A new reciprocating tribometer for wear testing under different fluctuating loading conditions

A. Abdelbary, M. N. Abouelwafa, I. M. El Fahham and A. I. Gomaa
Mechanical Eng. Dept., Faculty of Eng., Alexandria University, Alexandria, Egypt

A new reciprocating testing machine was designed and constructed to perform wear tests under constant and fluctuating loading conditions at a constant sliding speed for most of its stroke. The tribometer has the facility of changing the amplitude, mean load and the frequency of loading cycle. The wear tests can, also, be conducted under dry or wet conditions. The influence of loading mode on the wear behavior of Nylon 66 sliding against stainless steel in dry conditions was investigated on this test rig. The polymer was tested under constant and fluctuating loading conditions at two different loads and at three frequencies. Results suggested that under cyclic loading condition the polymer shows a significant increase in wear factor than those found under constant loads. The frequency of load cycle, also, has a pronounced influence on the wear behavior under cyclic load.

فى هذا البحث تم تصميم وإنشاء ماكينه جديده لإجراء تجارب التآكل وقد تم تصميمها لتجرى التجارب على عينات اسطوانيه رأسيه ثابته تنزلق على ألواح متحركه حركه أفقيه ترددية بسرعه ثابته فى أغلب المسار. والماكينه قادره على أداء التجارب تحت ظروف التحميل الثابت والمتغير كذا أداء التجارب فى وسط جاف او مبلل. الماكينه بها كذلك إمكانية تغيير السعه والحمل المتوسط و أيضا التحكم فى تردد الحمل المتغير. وقد أشارت نتائج الاختبارات التى تمت على الماكينه باستخدام عينات من البولى أميد المنزلق على الصلب الغير قابل للصدأ أن معامل التآكل يتأثر بطبيعة الحمل حيث وجد زياده ملحوظه فى معامل التآكل للبوليمر عند تعرضه للحمل المتغير عن قيمته تحت ظروف الحمل الثابت المساوى لقيمة متوسط الحمل . من جهه أخرى فقد ظهر من خلال النتائج أن معامل التآكل تحت ظروف الحمل المتغير يتأثر تأثرا واضحا بتردد الحمل المتغير.

Keyword: Wear, Tribometer, Cyclic load

1. Introduction

The need of investigating the effect of dynamic loading associated to many practical applications, on the wear behavior was the motive to develop a satisfactory laboratory tribometer, which is able to perform such tests. In many previous works [1, 2, 3] the wear tests were conducted using a reciprocating wear machine where the polymer pin was subjected to a constant load and slides on a reciprocating bed, which was driven by a cam mechanism. In such configuration, the counterface reciprocated with a variable speed having a pre-determined average value. In order to study the influence of variable load on the wear of Ultra-High Molecular Weight Polyethylene (UHMWPE) [4], a similar tribometer of six stations was used. The time dependent nature of loading was monitored using a load cell in the loading arm and could be controlled to give an approximate square wave form. Another system was developed [5] which incorporates a sine cam mechanical system to generate an alternating sine curve load at the wear surface to simulate the loading produced by masticatory process.

The effect of cyclic load on the wear behavior of polymers has previously been detected as a form of surface fatigue wear [4, 6] where a significant increase of 30% in the wear of UHMWPE was observed when testing the polymer under cyclic loading condition. The same trend was, also, found in other work [7]. The cyclic load has two major effects on polymeric wear; first, the loading – unloading cycle is responsible for creating a highly subsurface stressed regions which in turn, after a number of loading cycles, initiating subsurface cracks [7,8]. The microscopic crack, then, grows a small amount during the peak load of each cycle [9]. Subsurface crack propagation may well have accelerated the failure and removal of material from the highly strained polymer peaks, hence greatly increasing the polymer wear [10]. Second the thermal effect of the loading frequency on the dynamic mechanical properties of the bulk polymer. Generally, the effect of loading frequency is to increase the temperature of the bulk polymer, which in turn causes a decrease in the shear modulus, G, and in the fatigue life specially at high frequencies [9]. Although the frequency effect is small at low frequencies but the increase in the temperature of specimen due to friction will magnifies the frequency effect [11]. The mutual effect of the temperature and applied frequency is to soften the polymer and decrease its modulus, which leads to increase the fatigue wear.

In the present work a new reciprocating tribometer was designed and constructed to study the effect of different fluctuating loading conditions on the wear of polymers. The tribometer has the capacity of testing the wear behavior of materials under static or fluctuating load in dry or lubricated environment. The amplitude, mean and frequency of the cyclic load are controllable. To eliminate the effect of speed variations on wear, the new tribometer has the advantage of performing the tests at constant speed of the counterface for most of the stroke.

