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TRIBOLOGICAL PROPERTIES OF POLYMERIC MATERIALS LUBRICATED BY SAND CONTAMINATED WATER

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ABSTRACT

The aim of this work is to investigate the abrasive wear resistance of four types of polymeric materials such as polymethylmethacrylate (PMMA), polyamide (PA6), polyethylene terephthalate (PET) and polytetrafluoroethylene (PTFE). Friction and wear tests were carried out at water and salt water lubricated sliding conditions. Sand of particle size ranging from 30 to 50 µm was used as contaminant at 1.0 wt. % concentration. Tests were carried out at 150 N applied load and 0.4, 0.7 and 1.2 m/s sliding velocity for 300 seconds. The test results showed that a correlation between friction coefficient and voltage generated was found for polymers sliding against PET and against steel in water and salt water lubricated conditions.

The results showed that motion of sand particles trapped in the contact area may be rolling or sliding. Rolling causes lower friction and wear. Sliding occurs when sand particles are embedded in one of the rubbing surfaces then they abrade the counterface and increase wear and friction. Hardness as well as triboelectrification of the rubbing surfaces and sand particles influence rolling and sliding. Increasing ESC will increase the adhesive force between the two rubbing surfaces, where embedment of sand or sticking is prevailing. Based on that, sand particles embed into PTFE and abrade the steel surface, while in condition of PET sliding on PET, sand tends to roll than embed in PET surface leading to drastic decrease in both friction and wear.

Salt water as lubricating medium of PET shaft sliding on the tested polymeric materials caused significant friction increase. The lowest friction was displayed by sliding PET on PET, while wear of polymeric materials showed significant increase in the presence of salt water. The lowest wear was experienced by PTFE. Salt water caused remarkable wear increase. This behavior can be explained on the fact that good conductivity of salt water released the generated ESC and decreased the adherence of sand on the contact surface.

KEYWORDS

Friction, wear, polymeric materials, sand, water, salt water.

INTRODUCTION

Water lubricated bearings are extensively used in ship building industry. Most of the bearings are made of polymers, while the propeller is made of steel. Little attention was considered to understand the effect of sand particles on the performance of bearings lubricated by water, [1 - 4]. As result of the thin water film inside the bearing, it was found, [5], that sand particles cause surface scratches as well as severe damage because of scuffing.

The influence of triboelectrification on friction displayed by polymers was investigated, [6]. It was revealed that when PET surface was rubbed by PA, friction coefficient represented relatively lower values, while PET surface rubbed by PTFE gave the highest friction values. The dependency of friction coefficient on ESC generated from sliding of PE on PTFE was investigated, [7]. ESC could be controlled by applying magnetic or electric field. ESC built up on human skin and or clothes in direct contact with human body are very harmful and can cause serious problems, [8]. It was found that, iron nanoparticles addition into epoxy matrix increased friction coefficient. The change, in friction and ESC of alumina sliding against PTFE, was measured, [9], to have specific information about ESC to control friction coefficient.

ESC generated from PA and PET showed only the half value of raw PET when it is in contact with cotton, [10]. PET is widely used polymers in different applications. It can be fabric in clothes and resin as well as in nanomaterials and nanocomposites, [11 - 14]. PA has many of applicable properties, [15 - 17]. Weaving PA of positive ESC and PET of negative one to have a fabric of zero ESC was investigated. PTFE blended by cotton, wool and PA decreased ESC, [18]. ESC generated from the friction of head scarf and hair was measured, [19]. Besides ESC generated from polymeric textiles sliding against cotton was investigated, [20, 21], where increase of cotton content in polyester fabric decreased ESC.

The present work investigates the friction and wear of four of polymeric materials such as PMMA, PA6, PET and PTFE at sand contaminated water and salt water lubricated sliding conditions.

EXPERIMENTAL

Experiments were performed using block on cylinder wear tester, Fig. 1. The polymeric materials tested in the present work were PMMA, PA6, PET and PTFE. They were in form of cubic block of 30 × 30 × 30 mm^3. The counterfaces were 40 mm diameter bearing steel and polyethylene terephthalate as well as 120 mm diameter carbon steel cylinder of 11 mm width. The surface roughness of the cylinders was approximately 0.2 µm (Ra). Tests were performed at 80 N load, where the test time was 600 seconds.

