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Wet Sliding Wear and Frictional Behavior of Commercially Available Perspex

S. Reaz Ahmed, M. S. Kaiser

Abstract**—**The tribological behavior of commercially used Perspex was evaluated under dry and wet sliding condition using a pin-on-disc wear tester with different applied loads ranging from 2.5 to 20 N. Experiments were conducted with varying sliding distance from 0.2 km to 4.6 km, wherein the sliding velocity was kept constant, 0.64 ms^{-1}. The results reveal that the weight loss increases with applied load and the sliding distance. The nature of the wear rate was very similar in both the sliding environments in which initially the wear rate increased very rapidly with increasing sliding distance and then progressed to a slower rate. Moreover, the wear rate in wet sliding environment was significantly lower than that under dry sliding condition. The worn surfaces were characterized by optical microscope and SEM. It is found that surface modification has significant effect on sliding wear performance of Perspex.

Keywords**—**Perspex, wear, friction, SEM.

I. Introduction

PERSPEX is a trademarked acrylic product that has numerous applications in our day-to-day life. Among the important practical applications, windows, aircraft canopies, automobile tail lights, hobby crafts, sunscreens, furniture, table tops, sign boards, decorating panels, windshields, camera lenses, aquariums, toys, incubators, security shields, etc. are noticeable [1], [2]. The common shapes of acrylic include sheet, rod, cubes, balls, tubes, etc. The acrylic products have a number of attractive physical properties. For example, it is more flexible and shock resistant than glass. It is abrasion resistant as well as resistant to ultraviolet radiation and chemical damages. Acrylic can transmit or filter ultraviolet light. It can be easily cut and it is corrosion resistant and a good insulator. Polymeric and composite materials are used in many applications where friction and wear are important parameters. The importance of tribological properties eventually attracted many researchers to study the wear behavior and to improve the wear resistance of polymeric composites. Wear can be defined as the progressive loss of materials from the surface in operation as a result of relative motion at the surface [3], [4]. A number of mechanisms are realized to be operated simultaneously to remove materials from the surface. Adhesive wear, the primary mechanism of material loss, is characterized by fine particles of polymer being removed from the surface [5], [6]. In practice, wear rate and coefficient of friction between mating surfaces are found to depend on a number of parameters/conditions, for example, surface roughness, relative motion, material properties, temperature, applied force, stick slip, relative humidity, lubrication and vibration [7], [8].

In the present study, the wet sliding wear and frictional behavior of Perspex has been investigated in a comparative fashion with those observed under dry sliding environment.

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II. Experimental Details

The material used in the present study was commercially available Perspex. Sample of 12 mm length and 5 mm diameter were cut from 12 mm thick Perspex plate for wear study following ASTM Standard G99. Mild steel discs were used as the counter-body. The disc surfaces were machined using surface grinding machine and the corresponding hardness was found around RC 50. Finally, the surfaces were cleaned with cotton.

The frictional and wear behaviors of Perspex were investigated experimentally using a pin-on disc type wear apparatus following ASTM standard G99. During the dry wear tests, the end surface of the pin samples was pressed against horizontal rotating mild steel disc. Applied loads ranging from 2.5 to 20 N were used throughout the test. The tests were conducted at the sliding speed of 0.64 ms^{-1} with varying sliding distances from 192 m to 4616 m. The tests were carried out in ambient air (relative humidity 72%) under dry sliding condition (without lubrication). For wet wear test, distil water was used as the wet medium with all other parameters to be identical that of dry condition. Wet sliding test, the mild steel disc, and the wear samples were immersed in distil water. At least three tests were reported for each type of measurement with Perspex. Wear rates were calculated from average values of weight-loss measurements using the following expression

$$W.R = \frac{\Delta W}{S.D} \quad (1)$$

Here, W.R = Wear rate, ΔW = Weight loss and S.D = Sliding distance.

