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INFLUENCE OF PRE-TRIBOELECTRIFICATION ON FRICTION COEFFICIENT DISPLAYED BY POLYMERIC MATERIALS

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ABSTRACT

The present work aims to investigate the influence of pre-triboelectrification on friction coefficient displayed by polymeric materials by sliding of PP on PET at dry sliding. Thin sheets of steel, aluminium (AL) film, carbon fibres (CF), steel textile, copper textile and steel fibres were inserted behind PP to guarantee good distribution of ESC generated from friction on PET sheet.

The experiments showed that PET provided by thin steel sheets displayed the highest friction values followed by steel textiles, CF, copper textiles, steel fibres and aluminium film. When PET surface was rubbed by PA and gained negative ESC, friction coefficient represented relatively lower values than that recorded in the first condition, while PET surface rubbed by PTFE gained positive ESC, followed by extra ESC generated from rubbing with PP gave the highest friction values.

ESC generated on the PET surface significantly increased with increasing normal load and slightly increased with increasing the sliding distance. The highest values of ESC were recorded by inserting steel fibres in the back of PET sheet followed by copper textile and steel sheet, while Al film under PET sheet showed no effect on ESC generated on the two sliding surfaces. The same trend was observed for ESC generated from PP and PET when CF and steel textiles were inserted behind PET.

KEYWORDS

Electrostatic charge, friction coefficient, carbon fibres, copper textiles, steel sheet, polypropylene, polyester, polyamide, polytetrafluoroethylene.

INTRODUCTION

The dependency of friction coefficient on electrostatic charge (ESC) generated from sliding of polyethylene (PA) on polytetrafluoroethylene (PTFE) was investigated, [1]. It was found that ESC generated on PA and PTFE reinforced by CF and friction coefficient increase as CF content increases. This observation strengthens the dependency of friction coefficient on ESC. Therefore, specific information about the value of ESC can be useful in controlling friction coefficient. This behavior can be explained on the bases that increasing ESC can increase the adhesion between the two contact surface and consequently friction coefficient increases. Besides, ESC can be

controlled by applying magnetic or electric field. This behavior can be used in controlling friction coefficient of polymeric material when they are contacting each other.

The effect of reinforcing epoxy by copper wires of different diameters on the generation of the electric static charge and friction coefficient when rubber sole slides against epoxy floor was investigated, [2 - 6]. Tests have been carried out at dry sliding. The effect of number of wires, location and wires diameter inside the matrix of the epoxy was studied. It has been found that at the electrostatic charge measured in volts significantly increased with increasing the number of wires. As the sliding distance increased voltage increased. Voltage decreased with increasing the distance of wire location from the sliding surface. When the wires were closer to the surface, the generated voltage increased. Besides, the increase in the wire diameter caused significant voltage increase. At water wetted sliding, voltage decreased due to the good water conductivity. As the sliding distance increased, the generated voltage decreased.

Triboelectric static charges built up on human skin and or clothes in direct contact with human body are very harmful and can create serious health problems, [7]. Based on the experiments carried out, it was found that, at dry sliding, iron nanoparticles addition into epoxy matrix increased friction coefficient with increasing iron content. Voltage drastically decreased with increasing iron content. Voltage showed the maximum values for epoxy free of iron.

The electrical charges have been taken into account on friction between the two insulating materials. The change, in friction and electric charge of alumina sliding against polytetrafluoroethylene (PTFE) under boundary lubrication conditions, was measured, [8]. Specific information about the value of the electrical charge can be useful in controlling friction coefficient. In a study carried out by atomic force microscopy to measure forces and adhesion energy between tungsten and oxide surfaces, [9], it was concluded that the coulombic forces were not dominant but they could have influenced the adhesion forces.

Electrostatic charges generated during contact and separation as well as sliding of insulating materials indicated their ability to trap charges, where the interaction energy during friction depends markedly on these trapped charges. To explain that, it is known that charges occur easily during simple contact or friction on the surface and the bulk by charge trapping. Then charges can play a major role in adhesion energy and alter friction by the effect of the trapped charges and, consequently on the presence of surface defects introduced during friction. During sliding, time-dependent deformation of the lattice is observed, leading to possible ionic polarization and to local variations of the atomic polarizability, [10 - 12]. This behavior is due to the friction process, leading to an electric field. Besides, the charges in movement can be trapped on defects (traps) and the surface becomes charged. The trapping event involves impurity, dislocation and grain boundary, [13, 14], so that the trapping energy depends on the material properties such as elastic constant and electrification. Friction induces movement of charged particles by triboelectrification, [15], where these charges can be trapped during friction. Then the polarisation energy is can be relaxed inducing electric field. It is expected that dislocations are formed during friction, [16]. Consequently, the existence of an internal electric field acting on all the lattice sites is confirmed.

The friction and triboelectrification between two adhering SAM-coated molecularly smooth dissimilar metal surfaces were measured using a modified surface forces apparatus, [17]. As the pressure is increased, triboelectrification increases significantly with large fluctuations about the mean. When the surfaces are in static contact, none of these effects is observed. Triboelectrification strongly depends on the friction type and force, sliding distance, contact area and sliding history. The charge transferred during shearing significantly depended on the normal pressure applied. At low pressures, the average current density was zero before, during, and after shearing, but the fluctuations drastically increased during shearing. The magnitude of these fluctuations depended on friction observed where stick-slip motion generated the largest fluctuations.

When two surfaces are in contact, only the summits of the asperities will be in contact and large areas of the surfaces will be separated. It may be expected that the area of true contact will even for highly polished surfaces be considerably less than the apparent area of contact. For higher loads or rougher surfaces the pressure on the asperities reaches the local plastic yield pressure, which is very nearly constant and is comparable to the indentation hardness. For repeated sliding, during the time between the two runs, electrons may have diffused from traps near the surface into deeper-lying ones, thus leaving empty ones at the surface which can readily be filled again, [18 – 20]. Besides, the applied pressure varies because the two surfaces are in contact with fresh areas within the charged track of the sliding surface as well as the possibility of introducing new traps during the first run. Those factors can lead to extra amount of charge on the sliding surfaces.

The aim of the present experiments is to investigate the effect of pre-triboelectrification on friction coefficient displayed by sliding of PP on PET.

EXPERIMENTAL

Experiments have been designed to investigate the effect of pre-triboelectrification on the friction coefficient during sliding of polymeric materials. The test specimens were prepared from wooden block of 50 × 50 mm^2 and 30 mm height, where the sliding surface was covered by PP sheet of 0.25 mm thickness. Al film of 0.05 mm was inserted behind PP to guarantee good distribution of ESC generated from friction. The counterface was PET textile adhered to paper hollow box of 25 mm gap. Different materials such as Al film, CF, Cu textile, steel sheet of 0.1 mm thickness, steel textile and steel fibres (0.01 mm diameter) were inserted between PET and the paper box. PP surface was pressed and slid against PET surface, Fig. 1.