2. Tribometer

It consists of a 2.2 kW motor (2) drives the chain mechanism (3), using a gearbox to reduce the speed to 31.5 rpm. This mechanism is used to drive the carriage (5) by replacing one of the pins of the chain by a special pin with extra length to project from the side of the chain. A small deep groove ball bearing is mounted at the end of this pin and rolls inside a U-beam guide (4), which is welded at the bottom of the carriage. With such configuration the carriage reciprocates with constant linear speed for 80%of its, 310-mm, stroke. The sliding speed is selected to be 0.25 m/s. The carriage is divided into six separated channels to promote the activation of maximum number of independent tests at the same time. The counterfaces are fixed to the channels at 30-mm depth to enable both dry and lubricated tests. The fluctuated load is generated by a special loading system, which consists of a set of six eccentric replicable cams (6). The cam follower (7) transmits the displacement of the cam rotation to a vertical compression spring (8), which transmits the generated force to the pin holder (9). The spring is mounted on a movable controlled seat (10) that can be used to adjust the initial deflection of the spring. The loading cycle due to this arrangement has a sinusoidal form. The cam shaft is driven by a 0.74 kW motor with a second gearbox (11) giving three different frequencies.

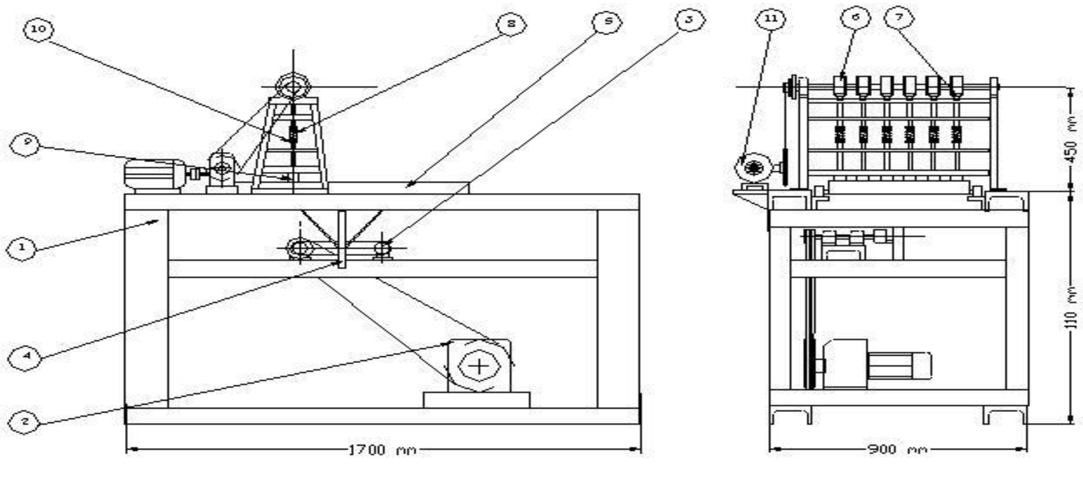

Fig. 1. General lay out of the wear testing M/C: (1) machine frame; (2) 2.2 kW motor; (3) chain drive mechanism; (4) U-beam guide; (5) carriage; (6) eccentric cam; (7) cam follower; (8) spring; (9) pin holder; (10) movable spring seat; (11) 0.74 kW motor.

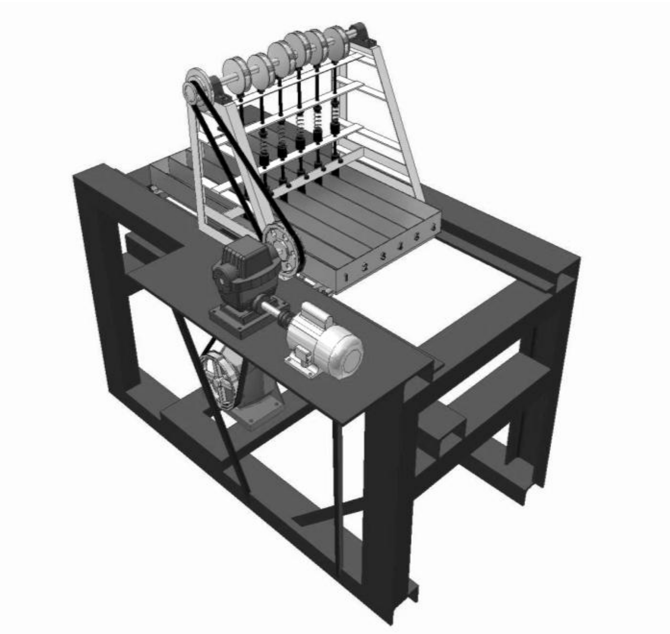

Fig. 2. Wear testing M/C.