Microstructural observation of the worn surfaces was carried out by using USB microscope and the selected photomicrographs were taken. The SEM investigation was conducted by using a JEOL scanning electron microscope with an energy dispersive X-ray analyzer (Model: Link AN - 10000). Some photographs of the sample prepared, counter body used, and the experimental setup are shown in Fig. 1.

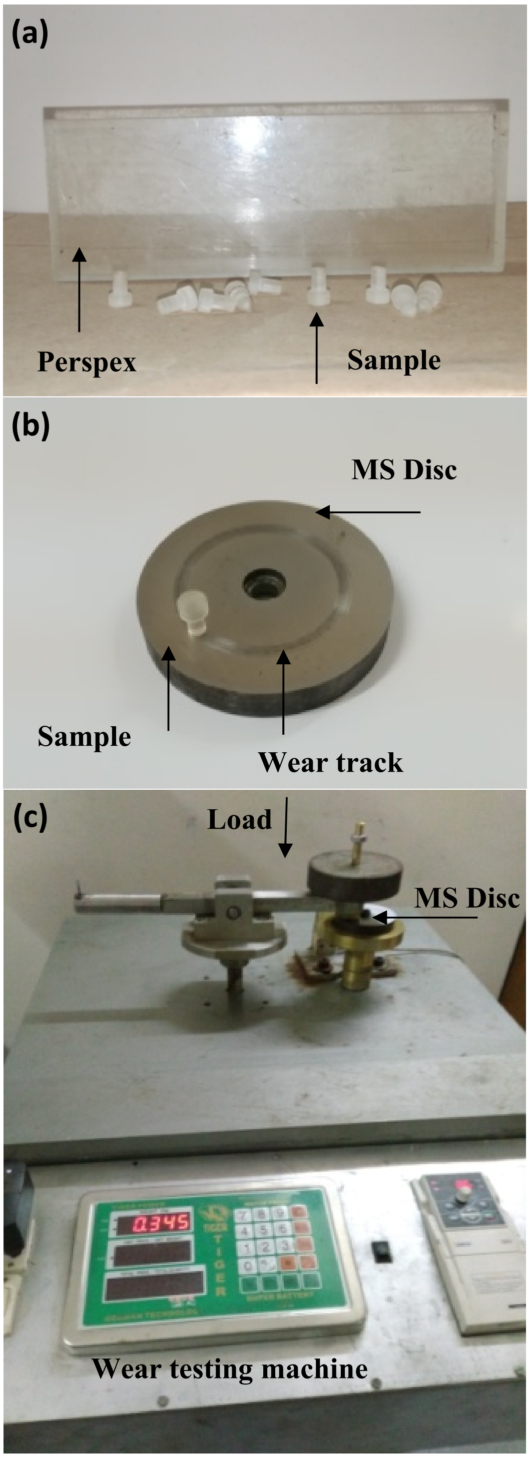

Fig. 1 (a) Experimental Perspex and wear samples, (b) MS counter disc and (c) Wear testing machine

III. Results and Discussion

A. Wear Test

Fig. 2 elucidates the variation of weight loss with the variation of sliding distance for Perspex at different applied loads of 2.5, 5, 10, and 20 N under dry sliding condition. Fig. 3 depicts the variation of wear rate with the variation of sliding distance for different loads. Other parameters, such as sliding velocity (0.64 ms^{-1}), surface roughness (0.31μm) and relative humidity (72%) were kept identical for all the measurements. It can be seen from Fig. 2 that, as the sliding distance increases, the weight loss increases typically for all the applied loads. At lower values of sliding distance, contact between the specimen and counter surface is less. At the higher values of the distance, the contact between the specimen and counter surface increases subjecting specimen to increased sliding action, which in turn, causes significant increase in weight loss of the Perspex samples. Further, the weight loss was found to increase with the increase of normal load. Weight loss was relatively low at lower loads because of lower penetration, and less numbers of abrasive particles were in action with the rubbing surface. Abrasion wear was greatly increased at higher load because most of the abrasive particles penetrated into the surface and created more grooves, resulting in more material removal by ploughing. At higher loads, the interface temperature rises, which will cause softening of the material at the interface, and as a result, more material will be deposited due to thermal fatigue than expected [9]. Acrylic is fully amorphous in its structure with little to no crystalline zones, causing in much less cohesive forces among the chains and as a result, it is more susceptible to abrasive wear [9], [10]. Fig. 3 shows the wear rate at different applied loads in abrasive wear mode as a function of sliding distance. As appears from the graph, at the initial state of sliding, the wear rate increased very rapidly; however, with increasing sliding distance, wear rate assumed lower rates for all the cases of applied loads. Initially, maximum wear rate was observed because abrasive paper was fresh. With consecutive runs, the wear rate decreased gradually because the abrasive grits become smooth and less effective. The wear debris filled the space between the abrasives, which reduced the depth of penetration in the sample. Also, the steady state condition is probably due to the transfer film of polymer onto the counter abrasives. At higher applied load, the shear force and frictional thrust are increased, and these increments accelerate the wear rate [10].