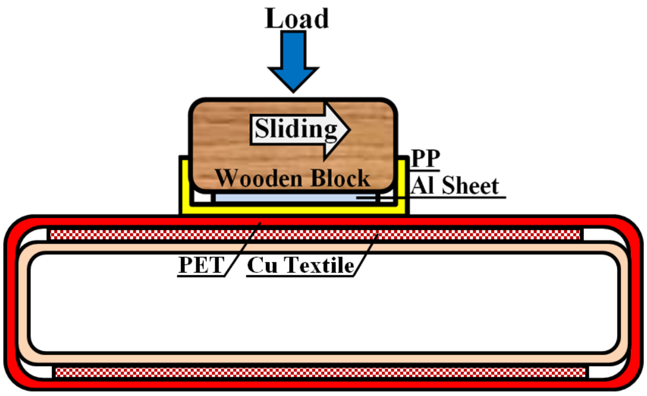

Fig. 1 Arrangement of the tested materials.

The applied force was ranging from 3 to 18 N. The sliding distance was 0 (contact and separation), 50, 100, 150 and 200 mm. After contact and separation as well sliding, ESC generated on the two sliding surfaces was measured. The friction force was measured by the deflection of the load cell of the test rig, [21]. The ratio of the friction force to the normal load was considered as friction coefficient. The load was applied by weights. The test speed was nearly controlled to be 2 mm/s. All measurements were performed at 30 ± 2º C and 50 ± 10 % humidity. The electric static fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens which is considered in the text as ESC.

RESULTS AND DISCUSSION

Triboelectrification is attributed to the transfer of electrons from one surface to the other during rubbing. 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. The triboelectric series can be used to estimate the relative charge polarity of the materials. Figures 1 – 3 illustrate the relationship between pre-triboectrification and friction coefficient. To reveal the relationship, three groups of tests were carried out. In the first group, it is shown that the tested materials that were not pre-triboelectrified displayed friction values increased slightly with increasing the applied normal load. Surface provided by thin steel sheets showed the highest friction values followed by steel textiles, CF, copper textiles, steel fibres and Al film. The maximum friction value was 0.27 displayed by steel thin sheet at 18 N load. In the second group, PET surface was rubbed by PA and gained negative ESC. After contact and separation as well sliding of PP, PET will gain positive ESC, Fig. 3, so that the resultant ESC generated on PET will be lower than that generated on PP surface. As result of that, the adhesion between the two contact surfaces will be relatively weaker than that observed in the first condition, Fig. 1. Consequently, friction coefficient represented relatively lower values than that recorded in the first group, Fig. 4. The third group included rubbing PET surface by PTFE, where PET gained positive ESC, Fig. 5. Then during sliding of PP, The counterface (PET) gained extra positive ESC. In that condition the adhesion between the two contact surfaces was the strongest among the three groups. That behavior was confirmed by the significant friction increase, Fig. 6.

The results of ESC generated on the PET surface are shown in Fig. 7, where it significantly increased with increasing normal load. ESC slightly increases with increasing the sliding distance. The maximum ESC value reached 420 volts at 18 N load after 200 mm sliding. ESC generated on the PP surface, Fig. 8, showed the same trend in negative charge. The polarity and amount of charge transferred when two materials sliding against each other depend on the amount of energy required by each to lose electrons, this property is called their relative work functions. The material with the higher work function (PP) will gain electrons from the other and thus acquire a negative charge. The amount of charge transferred can be influenced by friction between the sliding surfaces. Besides, the maximum level of ESC generated from the materials is dependent on their position in the triboelectric series relative to the surface material.

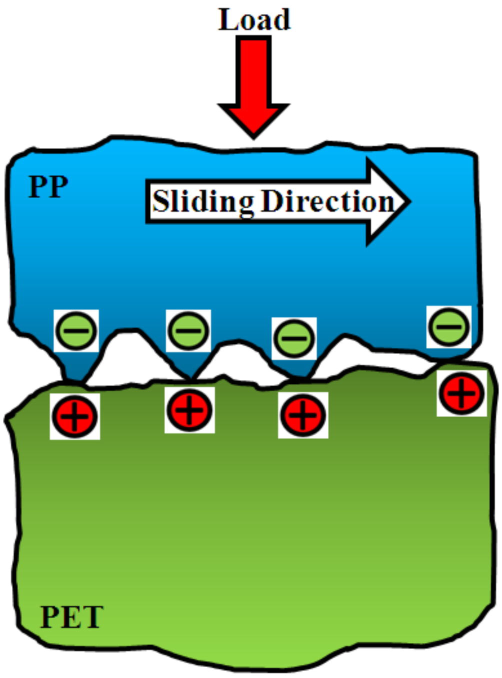

Fig. 1 ESC distribution on the friction surfaces.

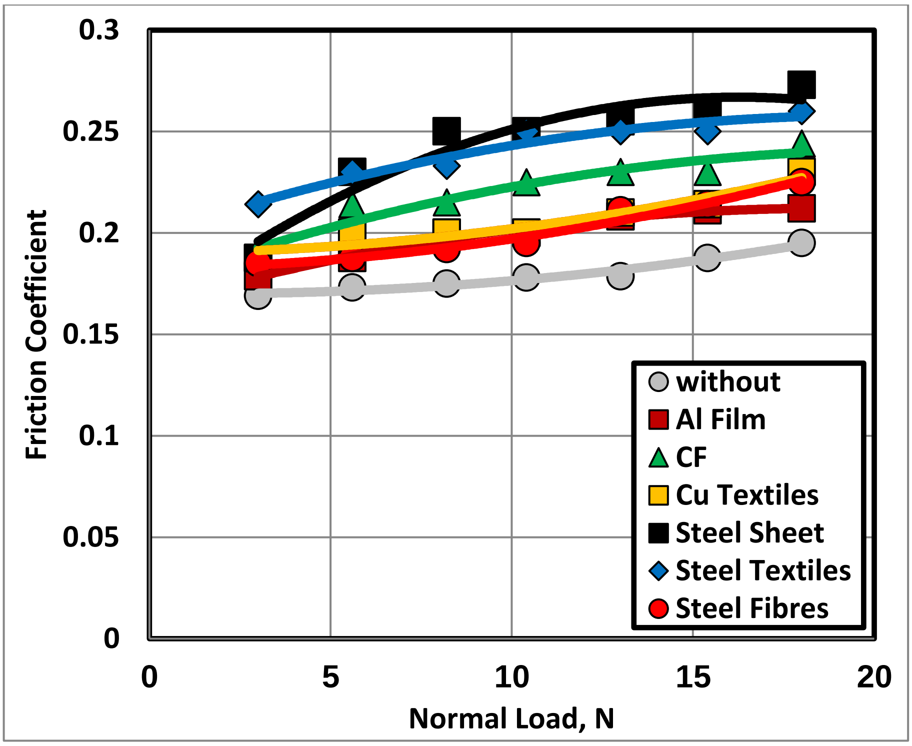

Fig. 2 Friction coefficient displayed by contact and separation as well as sliding of PP against PET.

