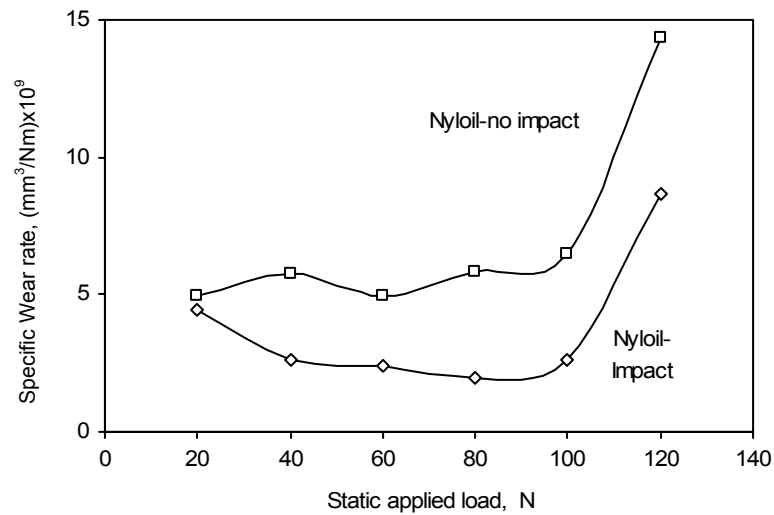


Fig. 8: Variation of Nyloil specific wear rate with static load.

6.2 Constant impact load superimposed to the static loads

The same Figs. (2-5), show also that wear volume of the examined materials increases as the static normally applied load increases under an impact force of (6 N) applied every (10 s) of running time. Fig. 12 compares these results for all four polymers.

Sharp wear increase takes place as the load exceeds the value of (70 N) for Nylon66 and Nyloil. As for GFNylon66 and NylatronGS, this takes place at lower values of applied static loads (40 N for GFNylon66 and 50 N for Nylatron). Needless to say that the same preceded explanation still holds. In

addition, comparison of results for this condition with that of no impact unexpectedly show that wear volume decreases as the impact force is applied, with the exception of NylatronGS and GFNylon66 at high static loads. There is no specific explanation at the present. However, it is thought that the low impact forces tend to dense the material at the contact area, strengthen the fibrils, and help in transferring and adhering a layer of worn polymer to the surface of the counterpart. These actions could be responsible for the reduction of the wear volume. However, more tests are needed for better understanding of this behaviour.

As for NylatronGS and GFNylon66, it is shown that the presence of impact loading tends to increase wear volume to higher levels. This is expected and could be related to their physical and mechanical properties such as heat transfer, hardness, brittleness, tensile strength, impact strength, and flexural strength which, are tabulated in Table 1.

Figs. (7 - 10) show also the variation of specific wear rate for polymers under normal statically applied load. Here also, different behaviour for each polymer is illustrated. Figs. 7, 8 and 10 show the decreasing wear rate of Nylon66, Nyloil, and Nylatron with increasing static applied load up to 70 N, for higher loads the curves change trends and wear rate increases with increasing applied load. Fig. 9 shows increasing wear rate for GFNylon66 as applied load increases. Fig. 13 compares the results of all four polymers; it shows that GFNylon66 has the highest wear rate. This behaviour thought to be related to the same reasons indicated for wear volume.