Fig. 4 presents the coefficient of friction of Perspex for contact loads 2.5, 5, 10 and 20 N, respectively. The coefficient of friction for all the cases of applied loads reaches a steady state after showing a sharp increase during the initial sliding distance. The sharp increase of the coefficient is probably because of the uneven contact between Perspex specimen (pin) and the counter body (disc). However, the variation of friction coefficient over the sliding distance becomes nearly uniform once an ideal contact between the pin and disc is achieved [10]-[13].

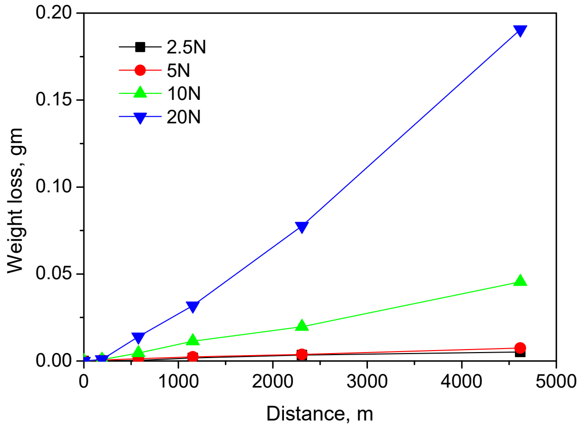

Fig. 2 Weight loss as a function of sliding distance at different applied loads under dry sliding condition at sliding velocity of 0.64 ms^{-1}

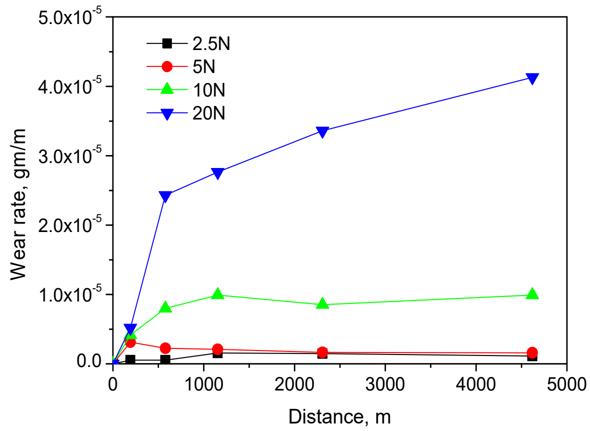

Fig. 3 Wear rate as a function of sliding distance at different applied loads under dry sliding condition at sliding velocity of 0.64 ms^{-1}

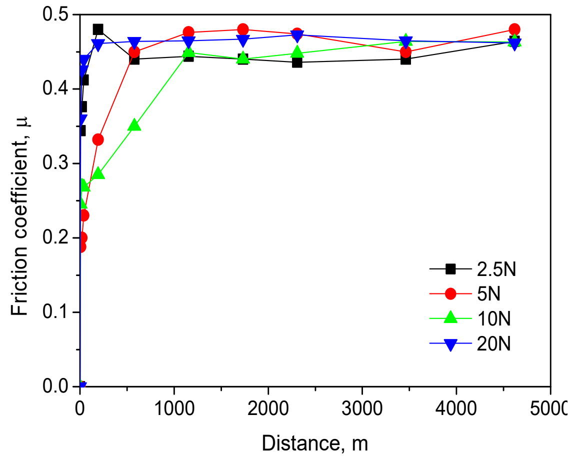

Fig. 4 Friction coefficient as a function of sliding distance at different applied loads under dry sliding condition at sliding velocity of 0.64 ms^{-1}