The polymeric blocks representing the bearing were fastened to the loading lever, where the load was applied by weights. The weights of the loading lever and the polymeric block were balanced by counter weight. The main shaft of the tester is driven by DC motor (250 watt, 230 volt) through a V-belt drive unit, where the motor speed is controlled by varying the input voltage using an autotransformer. The tester is fitted by a load cell to measure

the frictional torque generated in the contact zone between the rotating cylinder and polymeric surface. The wear of polymeric surface was determined by wear scar width measured by optical microscope of 0.01 mm accuracy. The wear tests were repeated three times and the mean value of the wear scar width was considered. The sand particle size ranging from 30 to 50 µm was used to contaminate the water at concentration of 1.0 wt. %. Water and salt water (5 wt. % NaCl) were used as lubricant. The voltage difference was measured by digital voltmeter of ± 0.1 mV accuracy.

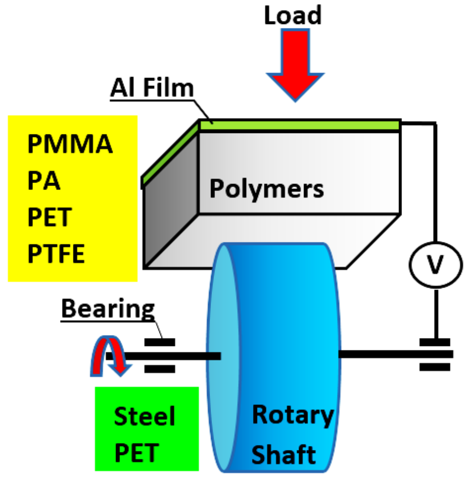

Fig. 1 Arrangement of the wear tester.

RESULTS AND DISCUSSION

The friction of sand, PMMA and PA6 surfaces generate positive ESC when they rub steel, while PET and PTEF surfaces gain negative ESC, Fig. 2. The tendency of the adherence of sand particles into the surface of PET and PTFE is relatively higher due to the higher intensity of ESC generated. Sand particles trapped in the contact area suffer from rolling and sliding action. Rolling causes lower friction and wear. When sand particles are embedded in one of the rubbing surfaces then they abrade the counterface. In that condition, wear and friction coefficient increases. Rolling and sliding are strongly influenced by the hardness of the rubbing surfaces.

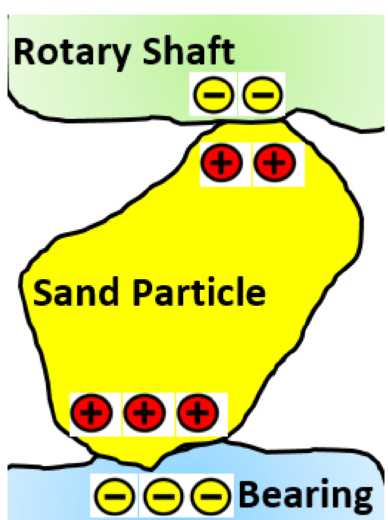

Fig. 3 Triboelectrification of the rubbing surfaces.

Table 1 Triboelectric Series of the tested materials.

Positive Charge +
Sand
Polyamide (PA6)
Polymethylmethacrylate (PMMA)
Steel Neutral
Polyethylene terephthalate (PET)
Polytetrafluoroethylene (PTFE)
Negative Charge -

The mechanism of triboelectrification of the rubbing surfaces is illustrated in Fig. 3. The intensity of ESC generated on the contact surfaces depends on the gap between the two materials in the triboelectric series as shown in Table 1. It is expected that when sand particles rub PTFE, the generated ESC displays the highest values. In contradiction to that, rubbing steel by PMMA or PET generates relatively lower values of ESC. Consequently, increasing ESC increases the adhesive force between the two rubbing surfaces. Based on that, sand particles stick to PTFE and abrade the steel surface.