The amplitudes and means of the cyclic loads can be controlled by changing the cams and/or springs. Other forms of loading cycle can be, also, applied using different cam shapes. Constant load tests can be performed separately by switching off the 0.74 kW motor and applying a specific constant deflection to the spring. The generated load can be calibrated using a load cell. The wear rate of test specimens is determined from measurement of weight or volume loss. Fig. 1&2 represent a general lay out of the tribometer.

3. Tests

Wear tests were carried out using Nylon 66 wear pins machined from solid bar into a cylindrical shape with one end machined to a truncated cone of 80° included angle, presenting an initial wear face of 16-20 mm². The counterfaces were prepared from stainless steel plates ground to provide a surface with a center line average (R_a) value of about 0.5 µm. These sheets presented a rectangular wear face of 330 x 30 mm. Role of control pins and standard test procedures [3] were taken into consideration. The Wear Factor (WF) is determined as WF = Volume loss/ Sliding distance X Applied load.

4. Results

First, the polymer was tested under two different constant loads 70N, 90N in a dry sliding condition. Then, the polymer was tested under cyclic loading at two different means; 70N and 90N while the amplitude of the cycle was adjusted to 35N. The tests were performed at three different frequencies 0.38, 0.7 and 1.38 Hz. Table 1 represents the wear results of these tests. Figs. 3 and 4 show the variation of the worn volume in mm³ with the sliding distance in km.

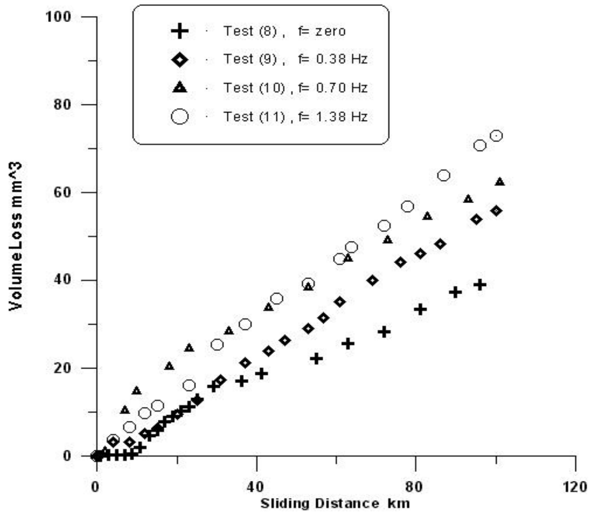

Fig. 3. Variation of Nylon 66 volume loss with sliding distance after 100 km, P (constant, mean) = 70 N.

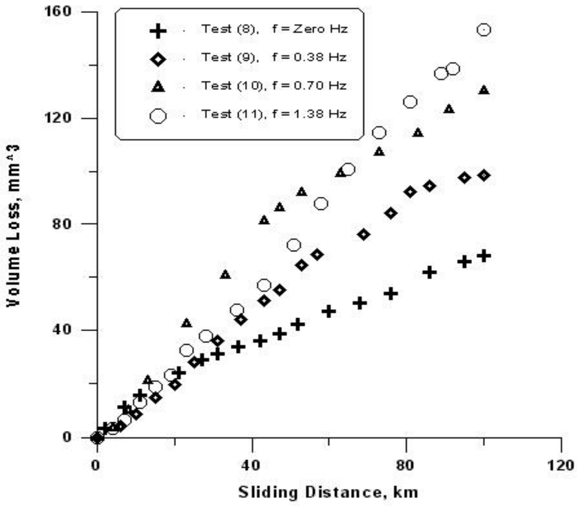

Fig. 4. Variation of Nylon 66 volume loss with sliding distance after 100 km, P (constant, mean) = 90 N.

Table 1
Wear results for constant and cyclic load testes

Test No.	f Hz	P N.	X km	V mm^3	WF $x10^{-6}$ $mm^3/N.m$
a- Constant Load Tests					
1	-	70	95	39	5.3
2	-	90	95	66	6.3
b- Cyclic Load Tests					
3	0.38	70*	133	70	7.7
4		90*	133	115	10
5	0.70	70*	100	62	7.5
6		90*	100	132	15
7	1.38	70*	100	73	10.6
8		90*	100	153	17

* Mean of the load cycle

The results show that the cyclic load produces more than 40% increase in the wear factor. This implies that the time dependent nature of the load in the cyclic load tests generates higher wear rates. The results also indicate that the increase in wear factor is influenced by the frequency of the loading cycle.

