

**ELECTRIC STATIC CHARGE GENERATED FROM THE SLIDING OF
POLYMERS AGAINST STAINLESS STEEL**

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ABSTRACT

The increase of polymeric materials use in engineering application necessitates to study their triboelectrification behaviour during friction. Experiments were carried out to measure the electric static charge generated from the friction of different polymeric {polyamide (PA 6), graphite filled polyamide (GPA 6), polyethylene terephthalate, (PET), polytetrafluoroethylene, (PTFE) and polymethyl methacrylate, (PMMA)} sliding against stainless steel at 60 and 180 N load. The test was carried out at water, salt water and oil lubricated sliding surfaces.

It was found that voltage generated from the sliding of PA 6 lubricated by oil against stainless steel showed the highest voltage, while that lubricated by water and salt water showed the lowest voltage. Significant voltage increase was observed with load increase. Water lubricated surfaces displayed the highest voltage values followed by salt water. Oil lubricated surfaces showed the lowest voltage. GPA 6 displayed relatively higher generated voltage than PA 6. Salt water showed the highest voltage followed by water, while oil showed very low voltage. It can be suggested that the presence of graphite in the matrix of PA 6 enhanced its electrical conductivity and homogeneously distributed the electric static charged generated on the surface. Besides, GPA 6 was more sensitive to salt water where the highest voltage was generated.

Voltage generated from the sliding of PET against stainless steel showed relatively lower values than that observed for PA 6 and GPA 6. This observation can explain the good tribological properties of PET. The voltage generated from PTFE was influenced by material transfer and transfer back from PTFE to steel surfaces. PMMA displayed relatively high voltage values, where water and salt water produced higher values than oil lubricated surface. As the load increased surfaces lubricated by salt water recorded the maximum voltage values (200 V).

KEYWORDS

Triboelectric static charge, polymers, stainless steel.

INTRODUCTION

The electrostatic charging generated from the sliding of polytetrafluoroethylene (PTFE), polyurethane (PU) and stainless steel (SS) against unstrained and strained latex rubber

sheets was studied, [1]. For polymers such as PTFE and PU, strain generated charge transfer of reversed charge due to material transfer. For SS, the charge transfer was of single sign, where strain reduces the frequency of electrical discharges occurring. It seems that strain changes the nature of contact between the surfaces and produces charged species, such as ions, electrons, and radicals. Based on this observation it can be concluded strain can strongly influence electrostatic charging. Silicon carbide is electrically semiconducting materials. The friction and wear behaviour of silicon carbide based materials may be influenced by electric potentials applied to the tribological system, [2 – 5]. Also, it was found that the surface state of SiC ceramics can be influenced by electric potentials.

Triboelectrification generated from the friction between polymers of PA66, POM, ABS, PET, PP, PVC, PE, and PTFE in various humidity conditions, [6]. The maximum charges of all the sliding couples were at 10 to 30% humidity. It seems that humidity enhanced the charge transfer which affected the electrification. The contact and separation generate charge transfer between dissimilar materials, [7, 8]. When shear stress breaks the bond between slip planes it induces electron emission from the insulating material.

It was found that voltage generated from the sliding of PTFE against rubber showed the highest values, while aluminium oxide, copper, aluminium, iron and silicon oxide generated the lowest voltages, [9]. Besides, it was found that voltage decreased with increasing load due to heating process which increased the temperature of the friction surfaces and consequently the relaxation of the electric charge proceeded. The maximum voltage was dependent on the position of the materials in the triboelectric series relative to the surface material. The triboelectric series can be used to estimate the relative charge polarity of the materials. This series can be used to estimate the relative charging capacity of many polymeric materials.

The electrostatic charge of epoxy composites filled by nanoparticles of aluminium (Al) sliding against rubber was investigated, [10]. It was found that at dry, water and detergent wetted surfaces, Al nanoparticles addition into epoxy matrix decreased friction coefficient with increasing Al content. As for voltage as a measure of the electrostatic charge generated from friction, it was observed that at dry sliding, voltage decreased with increasing Al content. Voltage showed the maximum values for epoxy free of filling materials and with decreasing load. At water wetted surfaces, epoxy free of Al showed relatively lower voltage than that observed for dry sliding. Voltage showed drastic decrease with increasing Al contents. The same trend was observed for detergent wetted surfaces.

Friction coefficient and electrostatic charge of epoxy composites filled by nanoparticles of aluminium oxide (Al_2O_3) sliding against rubber were investigated to develop proper materials to be used as flooring materials of high friction coefficient and low electrostatic charge, [11]. It was found that, at dry sliding, Al_2O_3 nanoparticles addition into epoxy matrix decreased friction coefficient and voltage with increasing Al_2O_3 content. Voltage showed the maximum values for epoxy free of filling materials. At water wetted surfaces, slight decrease in friction coefficient was observed. Epoxy free of Al_2O_3 showed relatively lower voltage than that observed for dry sliding. As Al_2O_3 content increased voltage significantly increased. At detergent wetted surfaces, friction coefficient and voltage slightly increased with increasing Al_2O_3 . In the presence of sand