When PET slides on PET in the presence of sand particles, it is expected that sand tends to roll than embed in PET surface leading to decrease both friction and wear. In the presence of salt water, the values of ESC will be influenced by the good electrical conductivity. Therefore, the rolling of sand particles prevails more than sticking in the rubbing surfaces.

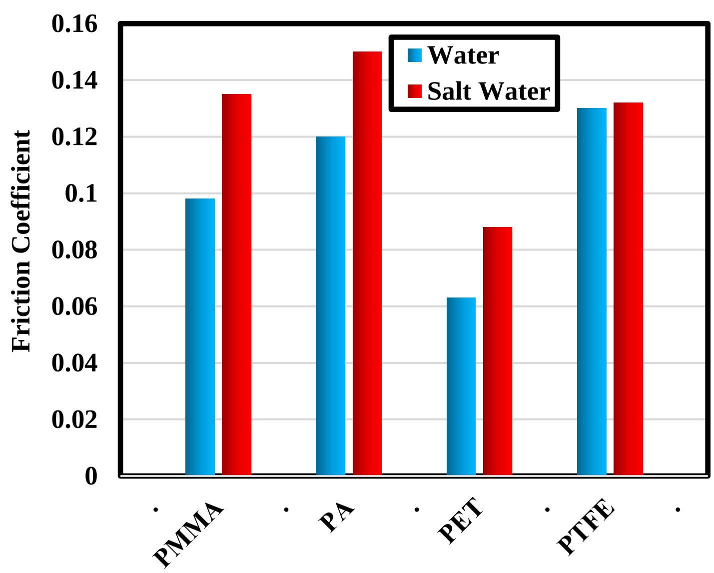

Fig. 4 Friction coefficient displayed by sliding of PET shaft on polymeric materials.

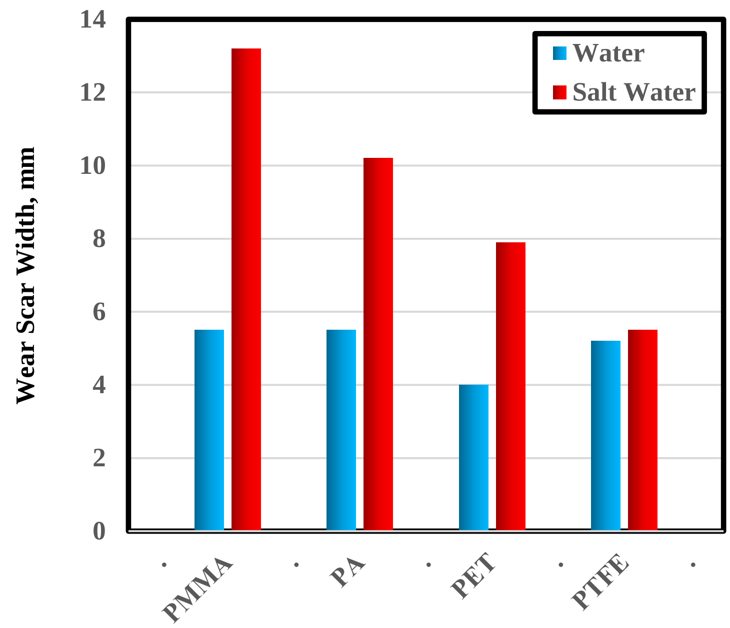

Fig. 5 Wear scar width of polymeric materials after sliding on PET shaft.