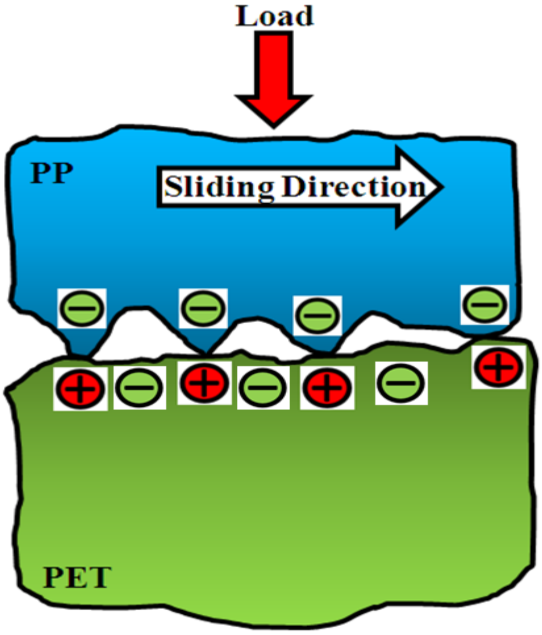

Fig. 3 ESC distribution on the friction surfaces pretriboelectrified by PA.

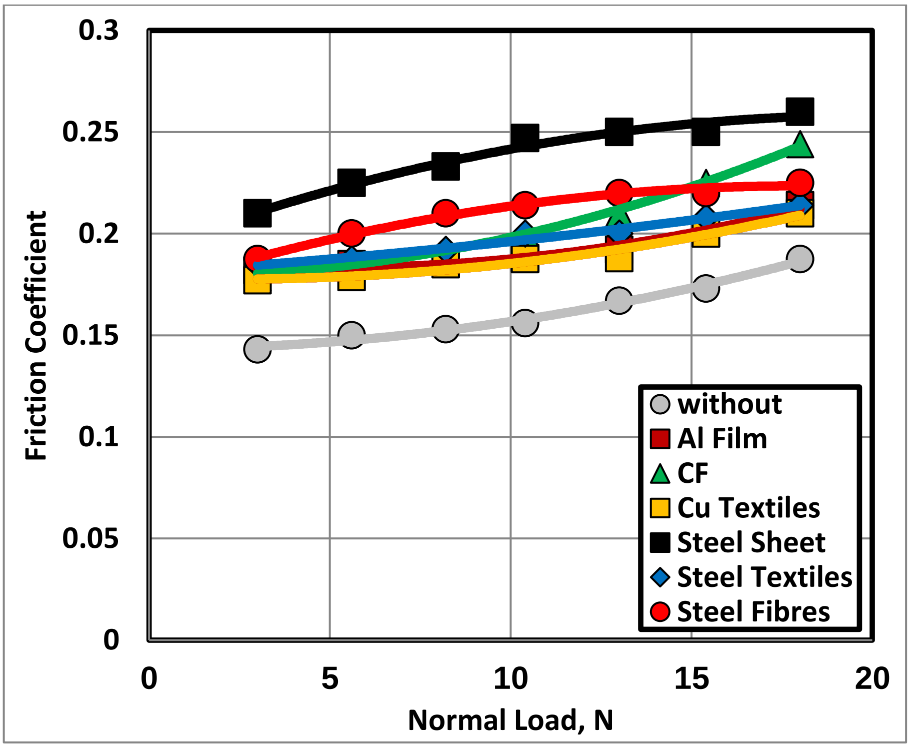

Fig. 4 Friction coefficient displayed by contact and separation as well as sliding of PP against PET pre-triboelectrified by PA.

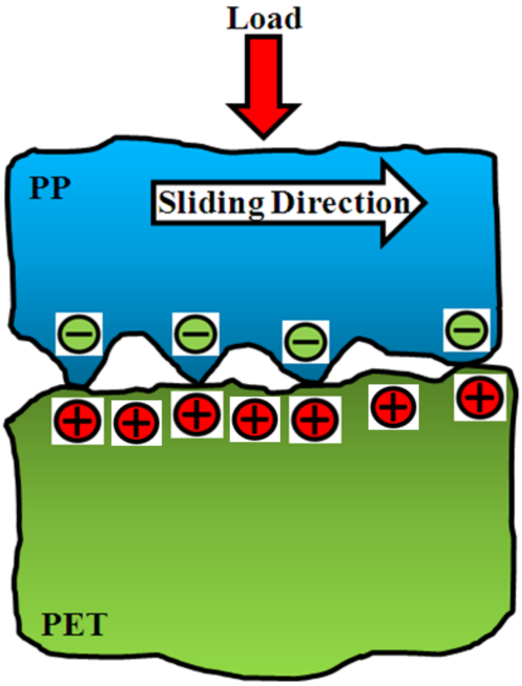

Fig. 5 ESC distribution on the friction surfaces pretriboelectrified by PTFE.

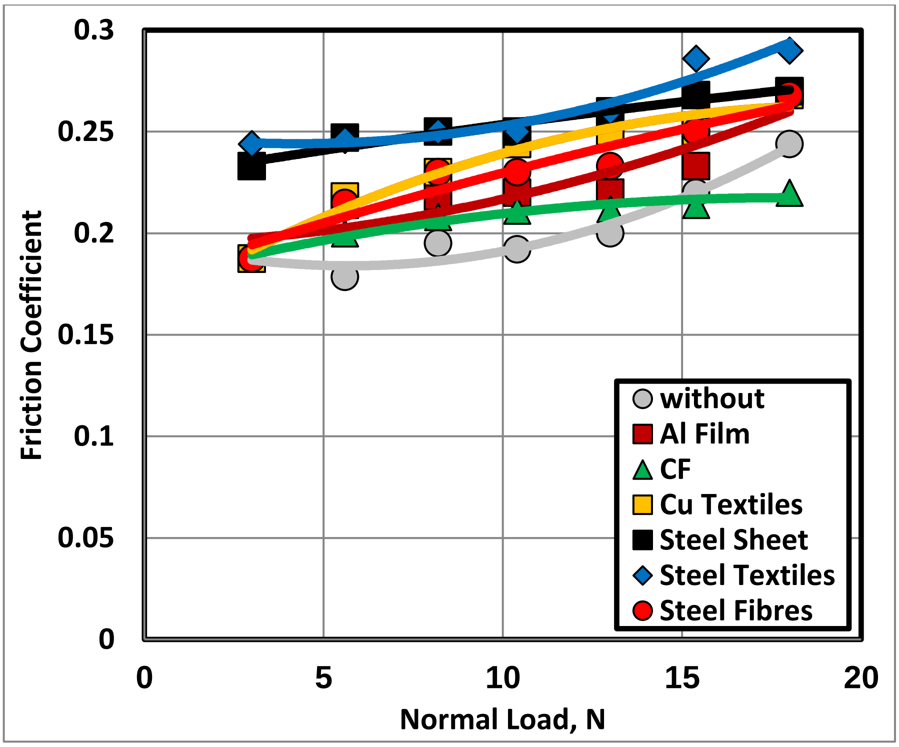

Fig. 6 Friction coefficient displayed by contact and separation as well as sliding of PP against PET pre-triboelectrified by PTFE.