particles on the sliding surfaces, slight increase in friction coefficient was observed with increasing Al_2O_3 . Values of friction coefficient indicated that sand particles action was dominating either by rolling between epoxy matrix and rubber surface or by embedment in the sliding surfaces. Voltage slightly increased with increasing Al_2O_3 , where the voltage displayed relatively low values. At water contaminated by sand, friction coefficient and voltage increased with increasing Al_2O_3 . For surface covered by detergent contaminated by sand, friction coefficient increased with increasing Al_2O_3 , while voltage drastically decreased with increasing Al_2O_3 . At oil lubricated surfaces, friction coefficient drastically decreased with increasing Al_2O_3 when sliding against rubber lubricated by oil. As the load increased, friction coefficient decreased. Voltage drastically decreased with increasing Al_2O_3 . At oil/water emulsion, friction coefficient significantly increased while voltage decreased with increasing Al_2O_3 . At oil contaminated by sand, friction coefficient significantly increased while voltage decreased with increasing Al_2O_3 . At water/oil emulsion contaminated by sand, friction coefficient slightly increased, while voltage drastically decreased with increasing Al_2O_3 .

The aim of the present work is to measure the electric static charge generated from the friction of different polymeric materials such as polyamide (PA 6), graphite filled polyamide (GPA 6), polyethylene terephthalate, (PET), polytetrafluoroethylene, (PTFE) and polymethyl methacrylate, (PMMA) sliding against stainless steel.

EXPERIMENTAL

Experiments were carried out using wear tester, Fig. 1. Test specimens were of polymers in form of cubes of $20 \times 20 \times 20$ mm. The polymers tested in the present work were polyamide (PA 6), Graphite filled polyamide, (GPA 6), polyethylene terephthalate, (PET), polytetrafluoroethylene, (PTFE) and polymethyl methacrylate, (PMMA). The friction surface of the test specimens was ground by an emery paper of 500 grades before test. The counterface, in form of stainless steel disc of 40 mm diameter and 11 mm width of surface roughness of $0.4 \mu m$ (R_a), was fastened to the rotating shaft of the tester. The steel disc was well insulated from the rotating shaft. Load was applied by weights. Experiments were carried out using loads of 60 and 180 N at 0.4 m/s sliding velocity.

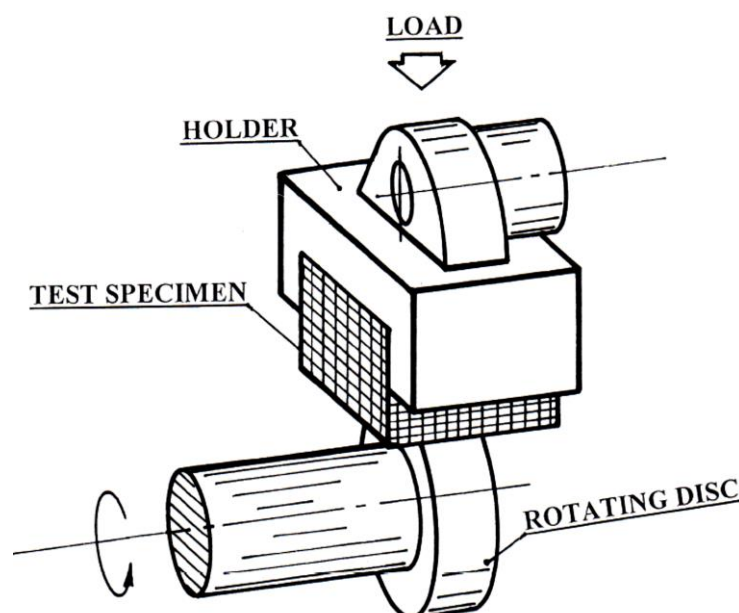


Fig. 1 Arrangement of the test rig.

The electrostatic fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens. It measures down to 1/10 volt on a surface, and up to 20 000 volts (20 kV). Readings were normally done with the sensor 25 mm apart from the surface of stainless steel disc.

RESULTS AND DISCUSSION

Voltage generated from the sliding of polyamide against stainless steel at 60 N load is shown in Fig. 2. Surface lubricated by oil showed the highest voltage, while that lubricated by water and salt water showed the lowest voltage. This behaviour can be explained on the bases that oil as insulator facilitated the accumulation of the electric static charge on the sliding surfaces while water and salt water conducting the charge and homogeneously distributed on the polyamide and steel surfaces. As the time increased the generated voltage increased.