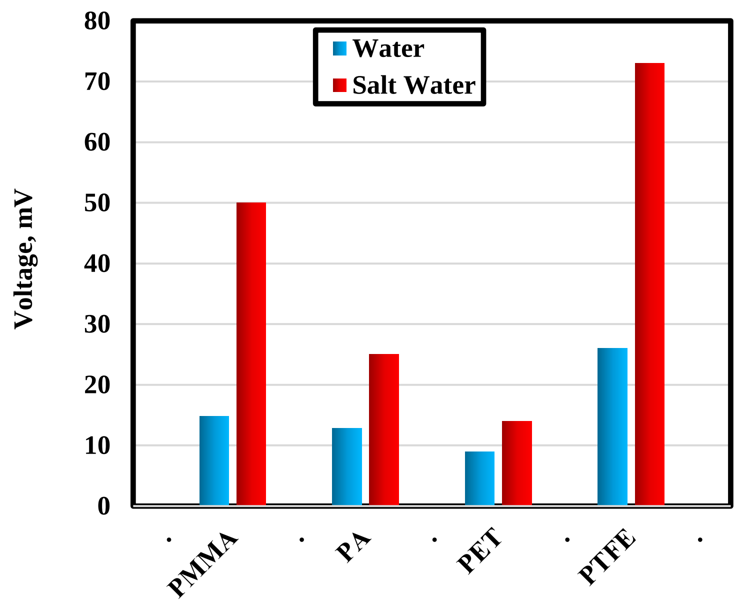

Fig. 6 Voltage generated from sliding of PET shaft on polymeric materials.

Figure 4 shows the friction coefficient displayed by sliding of PET shaft on the tested polymeric materials. Salt water as lubricating medium caused significant friction increase. The lowest friction was displayed by sliding PET on PET. It seems that the adherence of sand particles in the two contact surfaces was not enough to stick because of the low value of ESC. In the other side, PET sliding on PET recorded the lowest friction due to the relatively low ESC.

Voltage generated from sliding of PET shaft on polymeric materials recorded the highest values for salt water, Fig. 6, supporting the explanation of friction and wear results shown in Figs. 4, 5. The good conductivity of salt water enabled the homogeneous distribution of the ESC on the contact surfaces. Because PTFE is active charged, the measured represented the highest value at salt water (73 mV), while PET showed the lowest voltage 14 mV).

Wear scar width of polymeric materials after sliding on PET shaft showed significant increase in the presence of salt water, Fig. 5. The lowest wear was experienced by PTFE due to the embedment of sand particles in its surface protecting it from abrasion of sand particles. Salt water caused remarkable wear increase. This behavior can be explained on the fact that good conductivity of salt water released the generated ESC and decreased the adherence of sand on the contact surface.

The results of the sliding of bearing materials on bearing steel shaft are shown in Figs. 7 – 9. Friction coefficient displayed by sliding of steel shaft on the tested polymeric materials, Fig. 7, showed significant increase compared to that observed for PET shaft. Steel released the ESC generated on the contact area and sand particles. The relatively high hardness of steel allowed the sand particles to embed or stick in the polymeric surface. The abrasion of steel surface by sand particles increased leading to friction increase. Based on this explanation, it is expected that wear of bearing materials would decrease due to the formation of the protective layer of sand particles on their surfaces, Fig. 8. Wear in the salt water represented lower values for PMMA, PA6 and PTFE due to the release of ESC from the contact area. It can be observed that, PA6 provides the lowest wear due to the presence of sand particles at the contact area that react as third body between the two rubbing surfaces. The friction and wear decrease was noticed for both the fresh and salt water. It seems that wear decreased as the adherence of the polymeric film increased. Voltage measured from sliding of bearing steel shaft on polymeric materials showed higher values than measured for PET shaft, Fig. 9. Voltage increased as result of the salt water for PET sliding on steel, while decreased for PMMA, PA6 and PTFE where maximum voltage was 135 mV for PTFE sliding against steel in the presence of fresh water. The good conductivity of steel limited the influence the voltage increase caused by salt water. It can be noticed that there is correlation between friction coefficient and ESC measured in mV, where the friction increase was accompanied by voltage an increase. Knowing that embedment of sand particles in the tested polymeric surface increased friction coefficient. As the adhesive force between sand particles and the polymeric surface increased, their abrasion increased. The value of the adhesive force probably depends on the intensity of ESC.