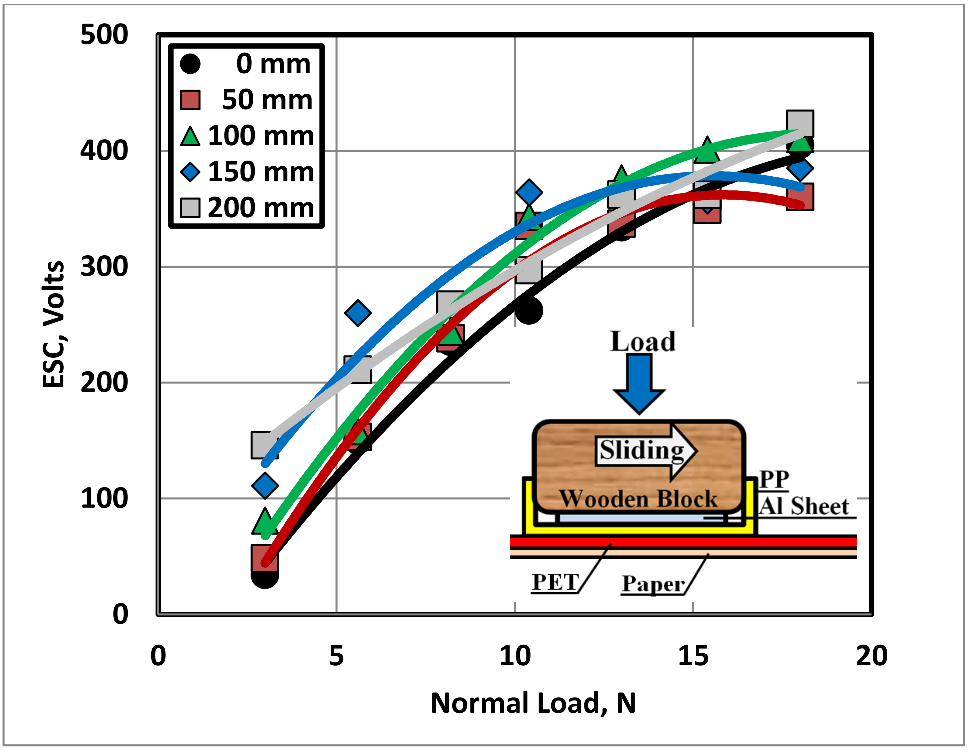

Fig. 7 ESC generated on the PET surface.

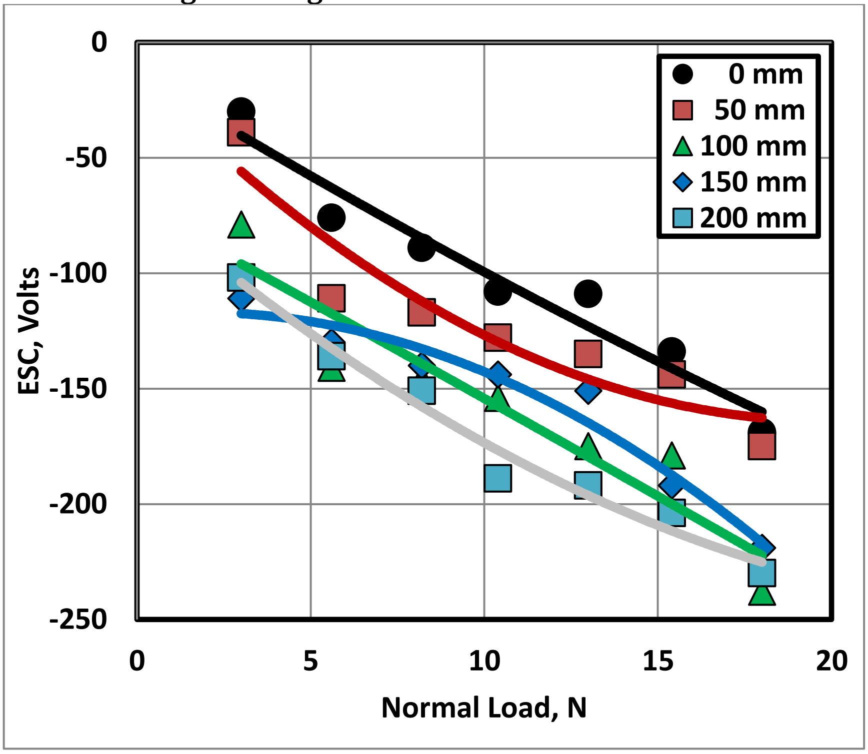

Fig. 8 ESC generated on the PP surface.

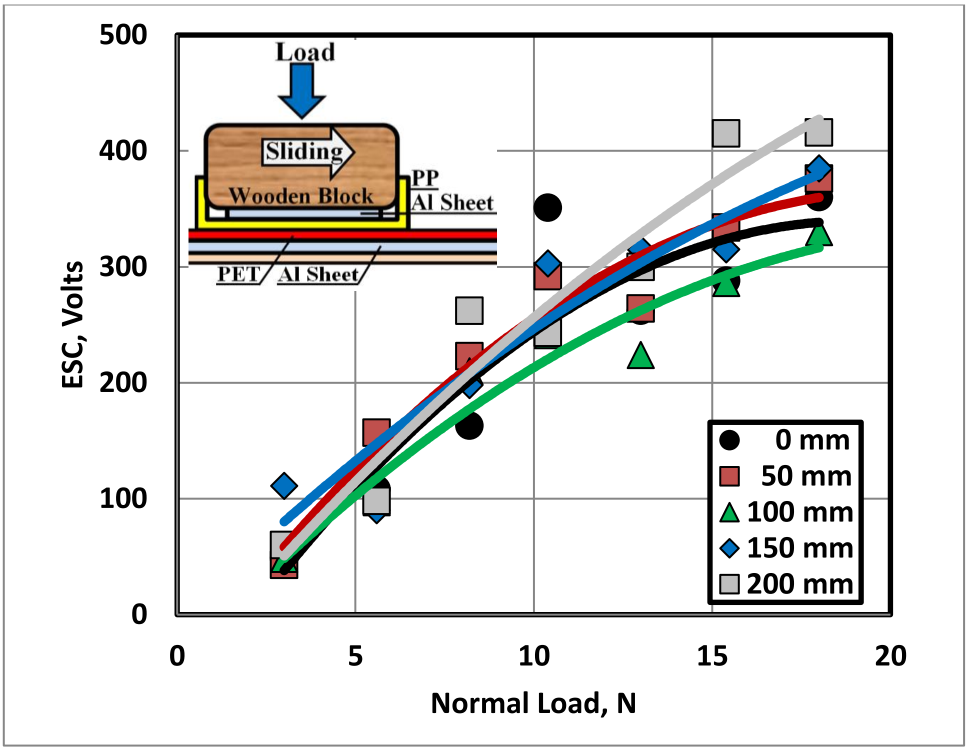

Fig. 9 ESC generated on the PET surface.