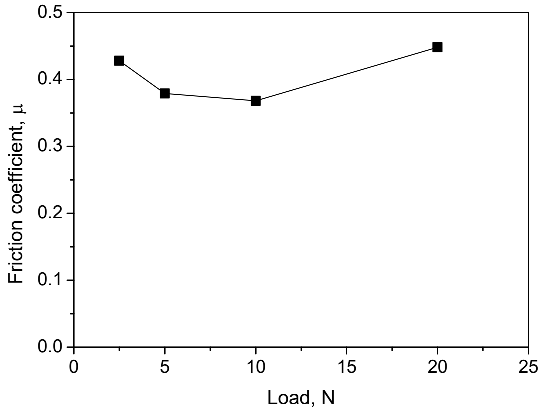

Fig. 5 Friction coefficient as a function of applied load under dry sliding condition at sliding velocity of 0.64 ms^{-1}

Results of Fig. 5 show that friction coefficient decreases initially with the increase in normal load for Perspex. The behavior under higher applied load is observed to be different from that of lower loads; that is, the friction coefficient shows an increasing trend with the increase of applied normal load. Some factors like, high ploughing, local surface damage, etc. may be responsible for obtaining higher friction coefficient under higher normal load [1].

Fig. 6 shows the variation of weight loss as a function of sliding distance under dry and wet sliding conditions. For the entire sliding distance, the weight loss under wet sliding condition is found to be around 50% of that under dry sliding condition. Wear rate in dry and wet sliding conditions is described in Fig. 7. The figure basically exhibits two regions, which may be called ‘running-in’ and ‘steady state’ periods. During the running-in period, the wear rate increased very rapidly with increasing sliding distance. However, for the steady state period, it progressed with a rate slower than that of the running-in period and varied linearly with increasing sliding distance. In case of wet sliding condition, water may act as a cooling agent at the polymer-metal interfaces, which can reduce the frictional heating, thereby hindering the normal thermo-mechanical behavior particularly, softening of polymers. Among the common phenomenon occurring in water lubrication, plasticization and water absorption in polymers are the two major ones. Water absorption not only causes changes in structure at the surface level through swelling, but also brings significant changes in the elastic modulus as well as strength, which, in turn, affects the friction and wear behavior of the polymer. Water absorption in polymers under wet sliding condition reduces the induced shear stress. It is thus realized that the reduction in shear strength caused by water absorption makes the formation of transfer layer difficult, as a result of which the wear resistance is decreased [14], [15]. Fig. 8 shows the difference of friction coefficient under wet and dry sliding conditions at an applied load of 20 N. When a surface gets wet, asperities in the substrate gets filled by the particles of liquid, which results in a smoother interface between Perspex and the disc, thereby causing a substantial drop of the roughness at the surface. On a wet contact surface, the water may partially or totally interrupt the contact between the Perspex and counter body surface, which, in turn, leads to a decrease in the coefficient of friction [16].