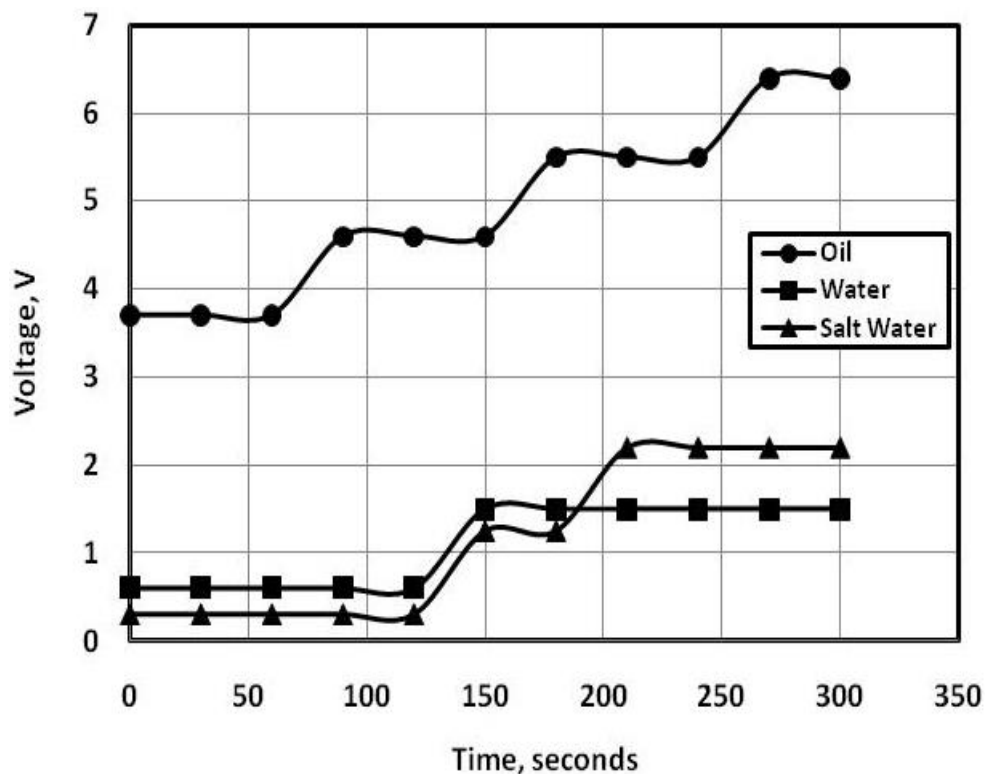


Fig. 2 Voltage generated from the sliding of polyamide against stainless steel at 60 N load.

Significant voltage increase was observed when the load increased up to 180 N. Water lubricated surfaces displayed the highest voltage values, Fig. 3, followed by salt water. Oil lubricated surfaces showed the lowest voltage. The load increase changed the contact condition, where the number of contact asperities as well as the contact area increased. As a result of that voltage increased. The mechanisms of triboelectrification are electron transfer, ion transfer and material transfer, [12 – 14]. For polymers, the electron transfers only happen on their surfaces, [15 – 17]. According to the triboelectric series the polarity of the charge that is transferred from one surface to another can be predicted, [18, 19]. At relatively high load the prevailing mechanism is material transfer,

where the sign of the electric static charge is frequently changed. Engineering materials including polymers can be arranged in a “triboelectric series” which lists the materials in the order of their relative polarity. In the triboelectric series the higher positioned materials will acquire a positive charge when contacted with a material at a lower position along the series, [20]. The triboelectric series can be used to estimate the relative charge polarity of the materials.

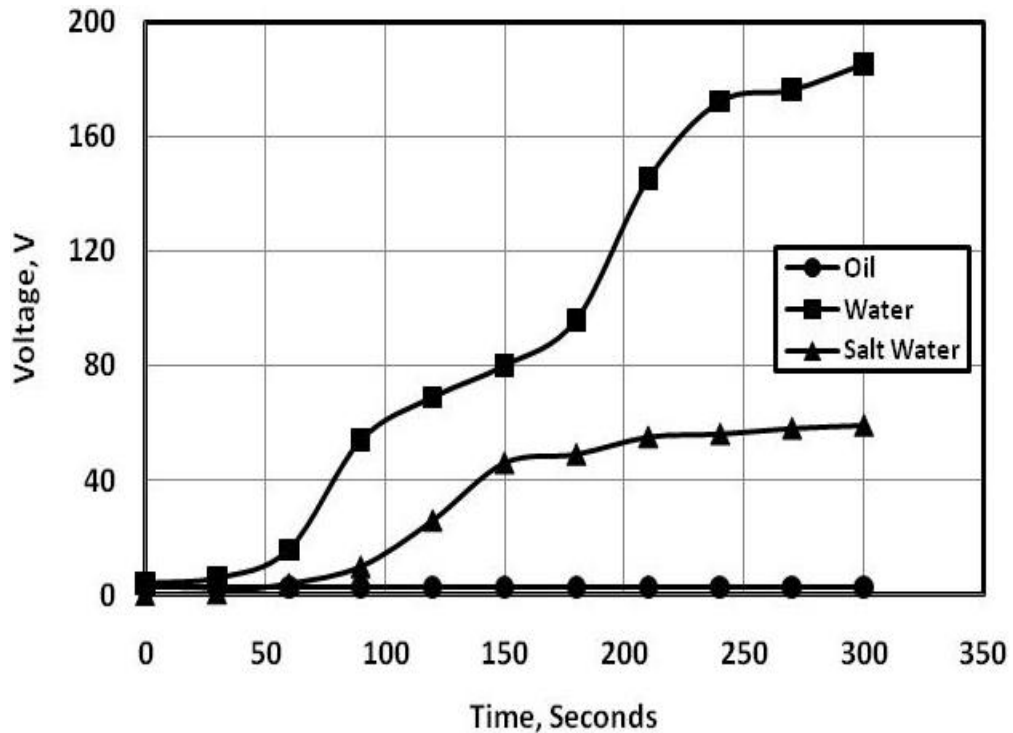


Fig. 3 Voltage generated from the sliding of polyamide against stainless steel at 180 N load.