Increasing the sliding velocity of carbon steel shaft to 1.2 m/s increased the temperature of the contact surface and consequently the ESC was relaxed. The effect of the interaction of sand particles into the two rubbing surfaces was dominating. Friction coefficient displayed by sliding of the carbon steel shaft on PTFE recorded lower values than that observed at 0.4 m/s velocity, Fig. 10. This decrease may be from the hydrodynamic sliding

condition that increased the lubricant film thickness and decreased the contacting asperities of the two rubbing surfaces.

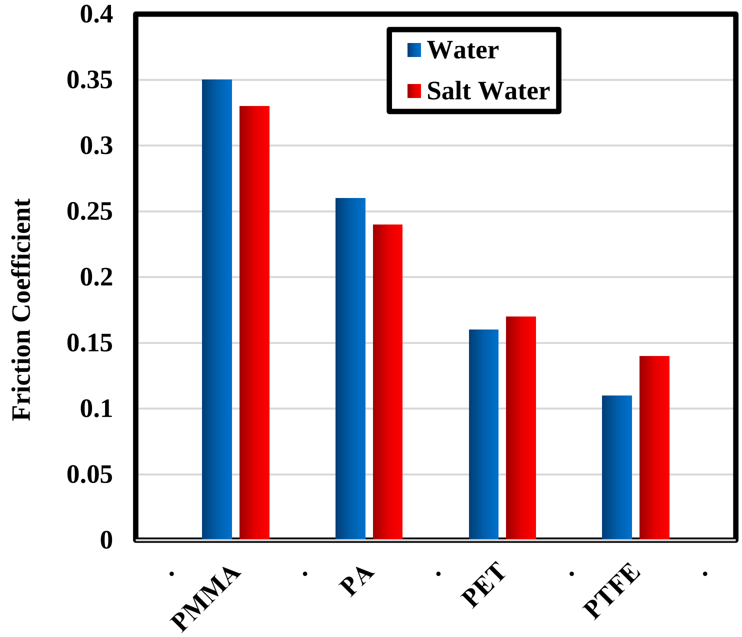

Fig. 7 Friction coefficient displayed by sliding of bearing steel shaft on polymeric materials.

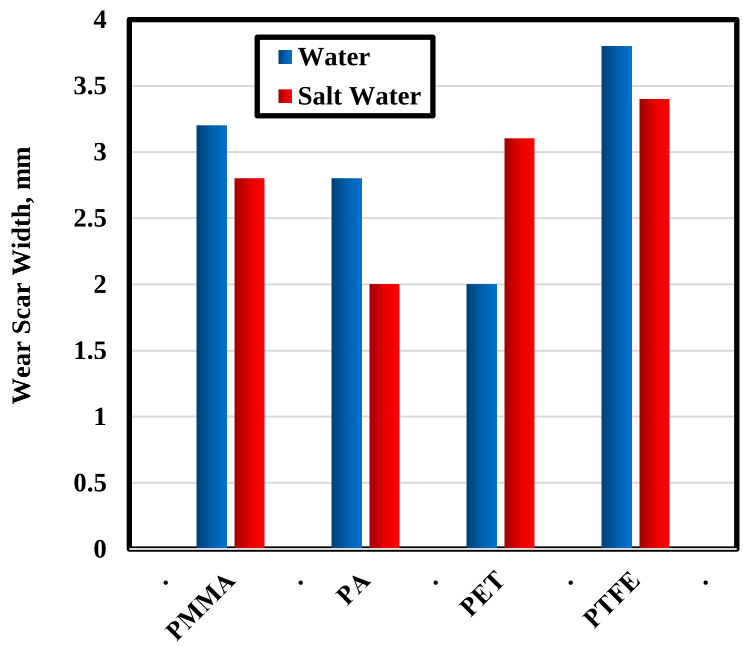

Fig. 8 Wear scar width of polymeric materials after sliding on bearing steel shaft.