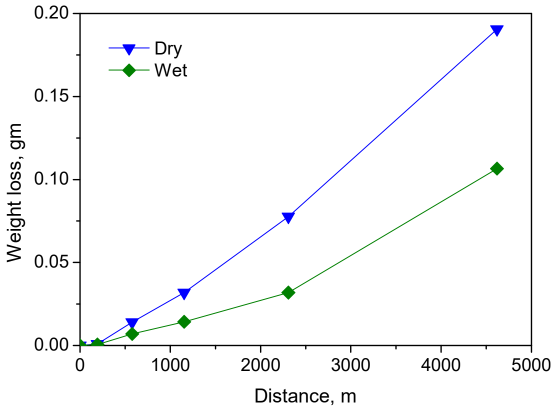

Fig. 6 Comparison of weight loss under different sliding conditions as a function of sliding distance at applied load of 20 N and sliding velocity of 0.64 ms^{-1}

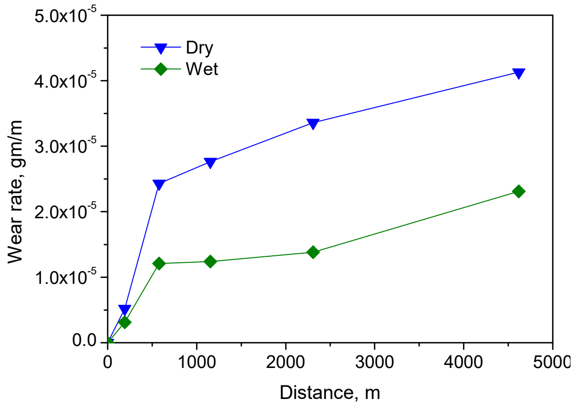

Fig. 7 Comparison of wear rate under different sliding conditions as a function of sliding distance at applied load of 20N and sliding velocity of 0.64 ms^{-1}

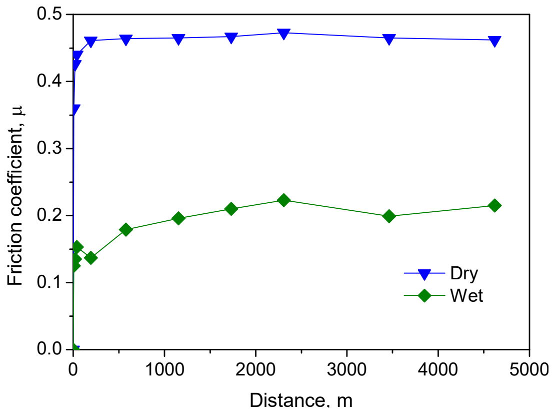

Fig. 8 Comparison of friction coefficient under different sliding conditions as a function of sliding distance at applied load of 20 N and sliding velocity of 0.64 ms^{-1}

B. Optical Micrographic Observation

Fig. 9 (a) shows the microstructure of polished Perspex before wear. A finish surface was observed. Figs. 9 (b) and (c) show the optical micrographs of the worn surfaces of Perspex after the dry sliding wear test for 5 and 120 minutes, respectively. Significant plastic deformation has occurred, and deep grooves were formed parallel to the sliding direction. It can be seen that the wear grooves and furrow marks caused by the micro-cutting and micro-ploughing of the counter face asperities were dominant on the worn surfaces. For higher sliding distance, relatively deep wear grooves and rough surfaces were observed. In Figs. 9 (d) and (e), relatively smoother worn surfaces were observed in wet sliding condition for 5 and 120 minutes, respectively. This clearly indicates that water absorbs heat that was generated at the specimen disc interface and also reduces friction to the greater extent. Hence, the amount of wear is low in case of wet sliding situation compared to dry sliding situation [17].