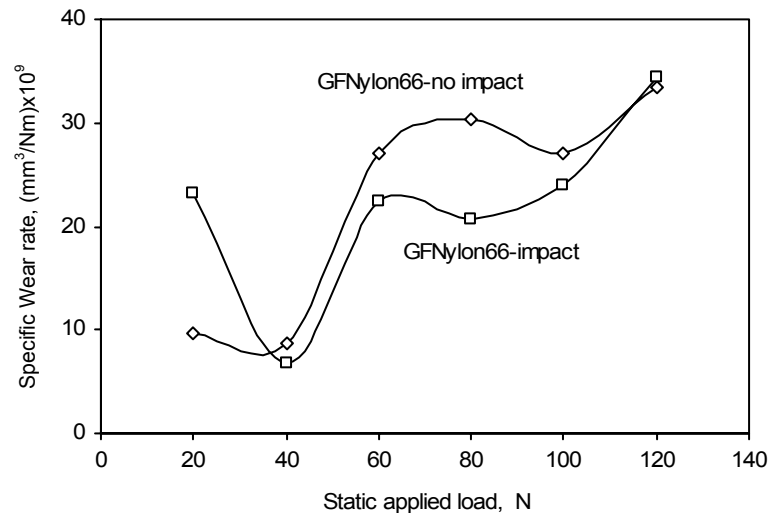


Fig. 9: Variation of GFNylon66 specific wear rate with static load.

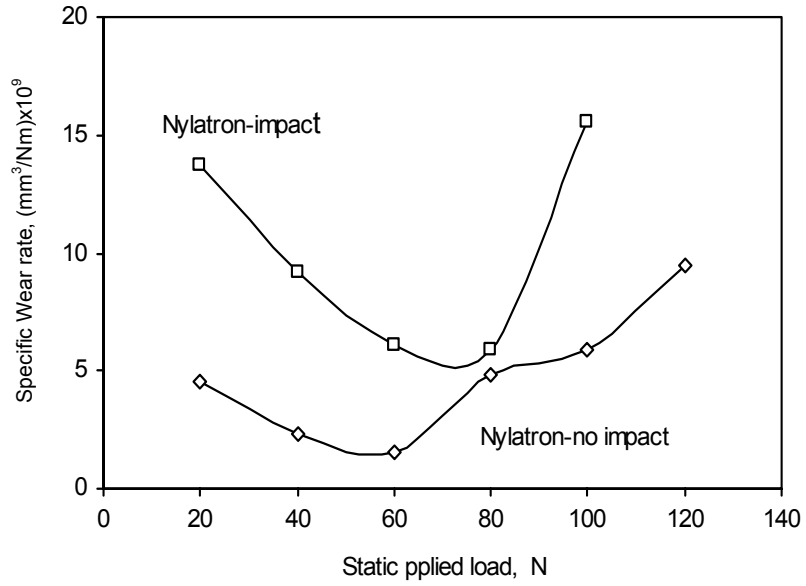


Fig. 10: Variation of Nylatron specific wear rate with static load.

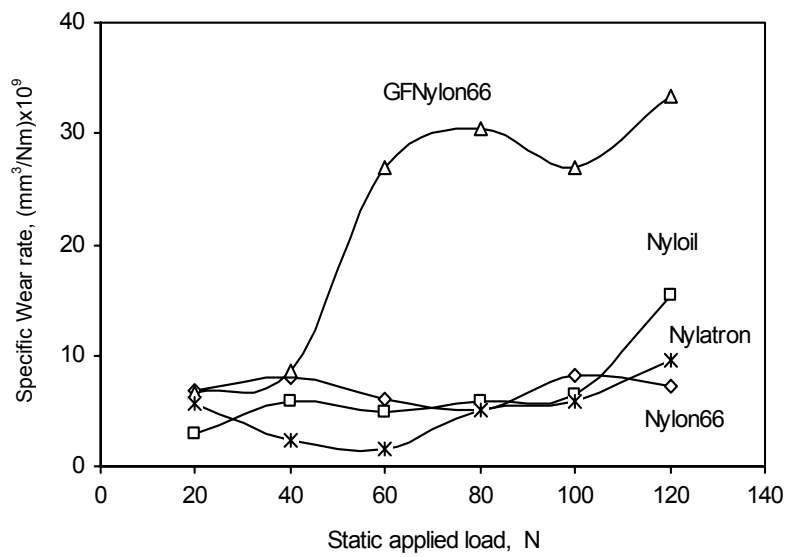


Fig. 11: Comparison of wear rate variation of all polymers with static load.

