Sliding Wear Behaviour of Injection Moulded ABS Samples Under Normal, Water Absorbed and Electroplated Conditions

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Abstract* - Tribological performance of polymers and its composites are generally sensitive to operating and test conditions. These conditions make it difficult to understand the wear performance of Polymer Matrix Composites (PMC's). Some of the factors like pre and post treatment operations on polymers, environmental and operational conditions, etc. have an effect on wear and friction properties. Various researchers have pointed out that the PMCs cannot offer opposition to all the different modes of wear. Researchers have also pointed out that the tribological behaviour of plastics can be enhanced by the inclusion of fillers. In the present investigation, the tribological performance of Acrylonitrile Butadiene Styrene (ABS) under normal / dry sliding, 24 hours water absorbed and electroplated (EP) conditions are compared. It is to be emphasized that very little information is available about the effects of electroplating on the wear performance of ABS plastics. The results of the research indicate that with electroplating the wear resistance of ABS plastics increases.

***Keywords:* ABS, Electroplating, Friction, Polymers, Water absorption, Wear.**

I. INTRODUCTION

PMC's have been used in numerous applications related to tribology such as in seals, gears, bearing, wheels, brakes and clutches [1]. Tribology is the study of interacting surfaces in relative motion, which includes boundary-layer interactions both between solids and between solids and liquids and/or gases. Tribology incorporates the entire field of friction and wear, including lubrication [2, 3]. Polymers have the ability to offer lightweight alternatives to conventional materials. Polymers have been classified into two types viz., Thermoplastics and Thermosetting. Thermoplastics are extensively studied as a matrix material for composite structures and commonly used in space and aerospace applications as they exhibit little shrinkage, superior mechanical properties, easy fabrication, outstanding moisture and chemical resistance, fine electrical characteristics and also some exhibit excellent wear resistance [1,4,5].

Wear is initiated as soon as the sample under study and the abrading surface come in contact, i.e., when the lubrication film thickness becomes too small or lubricant is unavailable, wear occurs. Wear is defined as a progressive loss of material from the surface of a solid, brought about by mechanical causes. Symptoms of wear are small, isolated / dislodged particles due to the rubbing / sliding, that causes the material to undergo material loss [2].

Wear is often severe in bearing-type applications, shafts and bars that slide through keyholes or roll in bearings and bushings. The energy that is passed on and/or dissipated in a bearing is a function of the load and rubbing speed of the application. As the load and rubbing speed increases, the heat and wear in the bearing surfaces also increases [6].

Bearing and wear-resistant plastic materials such as polyamides, ABS, Delrin, Torlon, Turcite, Rulon, UHMW, Fluorosint 207, and ABS are available in the market today. ABS has good chemical and stress cracking resistance to acids, oils, salt solutions (inorganic) and, alkalis. ABS has excellent abrasion resistance; electrical properties, moisture and creep resistance [7]. It is also one of the oldest plastics on which electroplating (EP) was experimented or in other words, plating of plastics (POP) was originally developed using ABS [8]. ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene [9]. ABS is a very useful material used in manufacturing automobile parts, helmets and parts of electronic devices, because it can be processed easily and has high thermal resistance and durability. To further enhance durability and thermal resistance and to give metallic properties to the plastic surface, it is plated with metals such as nickel, copper and chromium [8, 10-12].

In the present investigation, the tribological performance of ABS under normal / dry sliding, 24 hours water absorbed and EP conditions are compared. It is important to emphasize that very little information is available about the effects of electroplating on the wear performance of ABS plastics. The results of research indicate that with electroplating, the wear resistance of ABS plastics increases.

II. ELECTROPLATING OF PLASTICS

The procedure of the electroplating ABS plastics has been explained in detail by the authors in their work on POP (reference papers 8 and 13), as depicted in the reference section of this paper. A brief procedure has been explained in the following section. Usually, electroplating on ABS plastics involves the steps as shown in fig. 1. The first step, i.e. etching process involves removal of butadiene particles from ABS samples for creating microscopic holes in the samples. These microscopic holes later act as a site for the deposition of electro platable materials. The etched samples are then activated by laying a catalytic film on the etched surface. This prepares the samples for electroless metal plating. The electroless plated sample is then coated with a layer of nickel followed by a layer of copper and finally coated with Chrome [8, 13].