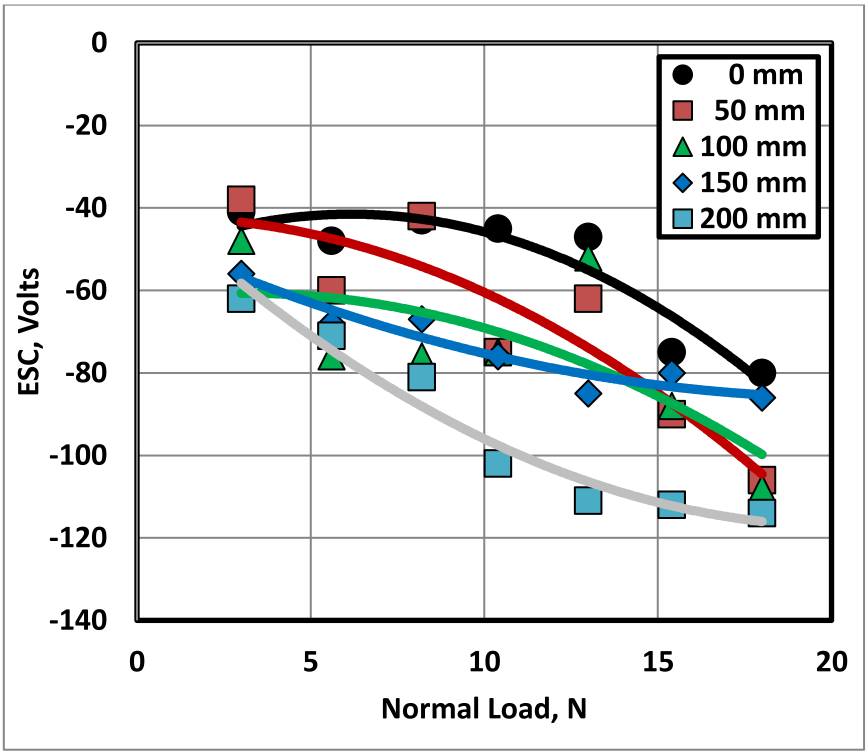

Fig. 10 ESC generated on the PP surface.

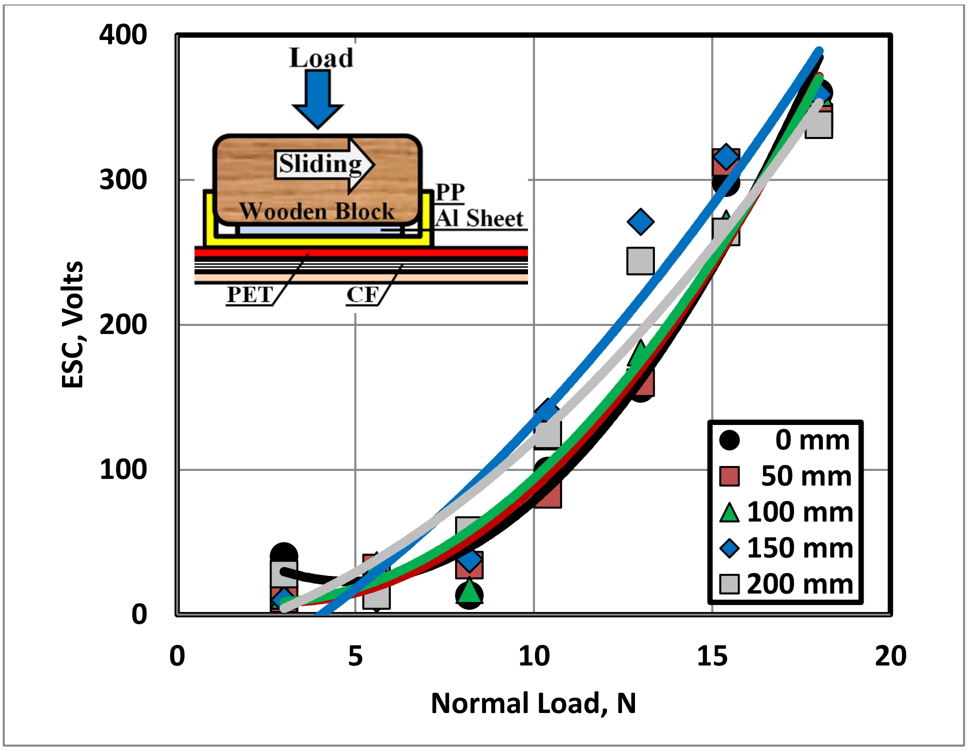

Fig. 11 ESC generated on the PET surface.

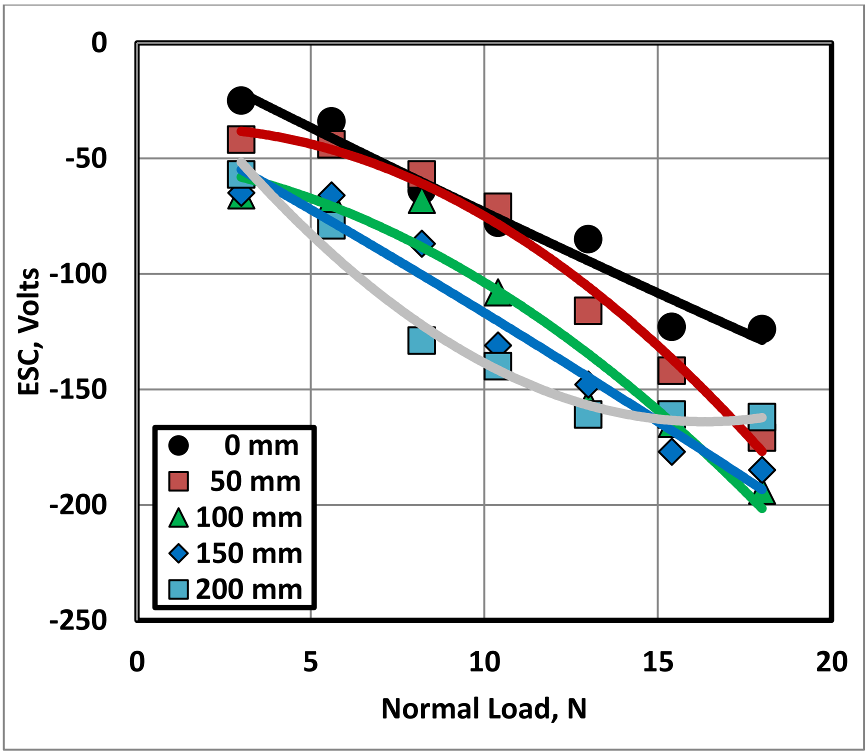

Fig. 12 ESC generated on the PP surface.