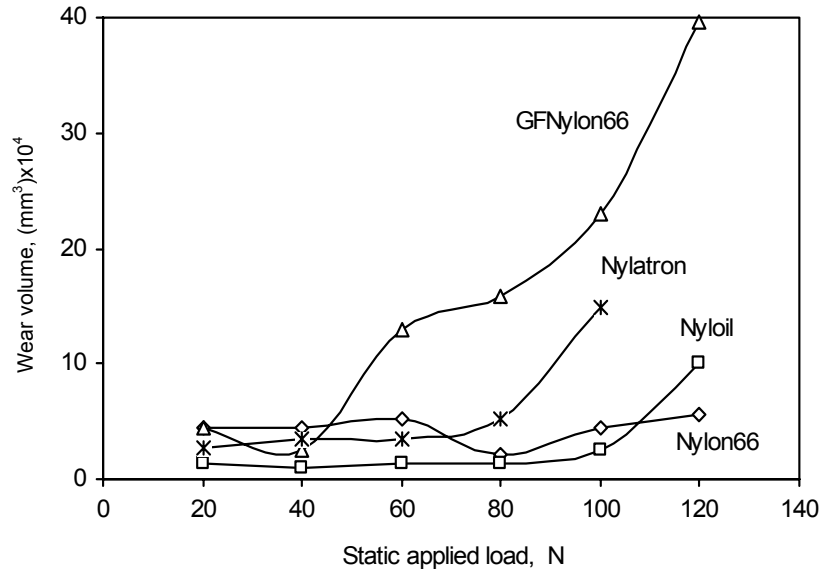


Fig. 12: Comparison of wear volume variation of all polymers with Static loading and superimposed impact load of (6 N).

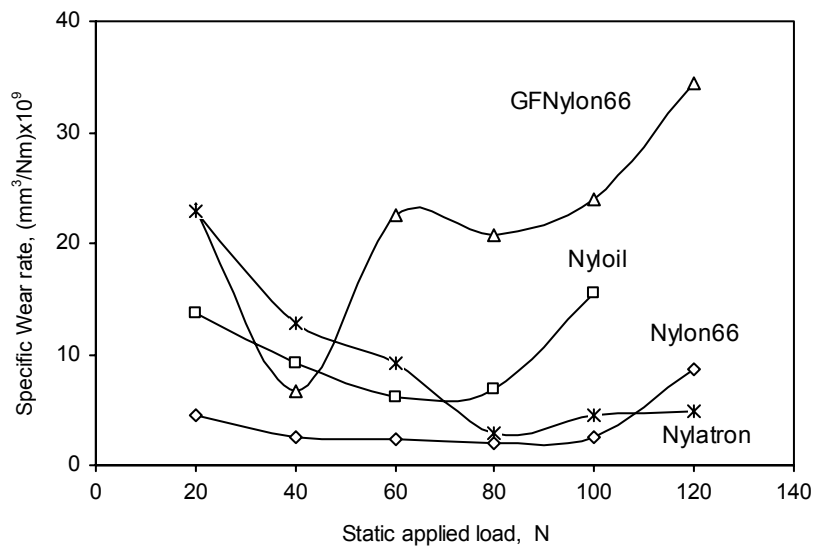


Fig. 13: Comparison of wear rate variation of all polymers with Static loading and superimposed impact load of (6 N).

6.3 Impact load

Figure 14 compares the variation of wear volumes of for all examined polymers with the impact loads under a constant value of statically applied load (80 N). It illustrates two different manners:

- the wear volume of Nylon66 and Nyloil decreases as the impact load increases up to about (7 N).
- Beyond this limit the wear volume increases as impact load increases. As for GFNylon66 and Nylatron.

The wear volume increases with the impact load. The reasons for such behaviour are thought to be as follows:

- The first manner follows the same explanation given in the preceding paragraph.
- The higher impact loads weakens some mechanical properties, such as tensile and compression strength of the polymers. Cracks are also observed on the impacted GFNylon66. This leads to higher wear volume.