Graphite filled polyamide (GPA 6) displayed relatively higher generated voltage than unfilled polyamide (PA 6), Fig. 4. Salt water as lubricating medium showed the highest voltage followed by water, while oil showed very low voltage. As the load increased up to 180 N, Fig. 5, no significant change was observed, where almost the same ranking and value were detected. It can be suggested that the presence of graphite in the matrix of PA 6 enhanced its electrical conductivity and homogeneously distributed the electric static charged generated on the surface. Besides, GPA 6 was more sensitive to salt water where the highest voltage was generated.

Voltage generated from the sliding of polyethylene terephthalate (PET) against stainless steel at 60 N load, Fig. 6, showed relatively lower values than that observed for PA 6 and GPA 6. The highest voltage values were 3.3, 2.0 and 1.25 volts for water, salt water and oil lubricated surfaces respectively. The low voltage values may be from the ranking of PET in the triboelectric series as well as from the material transfer from PET to steel surface or transfer back from steel to PET surface. Increasing the load up to 180 N caused slight voltage increase, where the highest voltage was 35 volts for salt water, Fig. 7. In the presence of oil, the voltage values did not exceed 2 volts. This observation can explain the good tribological properties of PET.

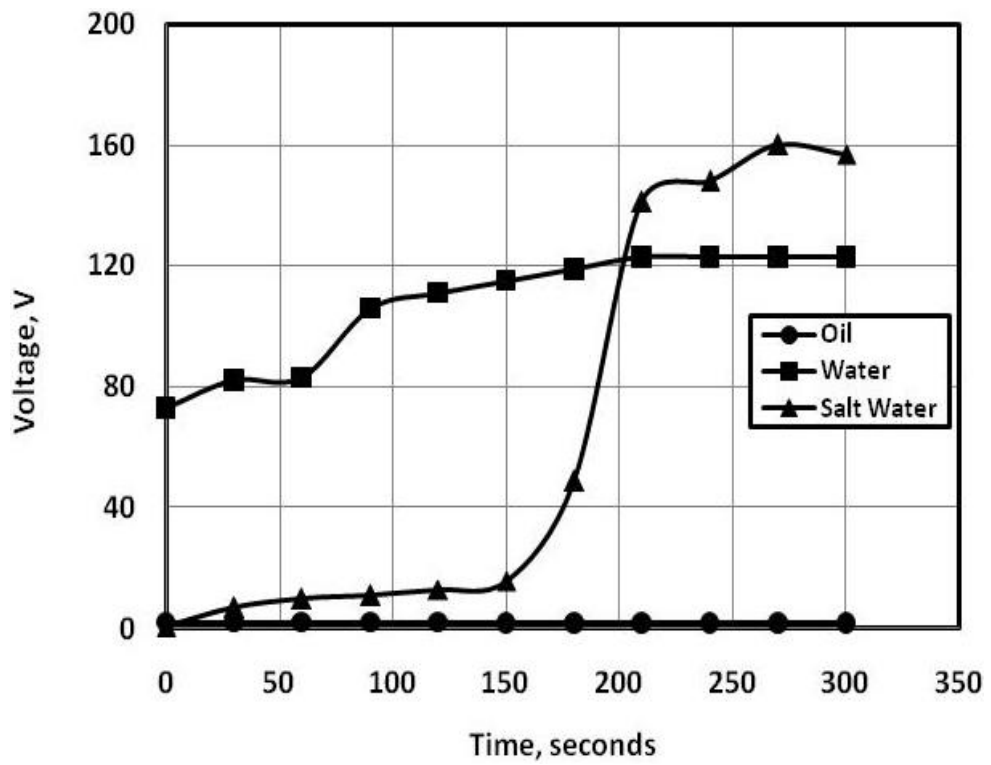


Fig. 4 Voltage generated from the sliding of graphite filled polyamide against stainless steel at 60 N load.