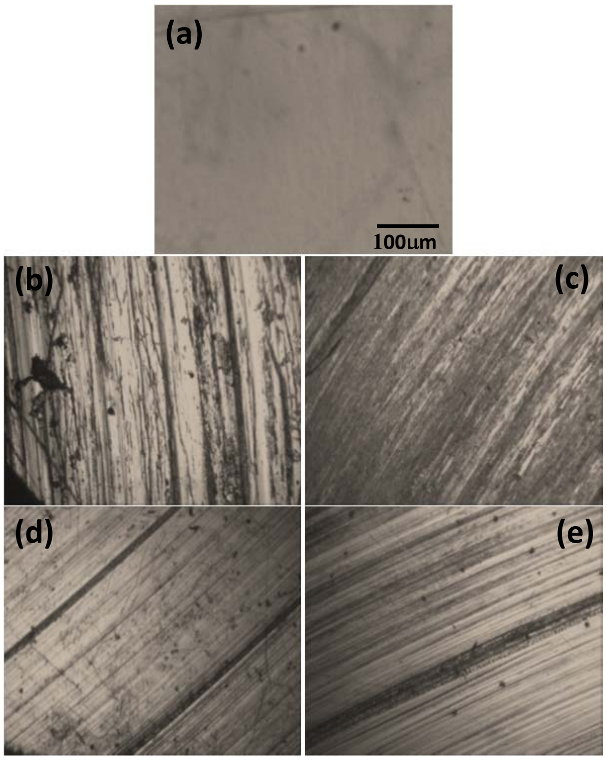

Fig. 9 Optical micrograph of worn surfaces a) before wear, b) 5 min in dry condition, c) 120 min in dry condition, d) 5 min in wet condition and e) 120 min in wet condition

C. SEM and EDX Observation

Fig. 10 (a) shows the SEM micrograph of the as-received structure of Perspex with more or less smooth surface structure and exhibits no symptom of plastic deformation or drawing. The weight percentage of elements found by corresponding EDX analysis (Fig. 10 (b)) of the SEM is 66.20% C and 33.80% O. It is disclosed as an organic substance, because it contains carbon. The carbon is bonded to oxygen and hydrogen [18].

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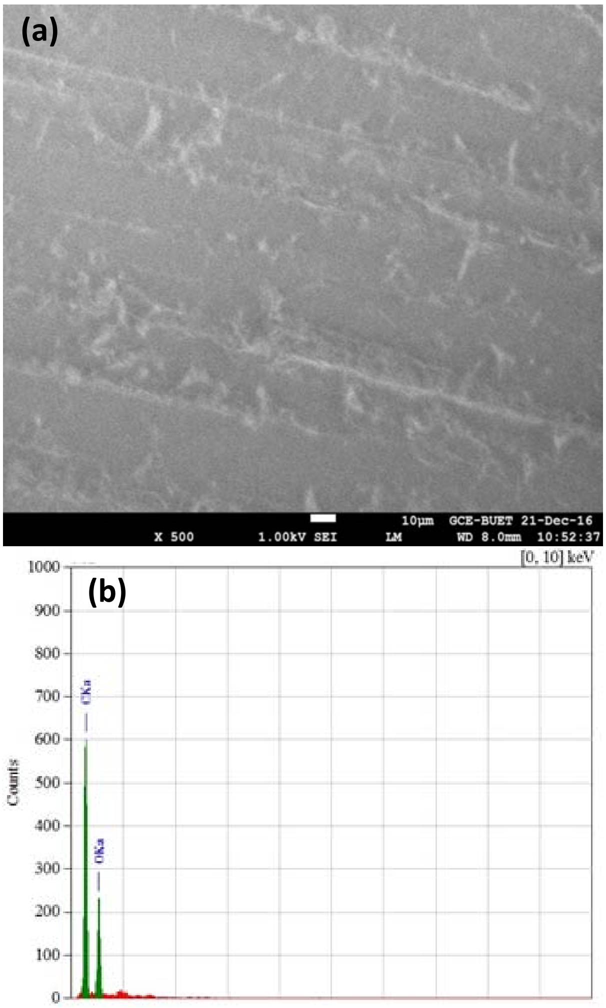

Fig. 10 (a) SEM images and (b) EDX spectra of worn surfaces of Perspex

IV. Conclusion

The following statements are the conclusions drawn from the tribological studies on the Perspex subjected to dry and wet sliding conditions.

The weight loss of Perspex increases with increase in the sliding distance due to higher sliding action of the composite and disc. The nature of the wear rate is similar in both the dry and wet environments. The wear rate and friction coefficient of Perspex in wet sliding condition was approximately twice lower than that in dry conditions for the roughness drop and also for sealing effect. The worn surface was characterized by surface with shallow grooves at constant load, while the groove width and depth increased as the sliding distance increases. The wear marks were visible least amount in wet sliding condition.

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