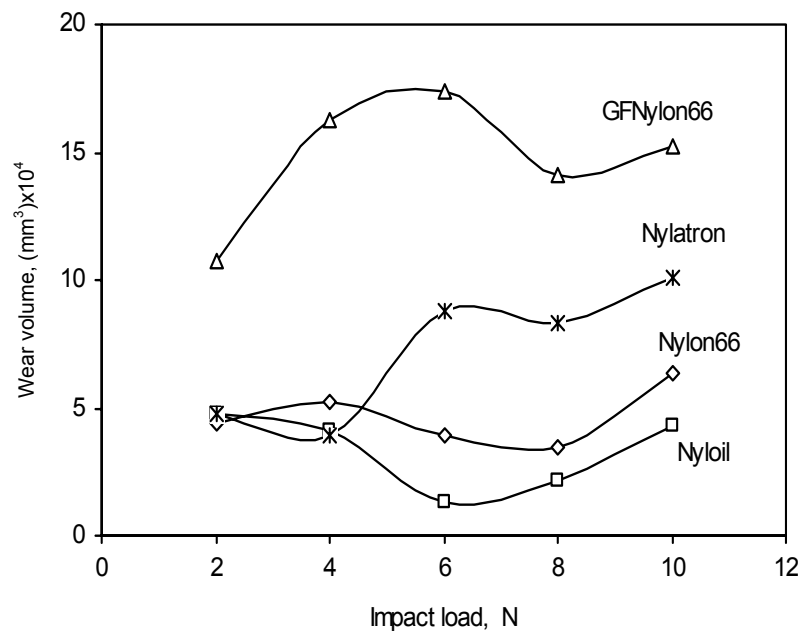


Fig. 14: Comparison of wear volume variation of all polymers with with impact load.

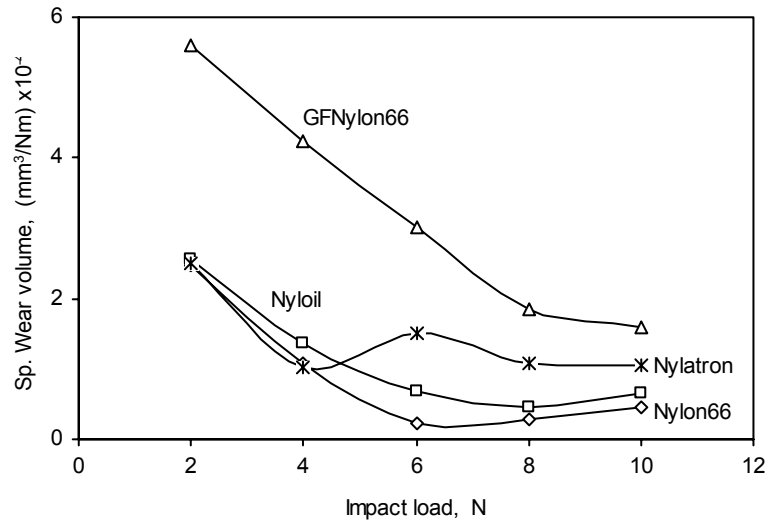


Fig. 15: Comparison of specific wear rate variation of all polymers with impact.

Figure 15 compares the variations of specific wear rate for all polymers with the impact loads under the same above-mentioned conditions. It shows that wear rate decreases with increasing impact load for all materials. The reasons for such behaviour are thought to be the same arguments as indicated above.

7. Conclusions

At low applied static loads and without impact loading, NylatronGS seems to be the highest wear resistive polymer, then Nyloil, Nylon66 followed by GFNylon66. When the statically applied loads are greater than (80 N), the above classification changes to Nylon66, NylatronGS, Nyloil and finally GFNylon66. The presence of small impact loads tends to improve the wear resistance of the polymer. And rearrange the above classification to Nyloil, Nylon66, Nylatron, and finally GFNylon-66. High impact loads seem to have damaging effects on the tribological properties of some polymers.

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