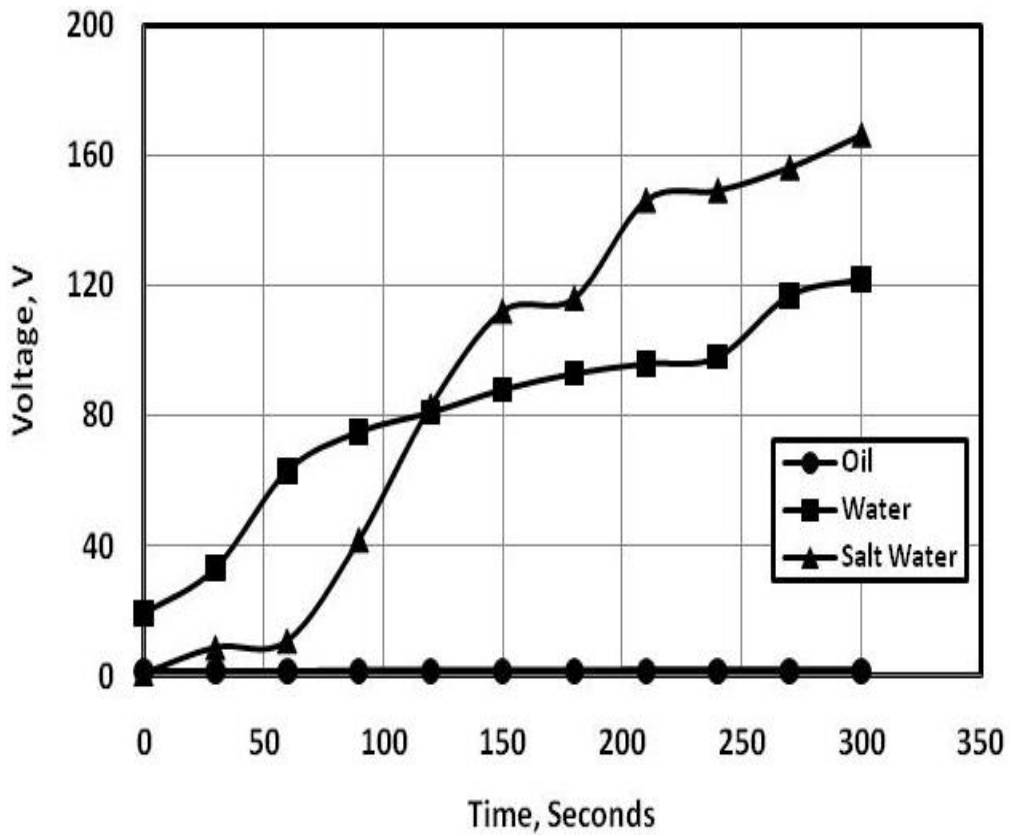


Fig. 5 Voltage generated from the sliding of graphite filled polyamide against stainless steel at 180 N load.

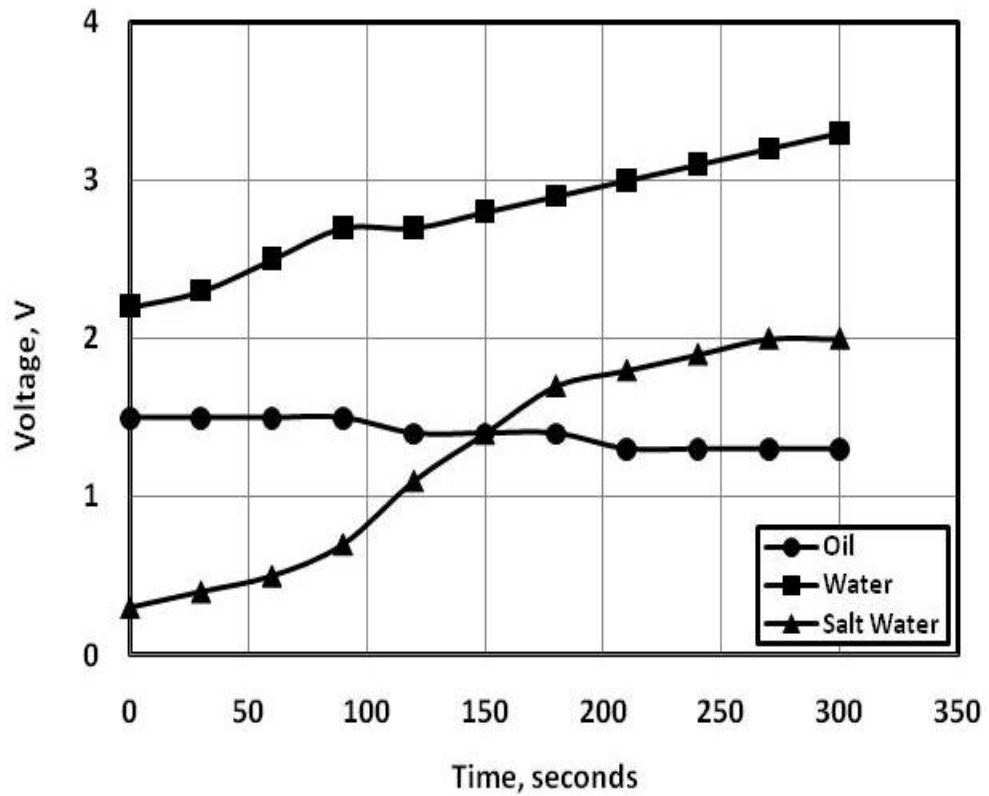


Fig. 6 Voltage generated from the sliding of polyethylene terephthalate against stainless steel at 60 N load.