Fig. 1: Electroplating procedure for ABS plastics [13]

III. EXPERIMENTAL WORK

Tribological performances of ABS based composites are generally sensitive to operating and testing conditions. Therefore, experimental tests for predicting the frictional and wear behaviours are complex owing to the many test parameters that can affect their tribological properties. Tribological performance of ABS can be improved significantly by the process of electroplating. A brief procedure on electroplating samples has been explained in the previous section.

A. Pin-on-Disc wear tests on ABS samples

The present study is motivated by the fact that there is insufficient published work pertaining to the sliding wear and friction behaviour of electroplated ABS plastics as rubbed against the metal surface. An attempt has been made to compare ABS samples in three different conditions viz., dry, wet, and electroplated.

B. Specimen preparation and test procedure

A pin-on-disc test setup in accordance with ASTM G99 was used for slide wear experiments. The test was conducted on a track of 95 mm diameter for the specified test duration, time and velocity. Prior to the testing, the samples and the disc surface were cleaned thoroughly. The wear samples were weighed with an accuracy of 0.001 mg using an electronic balance. The test was carried by applying normal load (1kg to 7kg) and run for a constant sliding distance (1000 m) at different sliding velocities (2.5, 5 and 7.5 m/s). At the end of the test, the wear samples were again weighed in the electronic balance. The wear loss was noted by measuring the difference between the final and initial weights of the samples. Minimum of three trials was conducted to ensure repeatability of test data. The Coefficient of Wear (COW) was also obtained. Few of the samples were then subjected to Scanning Electron Microscopic (SEM) study. The performance of the ABS composites was evaluated based on the changes in the wear coefficient as function of sliding velocity, applied normal load and weight loss of the composite sample with changes in sliding velocity and applied load. The initial weight of the test coupons / pin assembly was recorded accurately using digital balance after cleaning. After fixing the sample pin in its position, the normal load to the pin was applied by placing known dead weights in the pan. The wear studies were carried out by choosing the load, time and velocity. At the end of the test, samples were again weighed.

IV. RESULTS AND DISCUSSIONS

The test data of ABS samples subjected to wear studies, under three different conditions, are as shown in Table 1. The table gives the details of the changes in wear coefficient and weight loss in grams of ABS samples, which are subjected to sliding wear.

Table 1: Wear test results of ABS: Details of changes in wear coefficient and wear loss in grams for applied constant normal loads for varying velocities.

Sliding Velocity, m/s	Normal		24 Hrs Water Absorbed		Electroplated	
	COW	Wear Loss, gm	COW	Wear Loss, gm	COW	Wear Loss, gm
Applied Normal Load of 1 Kg						
2.5	4.42E-08	0.002	5.40E-07	0.025	1.76682E-08	0.001
5	1.09E-07	0.005	1.73E-07	0.008	2.94232E-08	0.0015
7.5	6.65E-08	0.003	6.46E-08	0.003	4.99061E-08	0.0025
Applied Normal Load of 3 Kg						
2.5	1.10E-07	0.005	6.61E-07	0.031	5.94004E-08	0.003
5	1.52E-07	0.007	3.65E-07	0.017	6.29196E-08	0.0035
7.5	8.71E-08	0.004	3.22E-07	0.015	7.94726E-08	0.004
Applied Normal Load of 5 Kg						
2.5	1.32E-07	0.006	7.79E-07	0.037	9.98983E-08	0.005
5	1.75E-07	0.008	5.38E-07	0.025	1.39677E-07	0.007
7.5	1.56E-07	0.007	3.23E-07	0.015	1.18043E-07	0.0065
Applied Normal Load of 7 Kg						
2.5	1.98E-07	0.009	1.02E-06	0.047	1.50639E-07	0.0085
5	2.43E-07	0.011	1.95E-07	0.009	1.86155E-07	0.0105
7.5	2.23E-07	0.0098	1.69E-07	0.008	1.73299E-07	0.0087