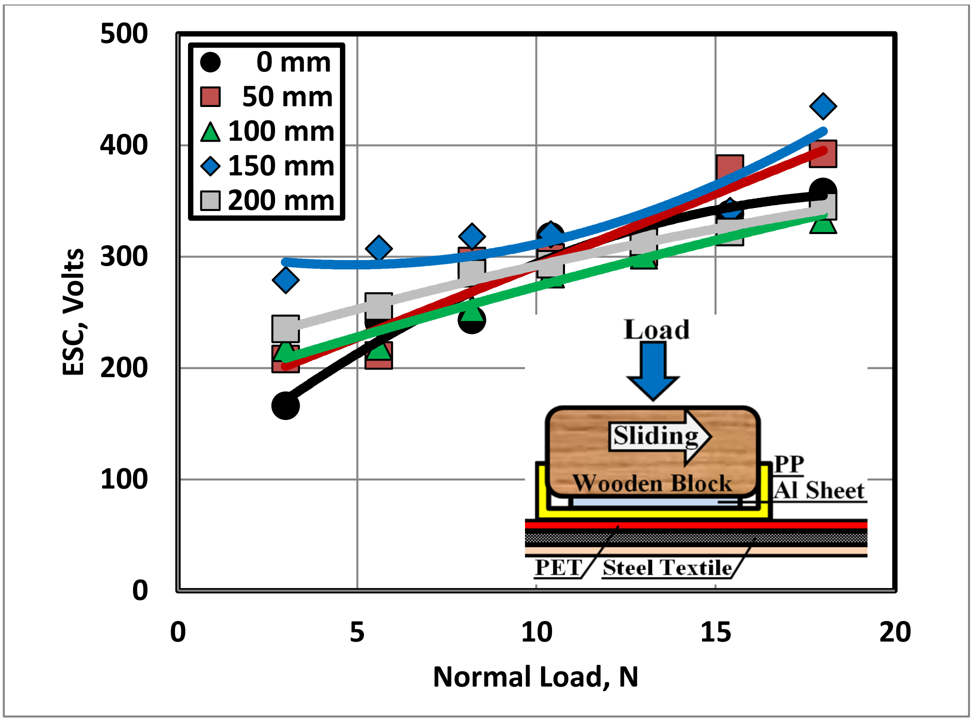

Fig. 13 ESC generated on the PET surface.

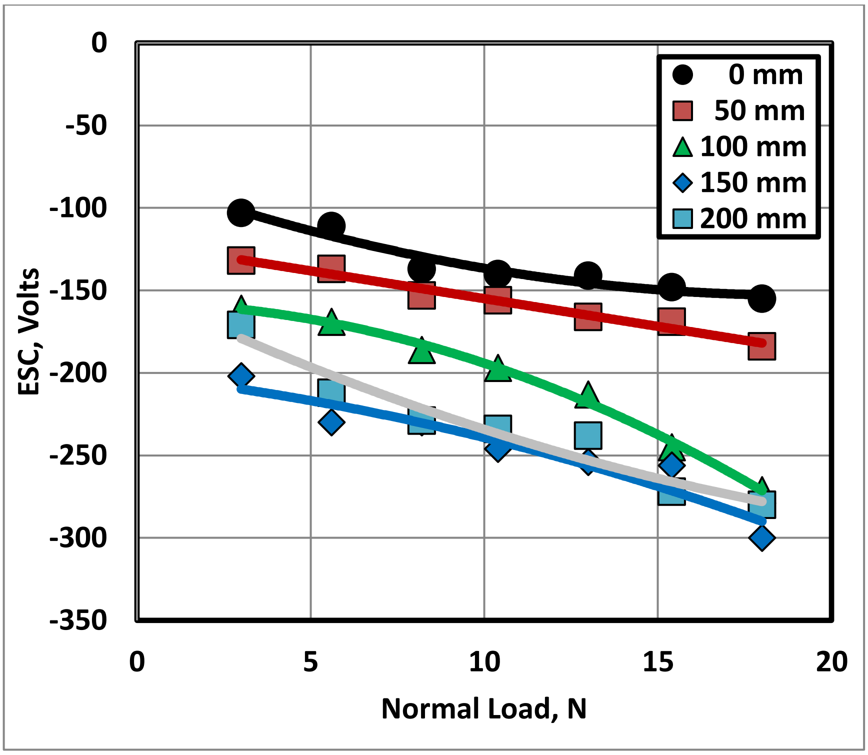

Fig. 14 ESC generated on the PP surface.

The ranking of the materials based on the values of the generated ESC depends on the triboelectric series, where the higher positioned materials (PET) will acquire a positive charge when contacts material (PP) at a lower position along the series. Thus, the triboelectric series can be used to estimate the relative charge polarity of the materials. The series can be used to estimate the relative charging capacity of many polymeric materials. The presence of Al film under PET sheet showed no effect on ESC generated on the two sliding surfaces, Figs. 9 and 10. ESC generated on the PP surface in this condition displayed lower values than that observed before. The same trend was observed for ESC generated from PP and PET when CF and steel textiles were inserted behind PET, Figs. 11 - 14.

Inserting steel sheet behind PET generated relatively higher ESC than that generated in the above mentioned sheets, Figs. 15 and 16. The increase of ESC may be attributed to the generation of magnetic field caused by the electric field and the steel sheets. The strength of the electric field is proportional to how much charge is generated on the friction surface. ESC generated during contact and separation as well as sliding of insulating materials indicated their ability to trap charges, where the interaction energy during friction depends markedly on these trapped charges. To explain that, it is known that charges occur easily during simple contact or friction on the surface and the bulk by charge trapping. Then charges can play a major role in adhesion energy and alter friction by the effect of the trapped charges and, consequently on the presence of surface defects introduced during friction.

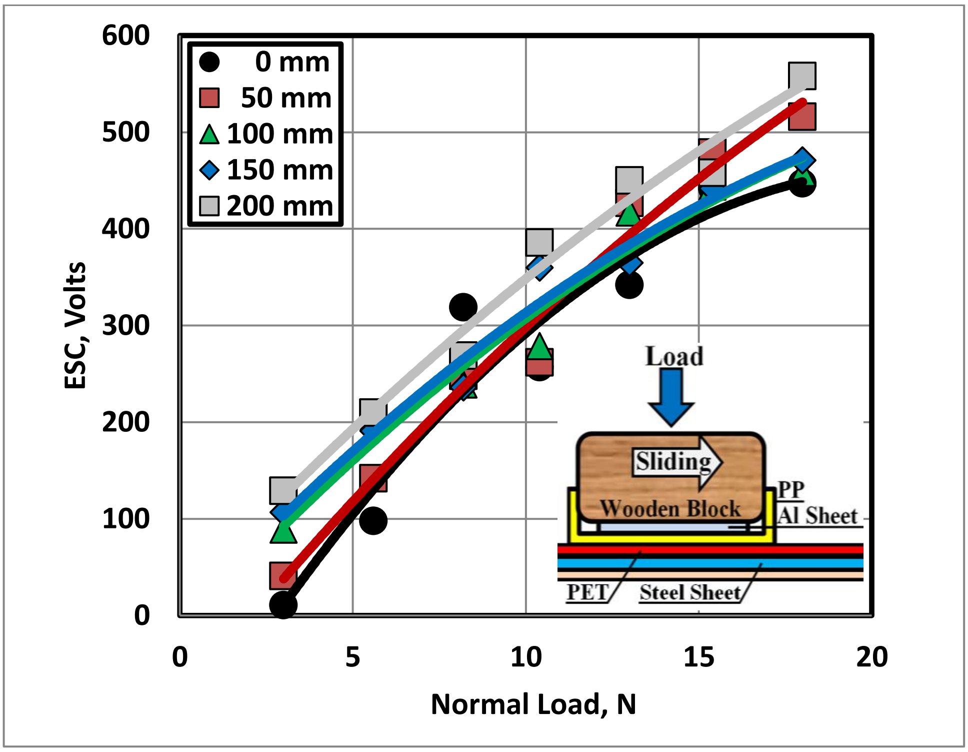

Fig. 15 ESC generated on the PET surface.