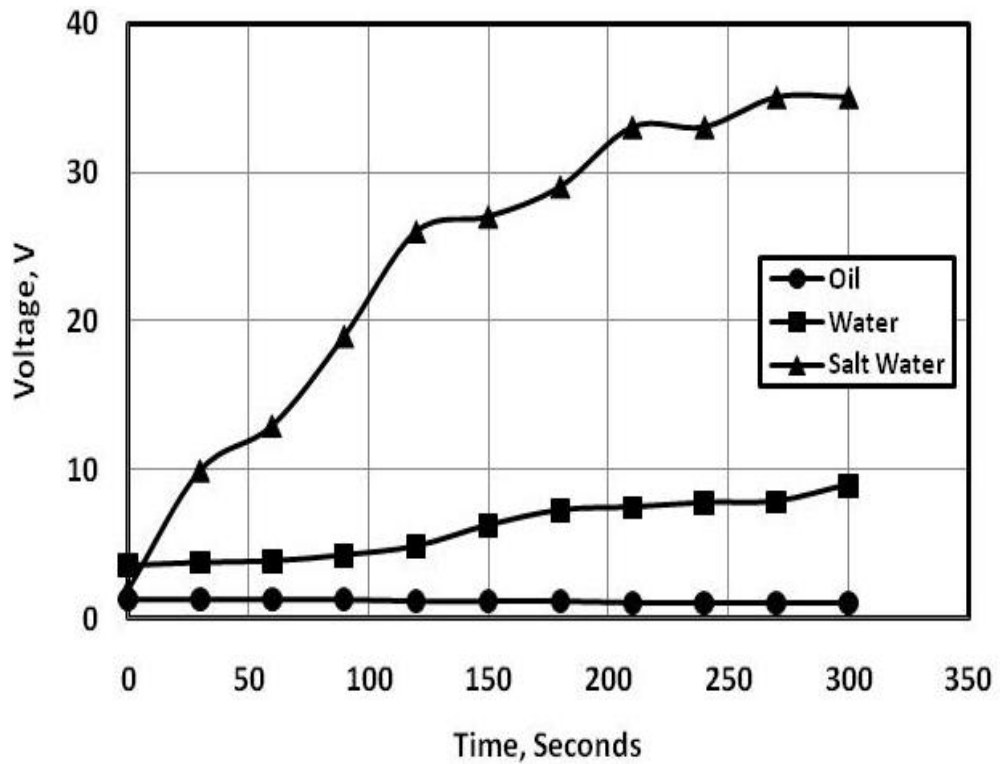


Fig. 7 Voltage generated from the sliding of polyethylene terephthalate against stainless steel at 180 N load.

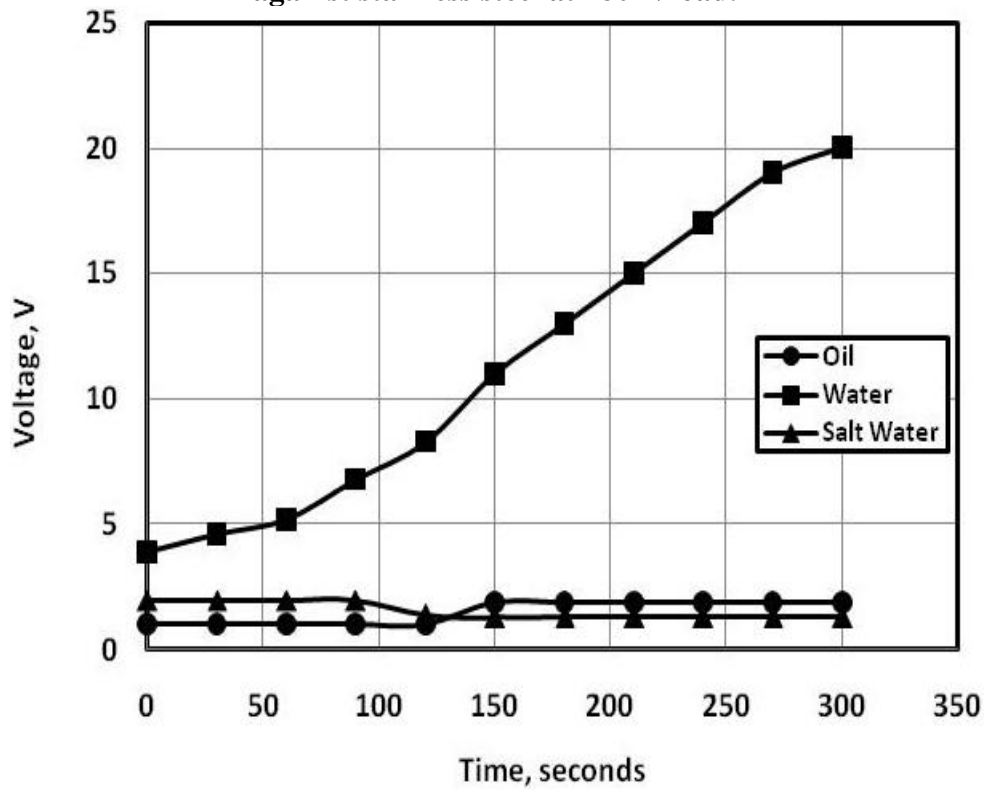


Fig. 8 Voltage generated from the sliding of polytetrafluoroethylene against stainless steel at 60 N load.