Fig. 2 shows the ABS normal samples subjected to different rubbing velocities and varying load conditions. The results indicate that the samples show higher wear coefficient and wear loss when rubbing velocity changes from 2.5m/s to 5 m/s. The behaviour observed is different when the velocity changes from 5m/s to 7.5m/s that is, reduced wear coefficient and wear loss. This indicates that sliding speeds play an important role in friction and wear. With the increase in sliding velocity from 2.5m/s to 5m/s, the frictional heat accompanied with normal load, shear force and frictional thrust decrease the strength of the samples and these factors accelerate the wear rate thus increasing the wear coefficient. The findings are in agreement with the findings of Mimaroglu A [14] and Suresha B C [15].

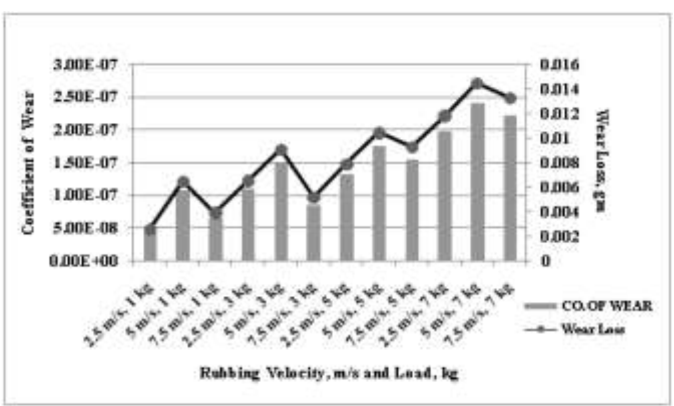

Fig. 2: Coefficient of wear and Wear loss as a function of Rubbing velocity and Load for a constant sliding distance of 1000 meters for Normal ABS Samples

But, when the velocity changes from 5m/s to 7.5m/s, the frictional heat developed would be so large that it starts to melt the samples. The melting smoothens the surface of ABS samples, which are in contact with the rotating disc and further contributes to slipping between samples and disc interface that reduces the wear coefficient and wear loss.

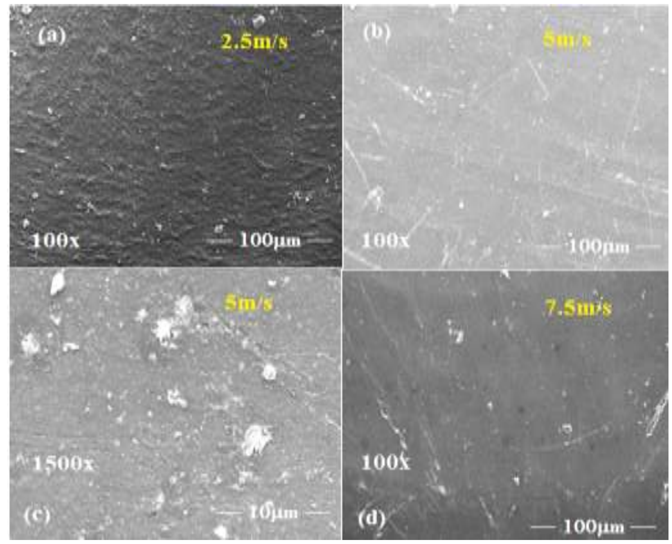

Fig. 3: SEM image of Normal ABS samples subjected to wear studies with an applied load of 7Kg and a sliding distance of 1000m with varying sliding velocity.

The SEM from the fig. 3 provides the evidence for the explanation contained in the present section. Fig. 3 (a) shows the SEM of normal ABS sample subjected to rubbing velocity of 2.5m/s and an applied load of 7kg. No cracks or scars were found in these samples. The fig. 3 (b) shows the presence of scars or pockmarks that are formed due to the change in rubbing velocity from 2.5m/s to 5m/s. These were formed when particles of polymer were torn from the surface of the polymer due to the increased load and speed. The local shear stresses and the frictional heat softens the polymer surface and further tears the polymer surface. Debris or torn particles as observed from fig. 3 (c) now plays the role of a third body (abrasives) that causes additional wear loss [16]. Fig. 3 (d) reveals the reduction in number of scars or scratches formed on the samples subjected to a rubbing velocity of 7.5m/s, which indicates that frictional heat, load and sliding velocity play a major role in bringing down the wear loss and wear coefficient.