5. Discussion and conclusion

The results of tests at the three examined frequencies, 0.38, 0.7 and 1.38 Hz, indicate that the wear factor increases significantly with increasing the cyclic frequency at the two ranges of mean loads. As mentioned earlier, the existence of the time dependence nature of loading increases the wear factor than its value under constant load of the same magnitude as the mean load. The fatigue wear process seems to be the dominant mechanism of wear. Generally, increasing frequency produces an increase in temperature of the bulk polymer leading to a decrease in mechanical properties and fatigue safe-life [9, 12].

The dynamic fatigue properties of polymer in bulk often involve thermal effects attributable to heat build – up within the polymer and are thus very sensitive to the frequency and form of the applied cyclic stress [13]. This suggests that the increase in wear factors found when increasing frequency is due to the effect of frequency on the fatigue and mechanical characteristics of the bulk polymer.

A useful observation is that there is a significant increase in the total worn volume due to the applied frequency. The need of such remark is that in many mechanical and medical polymeric applications, the total volume loss may has a superior priority in calculating the life time of the component rather than the wear factor.

The presented tribometer has been demonstrated as a good testing instrument for particular applications where investigating the wear behavior under fluctuating loading is required. The tribometer has the capacity to perform wear tests under constant or cyclic loading conditions. Also, it has the ability to change the amplitude, mean load and frequency of the loading cycle. The wear tests that have been conducted on the tribometer indicated that;

Under cyclic loading condition, in which the mean of the load cycle equals in magnitude to the constant load, Nylon 66 shows a significant increase, for more than 40%, in wear factors than those found under constant loads. This can be explained as that the fluctuating load generally increases the fatigue effect on wear that existed under constant loading condition.

Increasing the frequency of load cycle leading to an increase in wear factor as well as in total volume loss. Results indicated a linear relationship between frequency and both wear factors and worn volume.

References

[1] P.S.M. Barbour, D.C. Barton and J. Fisher, "The Influence of Contact Stress on the Wear of UHMWPE for Total Replacement Hip Prostheses", Wear, Vol. 181-183, pp. 250-257 (1995).
[2] D. Dowson, J.M. Challen, K. Holmes and Atkenson J.R., "The Wear of Non-Metallic Materials", Paper IV, Proceeding of the 3rd Leeds-Lyon Symposium on Tribology, September (1976).
[3] K. reber, J.R. Atkenson and D. Dowson, "The Mechanisms for Nylon 66" Paper II, Proceeding of the 3rd Leeds-Lyon Symposium on Tribology, September (1976).
[4] J. Fisher, "Wear of UHMWPE in Total Artificial Joints", Current Orthopedics, Vol. 8, pp. 164-196 (1994).

[5] X. Hu, E. Harringlon, P.M. Marquis and A.C. Shortall, "The Influence of Cyclic Loading on The Wear of a Dental Composite", Biomaterials, Vol. 20 (10) pp. 907-912 (1999).
[6] P.S.M. Barbour, M.H. Stone, J. Fisher, "A Study of The Wear Resistance of Three Types of Clinically Applied UHMWPE for Total Replacement Hip Prostheses", Biomaterials, Vol. 20, pp. 2101-2106 (1999).
[7] G.W. Blumm, S. Walker, A. Joshi and K. Hardinge, "The Dominance of Cyclic Sliding in Producing Wear in total Knee Replacements", Clin. Orthop., December (1991).
[8] L.H. Mair, "Wear in Dentistry – Current Terminology", J. Dent., Vol. 20, pp.140–144 (1992).
[9] K. Gupta Rakesh, Polymer and Composite Rheology, Marcel Dekker Inc, (ISBN: 0-8247-9922-4) (2000).
[10] A.U.J. Yap, S.H. Teoh and C.L. Chew, "Effect of Cyclic Loading on Occlusal Contact Area Wear of Composite Restoratives", Dental Materials, Vol. 18 (2), pp. 149-158 (2002).
[11] V. Zivlar, "Plastics Polymers", Vol. 39, p. 328 (1971).
[12] C. Osgood Carl, Fatigue Design, Pergamon Press, (ISBN: 0-08-026167-1).
[13] A.E. Hollander, J.K. Lancaster, "An Application of Topographical Analysis to The Wear of Polymers", Wear, Vol. 25, pp. 155-170 (1973).

Received December 13, 2003
Accepted March 20, 2004