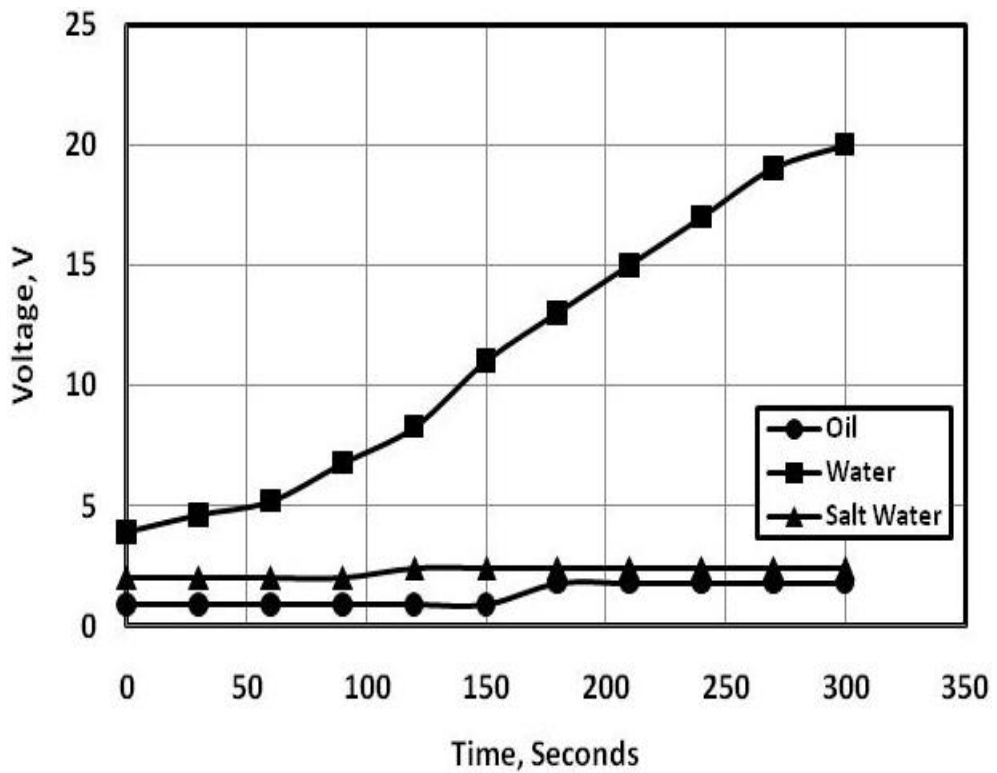


Fig. 9 Voltage generated from the sliding of polytetrafluoroethylene

against stainless steel at 180 N load.

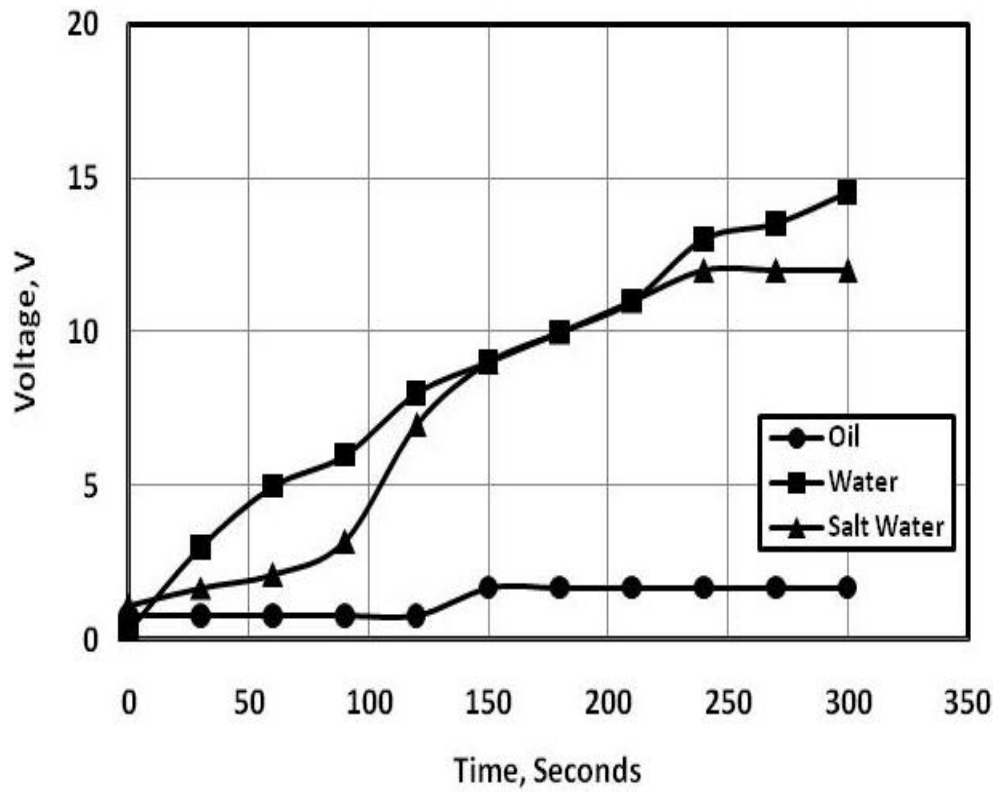


Fig. 10 Voltage generated from the sliding of polymethyl methacrylate against stainless steel at 60 N load.