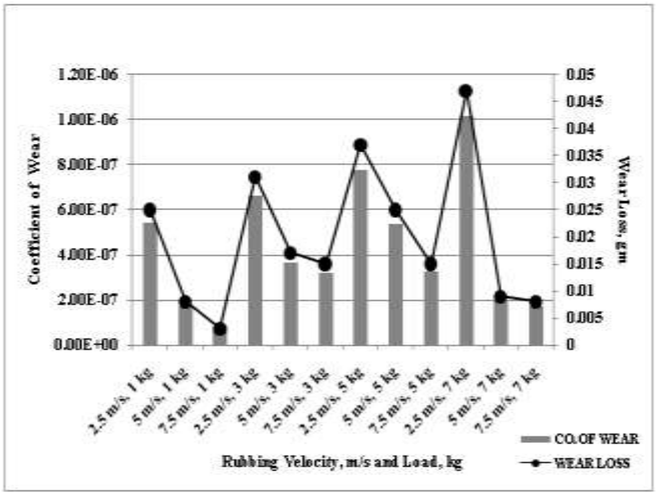

Fig. 4: Coefficient of wear and Wear loss as a function of Rubbing velocity and Load for a constant sliding distance of 1000 meters for 24 hours water absorbed ABS Samples

Fig. 4 shows the samples subjected to 24 hours water absorbed conditions. Samples subjected to 2.5m/s sliding velocity exhibit a higher wear loss and COW than the samples subjected to 5 m/s and 7.5 m/s rubbing velocities. It is noted that the wear of the polymer samples is in the decreasing order of 2.5 m/s > 5 m/s > 7.5 m/s rubbing speeds. From the fig. 5 it is understood that the frictional heat increases almost linearly with the increase in applied load for the samples subjected to 2.5 m/s rubbing speed. But the frictional heat developed in the case of 5m/s and 7.5m/s increases till 5kg load and then decreases at 7kg load.

When the applied load *'P'* and the sliding velocity *'V'* value is small, the thermal motion of ABS molecules is weak because the frictional heat is relatively low, then the deformation of ABS molecule cannot respond to external forces, so the wear coefficient and the wear rate are relatively high as observed at 2.5 m/s sliding velocity and 1kg applied load. It is also observed from the fig. 5 that frictional heat decreases as sliding speed increases. The reason for the decrease in frictional heat is due to the slipping. The samples, as they are wet, release the stored moisture that acts as a lubricant and reduces the heat. Due to the slither between the sample and the disc, friction is greatly reduced and so is with the COW and wear rate as observed at 5m/s and 7.5m/s rubbing speed and 1kg applied load. With the increasing frictional heat as observed from the fig. 5, the molecular segments of ABS are likely to move, so the friction and wear of ABS increase with increasing frictional heat because ABS molecules can easily entangle or interpenetrate into each other in this state. When the frictional heat increases with the increasing *'P'* and *'V'* value, the ABS main molecules can move freely and the molten sliding surface forms a low shear-strength interface layer, which behaves as a lubricant, so the wear coefficient decreases. Furthermore, the ABS sliding surface can melt flow under external forces, so the wear rate of ABS increases sharply. Therefore, the samples subjected to a sliding speed of 2.5m/s and applied load of 7kg exhibits the highest wear loss. The findings in this section are in agreement with the findings of Praveen R N [17] and Sinha K [18].