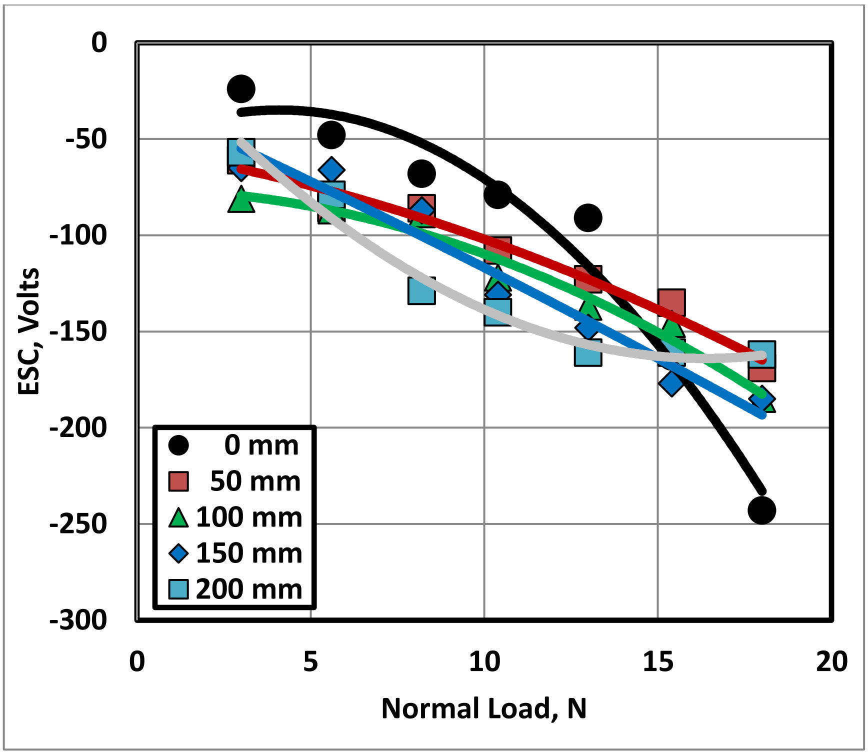

Fig. 16 ESC generated on the PP surface.

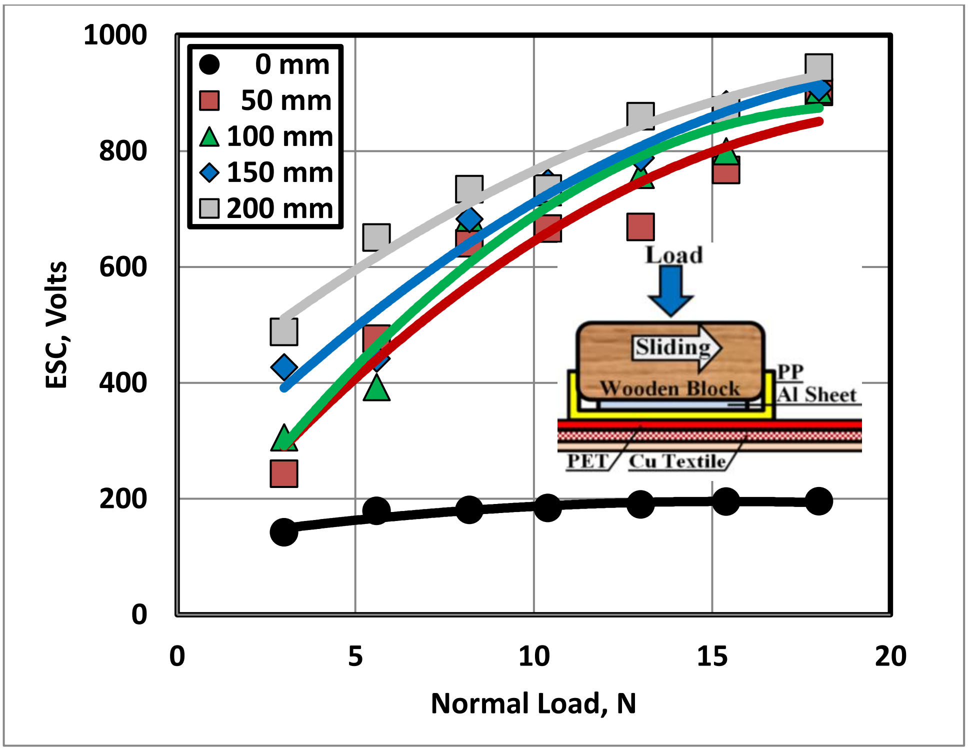

Fig. 17 ESC generated on the PET surface.

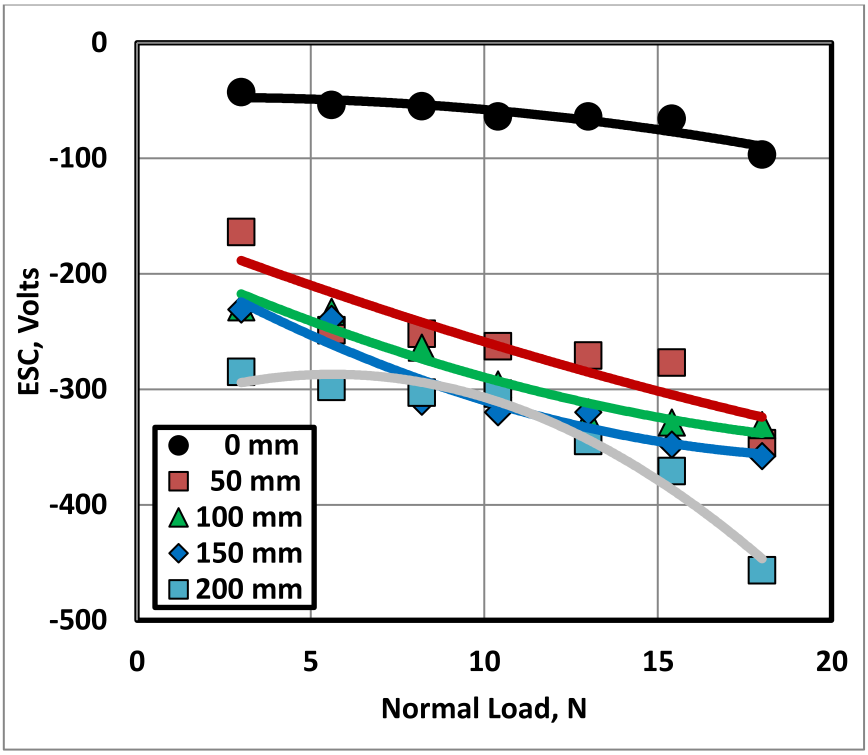

Fig. 18 ESC generated on the PP surface.