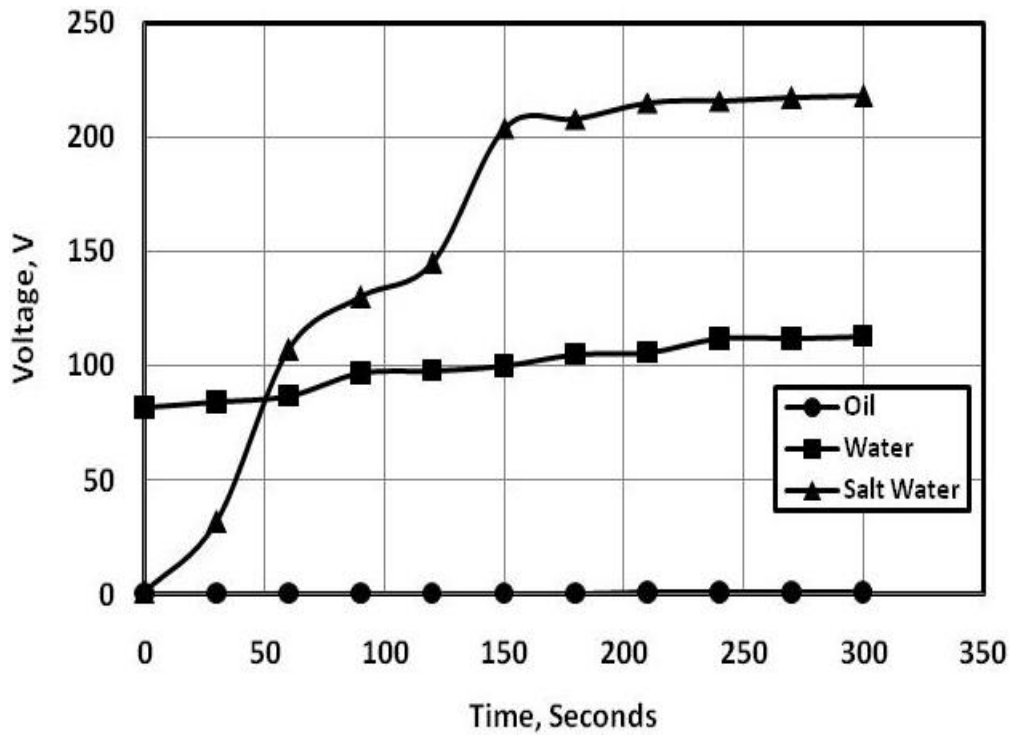


Fig. 11 Voltage generated from the sliding of polymethyl methacrylate

against stainless steel at 180 N load.

Voltage generated from the sliding of polytetrafluoroethylene against stainless steel at 60 N load showed relatively higher values compared to that observed for PA 6 and PET, Fig. 8, where the highest value was 20 volts. As the load increased to 180 N, Fig. 9, no significant change was observed. It was expected that with load increase voltage increased. This behaviour may be from the material transfer and transfer back from PTFE to steel surfaces. PTFE is aggressive negative charged polymer but due to the material transfer the friction would be between similar materials.

Sliding of polymethyl methacrylate (PMMA) against stainless steel at 60 N load displayed relatively high voltage values, Fig. 10. Water and salt water produced higher values than oil lubricated surface. As the load increased to 180 N, Fig. 11, the surface lubricated by salt water recorded the maximum voltage values (200 V). The ranking of PMMA in the triboelectric series in the positive charged. Oil lubricated surfaces showed the lowest voltage generation.

CONCLUSIONS

1. Voltage generated from the sliding of polyamide lubricated by oil against stainless steel showed the highest voltage, while that lubricated by water and salt water showed the lowest voltage. Significant voltage increase was observed when the load increased. Water lubricated surfaces displayed the highest voltage followed by salt water, while oil lubricated surfaces showed the lowest voltage.
2. Graphite filled polyamide (GPA 6) displayed relatively higher voltage than unfilled polyamide (PA 6). Salt water as lubricating medium showed the highest voltage followed by water, while oil showed very low voltage. As the load increased no significant change was observed.
3. Polyethylene terephthalate showed relatively lowest voltage values. Increasing the load caused slight voltage increase. In the presence of oil, the voltage values did not exceed 2.0 volts. This observation can explain the good tribological properties of PET.
4. Sliding of polytetrafluoroethylene against stainless steel showed relatively higher values compared to that observed for PA 6 and PET. As the load increased no significant change was observed due to the material transfer and transfer back from PTFE to steel surfaces.
5. Sliding of polymethyl methacrylate (PMMA) against stainless steel displayed relatively high voltage values, where the surface wetted by salt water recorded the maximum voltage values (200 V).

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