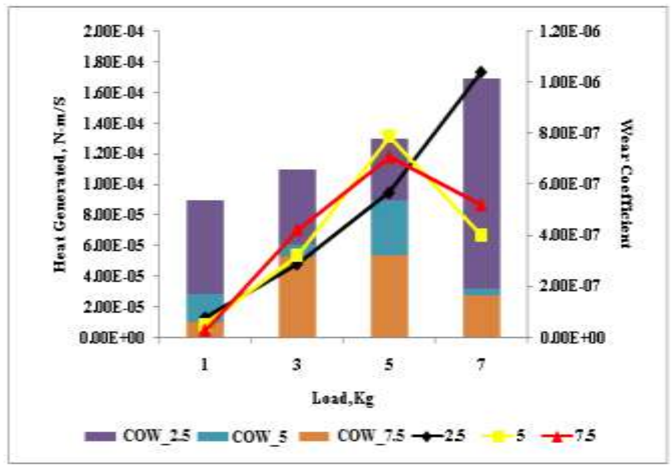

Fig. 5: Heat generated and COW as a function of applied load for a constant sliding distance of 1000 meters for 24 hours water absorbed ABS Samples

The SEM micrographs of worn surfaces of ABS pins, under dry friction and 24 hours water absorbed conditions at a sliding speed of 2.5m/s and 7kg applied load, are given in fig. 3 (a) and fig. 6. It is observed that the worn surface of ABS under dry friction condition is characterized by obvious smooth surface; and no debris is found in these cases. As for 24 hours water absorbed condition, there is much debris on the worn surface; the surface of ABS is noted to have obvious and deep frictional marks (fig. 6). The previously discussed experimental results find that the wear rate of ABS under 24 hours water absorbed condition is greater than under the dry friction. Combined with the morphology of ABS worn surface, it can be deduced that water that diffuses into ABS surfaces from micro-cracks and micro-pores of polymer surfaces induces the reduction of mechanical strength under water absorbed conditions, so higher wear is observed under water absorbed conditions.

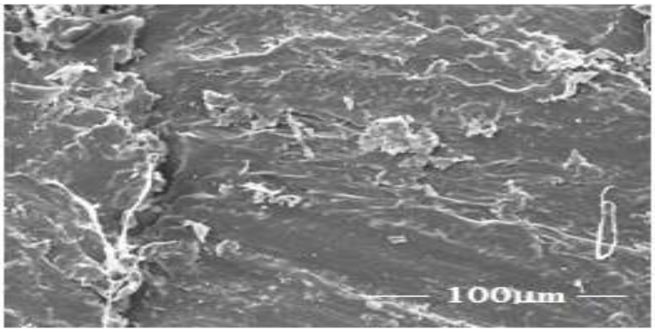

Fig. 6: SEM of 24 hours water absorbed ABS sample subjected to applied load of 7 kg, sliding velocity of 2.5 m/s and sliding distance of 1000 m

From the fig. 7, it is seen that the COW and wear loss increases almost linearly upto the rubbing velocity of 5m/s and a load 5Kg, thereafter rise and fall of the values has been observed. This rise and fall trend is same as the one observed in fig. 2 that is for normal samples. This is a clear indication that up to 5m/s and 5Kg load the EP layer offers the resistance to wear, and hence the wear coefficient and wear loss are considerably lower as compared to normal samples.

It is noted that samples subjected to 7.5m/s sliding velocity and 5kg applied load and beyond does not have the necessary resistance to wear. The sample looses the EP layer at this point, and the ABS surface gets exposed to the disc and due to which lower wear loss and wear coefficient is observed. The wear loss increases at 2.5m/s and 7Kg load and this is due to the high frictional heat that is transferred from copper layer to the core (ABS) before the sample gets completely rid of the EP layer. Also, the rise in the COW and wear rate is accelerated by the worn out EP particles that acts as abrasives and increases the wear rate and COW.