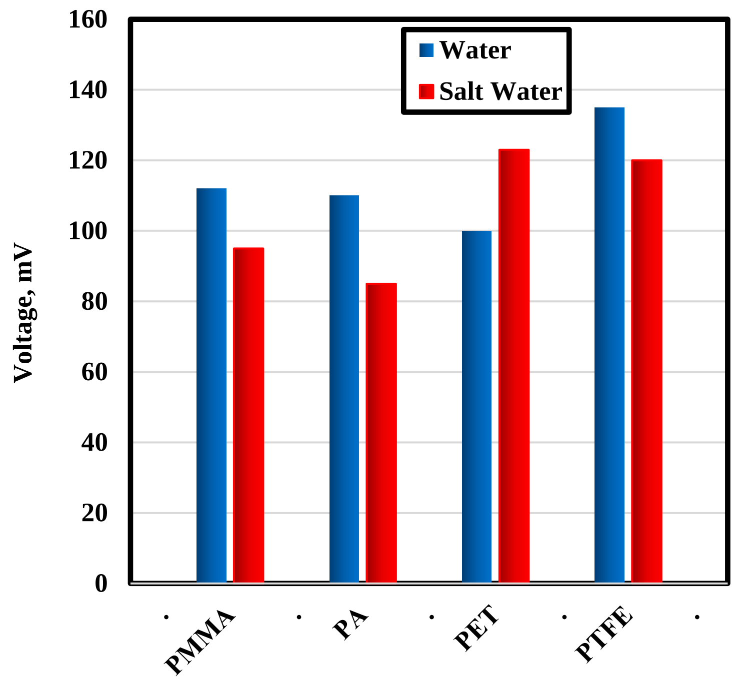

Fig. 9 Voltage generated from sliding of bearing steel shaft on polymeric materials.

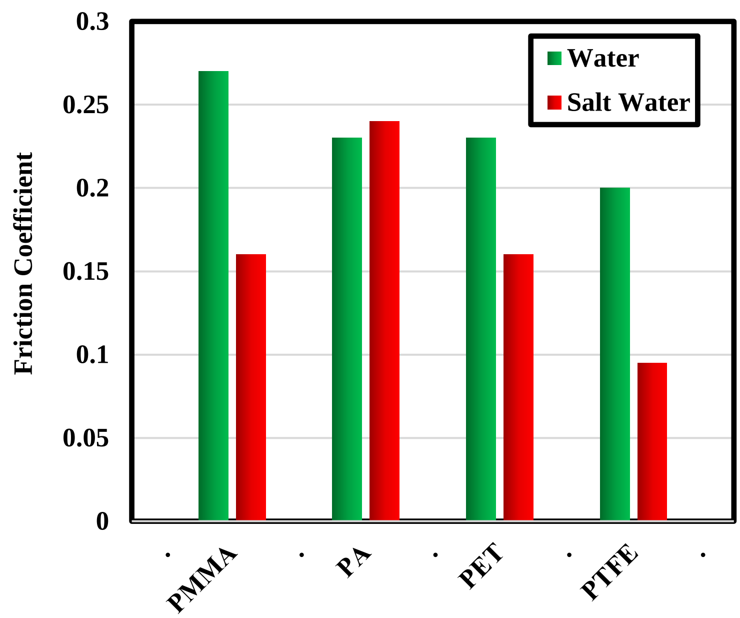

Fig. 10 Friction coefficient displayed by sliding of steel shaft (120 mm diameter) on polymeric materials.