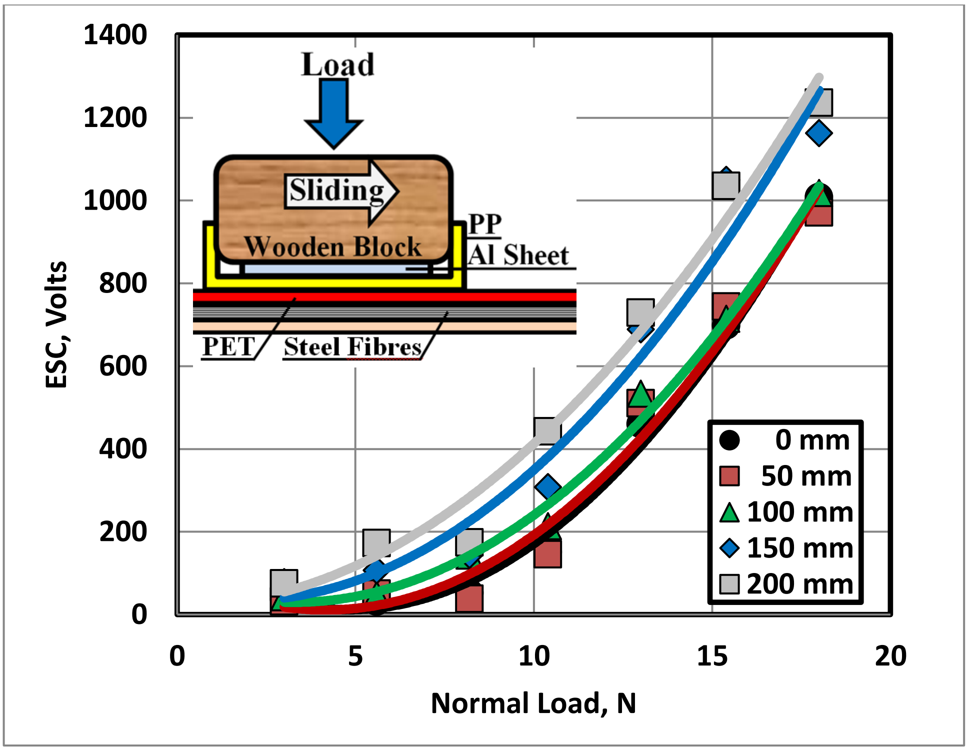

Fig. 19 ESC generated on the PET surface.

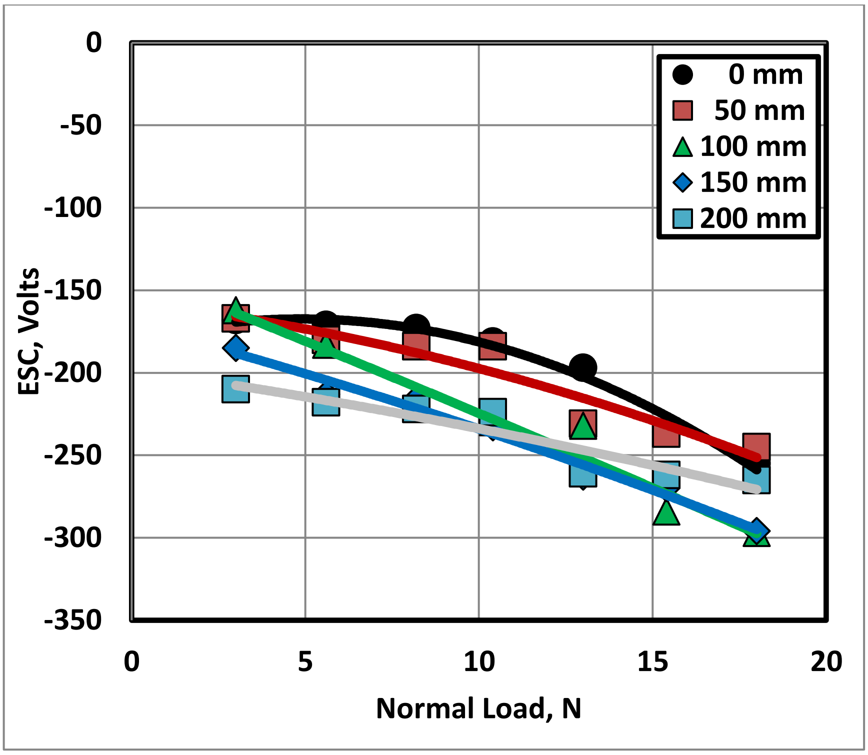

Fig. 20 ESC generated on the PP surface.

Remarkable increase in ESC generated on PET and PP surfaces was observed when copper textile was inserted behind the PET sheet, Figs. 17 and 18 respectively. The maximum recorded ESC value was 940 volts at 18 N load and 200 mm sliding distance. This behavior can be interpreted on the basis that ESC will generate electric field crossing copper textile leading to induction of voltage. It is expected that the intensity of ESC will increase. Basically, sliding of materials as well contact and separation cause the charge transfer to build up on the sliding surfaces forming double layers of ESC on the sliding surfaces which are responsible for generation of the electric field that induces electric current flowing in the copper textile. The strength of the electric field inside the matrix is proportional to how much charge is generated on the friction surface.

The highest values of ESC were recorded by inserting steel fibres behind PET sheet, Figs. 19 and 20. The significant ESC increase in the presence of steel fibres confirmed the generation of a magnetic field around the steel fibres that is directly proportional to the current value. Based on Faraday principle that states if an electric conductor is moved through a magnetic field, or a magnetic field moves through the conductor, electric current will be induced and flow into the conductor. The induced current creates an induced magnetic field. ESC has been taken into account on friction between the two insulating materials. Specific information about the value of the electrical charge can be useful in controlling friction coefficient. ESC generated during contact and separation as well as sliding of insulating materials indicated their ability to trap charges, where the interaction energy during friction depends markedly on these trapped charges. To explain that, it is known that charges occur easily during simple contact or friction on the surface and the bulk by charge trapping. Then charges can play a major role in adhesion energy and alter friction by the effect of the trapped charges and, consequently on the presence of surface defects introduced during friction.

Besides, the charges in movement can be trapped on defects (traps) and the surface becomes charged. Friction induces movement of charged particles by triboelectrification, where these charges can be trapped during friction.

CONCLUSIONS

1. Surface provided by thin steel sheets showed the highest friction values followed by steel textiles, CF, Copper textiles, steel fibres and aluminium film.
2. When PET surface was rubbed by PA and gained negative ESC, friction coefficient represented relatively lower values than that recorded in the first condition.
3. When PET surface was rubbed by PTFE, PET gained positive ESC, followed by extra ESC so that adhesion between the two contact surfaces was the strongest. That behavior was accompanied by the highest friction values.
4. ESC generated on the PET surface significantly increased with increasing normal load while slightly increased with increasing the sliding distance. The presence of Al film under PET sheet showed no effect on ESC generated on the two sliding surfaces. The same trend was observed for ESC generated from PP and PET when CF and steel textiles were inserted behind PET.
5. Inserting steel sheet behind PET generated relatively higher ESC than that generated in the above mentioned sheets. Remarkable increase in ESC for PET and PP surfaces was observed when copper textile was inserted behind the PET sheet. The highest values of ESC were recorded by inserting steel fibres behind PET sheet.

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