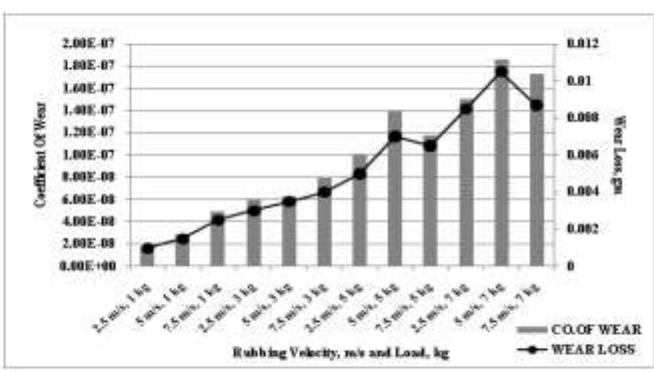

Fig. 7: Coefficient of wear and Wear loss as a function of Rubbing velocity and Load for a constant sliding distance of 1000 meters for Electroplated ABS Samples

The rise in temperature of the samples is observed in the fig. 8. This trend continues till 5m/s and 7kg applied load. But the samples subjected to 7.5m/s and 7kg load exhibit a reduced wear rate and COW, and this is due to the enhanced heat that melts the samples and the rubbing surface becomes smoothened (lesser friction) due to which samples undergo lesser wear loss.

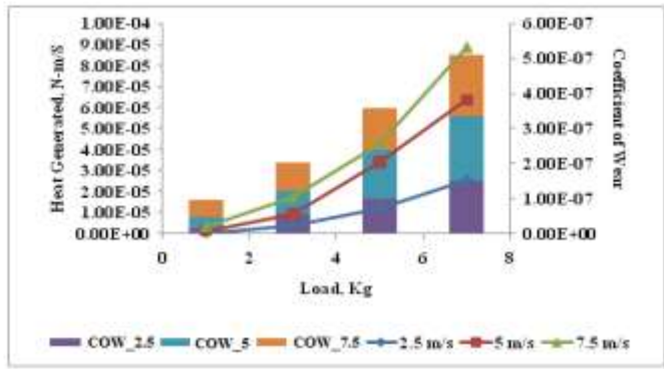

Fig. 8: Heat generated and COW as a function of applied load for a constant sliding distance of 1000 meters for electroplated ABS Samples

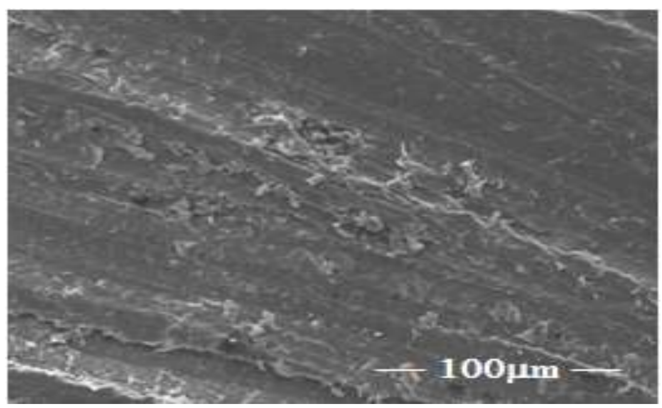

Fig. 9: SEM of Electroplated ABS sample subjected to applied load of 7 kg, sliding velocity of 5 m/s and sliding distance of 1000 m

Fig. 9 shows the SEM image of the EP-ABS sample, subjected to a normal load of 7kg and rubbing velocity of 5 m/s. It is observed that the worn surface of ABS under EP condition is characterized by scratching at an angle of approximately 15-30^{O} to the sliding direction. But the SEM of the normal sample (fig. 3b) subjected to the same condition shows a different wear, where lesser debris is found adhering to the normal sample as compared to EP sample. The debris in EP sample is due to the hard chrome and nickel particles that act as abrasives and dig more into the soft ABS surface.

V. Conclusions

- Heat due to friction has a significant effect on the tribological behaviours of polymer–metal combinations.
- The higher wear of ABS in water absorbed conditions may be due to the reduction in mechanical strength and weakened ABS matrix due to the lower water absorption.
- ABS samples under electroplated conditions exhibit lower wear in comparison to dry sliding and water absorbed samples.
- The friction and wear behaviours of ABS–metal combination are closely dependent on the *PV* value for the water absorbed condition, while the PV value has little effect on the tribological behaviours for dry sliding and electroplated conditions.

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