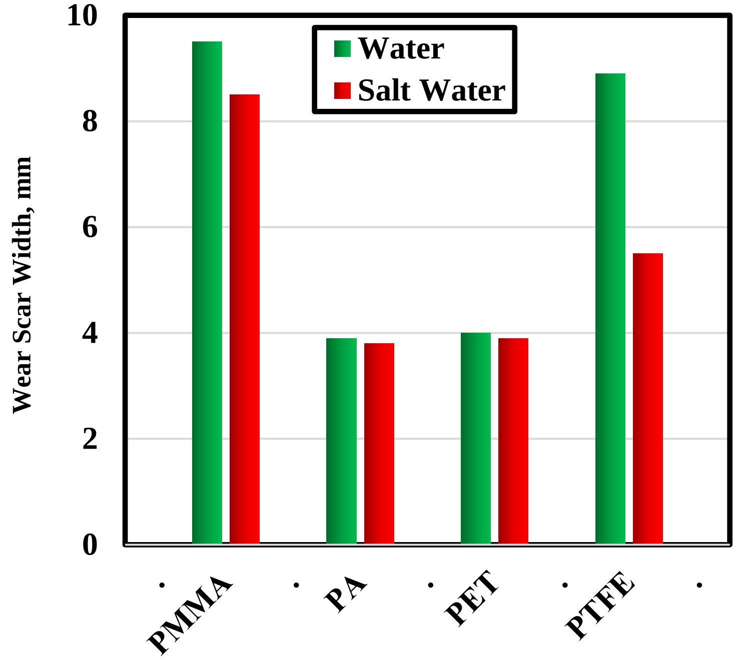

Fig. 11 Wear scar width of polymeric materials after sliding on bearing carbon steel shaft.

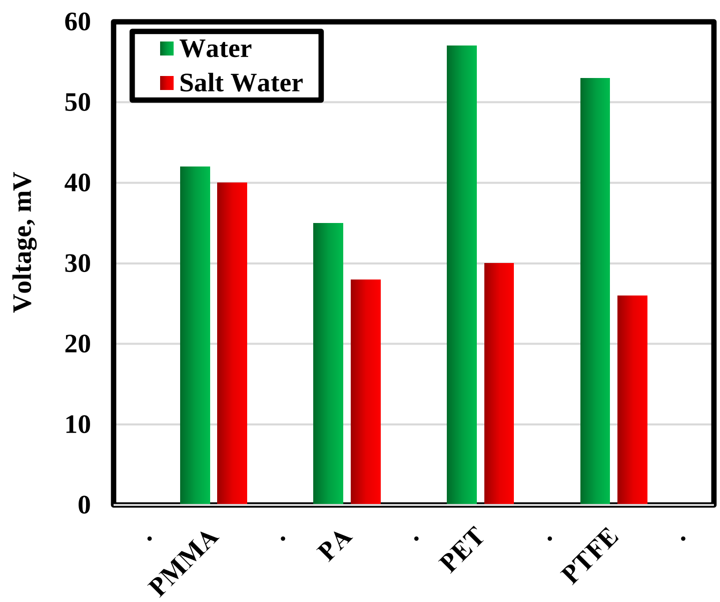

Fig. 12 Voltage generated from sliding of carbon steel shaft on polymeric materials.

PTFE showed the lowest friction values followed by PET, PA6 and PMMA. In contradiction to that, wear increased with increasing the sliding velocity, Fig. 11, where maximum wear was displayed by PTFE and PMMA. Wear increase can be offered to the temperature rise that reduced the shear strength of the tested polymers. Sand particles were completely embedded in the surface of the polymers decreasing the area of the

protective layer supported by sand particles. Minimum wear was observed for PA. Voltage generated from sliding of carbon steel shaft on polymeric materials decreased with increasing sliding velocity as result of the heat generated on the contact zone that was responsible for the charge relaxation, Fig. 12. The maximum voltage value was 57 mV displayed by PETP.

CONCLUSIONS

1. Adherence of sand particles into the sliding surface depends on the intensity of the generated ESC.
2. Salt water as lubricating medium of PET shaft sliding on the tested polymeric materials caused significant friction increase. The lowest friction was displayed by sliding PET on PET, while wear of polymeric materials showed significant increase in the presence of salt water. The lowest wear was experienced by PTFE. Salt water caused remarkable wear increase. Voltage generated from sliding of PET shaft on polymeric materials recorded the highest values for salt water.
3. Friction coefficient displayed by sliding of steel shaft on the tested polymeric materials showed higher values compared to that observed for PET shaft. PA6 offers the lowest wear for both the fresh and salt water. Voltage showed higher values than measured for PET.
4. Friction coefficient displayed by sliding of the carbon steel shaft on PTFE recorded lower values than that observed for bearing steel. PTFE showed the lowest friction values followed by PET, PA6 and PMMA. Wear increased with increasing the sliding velocity. ESC decreased with increasing sliding velocity.

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