Influence of Triboelectrification on Friction Coefficient

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Abstract— **The influence of triboelectrification of the contact surfaces on friction coefficient displayed by polymethyl methacrylate (PMMA), and high density polyethylene (HDPE) spheres sliding against polytetrafluoroethylene (PTFE) and steel sheets is discussed. The effect of insulating the sliding surfaces on the friction coefficient is discussed at dry and water as well as salt water wetted sliding conditions.**

It was found that isolated test specimens showed relatively lower friction coefficient than that observed for the connected ones. This behaviour can be explained on the basis that sliding of PMMA sphere on PTFE surface generated positive charge on the PMMA surface and negative charge on PTFE surface. The lower surface of PTFE sheet would be charged by positive charge which, in condition of connecting the steel sheet by the grounded steel pin, would move to the steel pin and increase the positive charge generated on its surface. In that condition, the electric static charge would increase and consequently the attractive force would increase leading to an increase in friction coefficient. As for isolated test specimens, the electric static charge on the contact would be lower and consequently the attractive force would be lower causing slight decrease in friction coefficient. The same trend was observed for sliding of PE against PTFE and steel. Based on the experimental results, it is recommended to insulate the sliding surfaces in order to decrease friction coefficient.

KEYWORDS
Triboelectrification, friction coefficient, PMMA, HDPE, PTFE and steel.

I. INTRODUCTION

Electric static charges generated from friction of engineering materials have a negative effect in technological applications. The increased use of polymeric materials raised the importance of studying that effect. One of the few attempts was to study the voltage generated from the dry sliding of aluminium oxide (Al2 O3), copper (Cu), aluminium (Al), iron (Fe), silicon oxide (Si O2), polymethyl methacrylate (PMMA), high density polyethylene (HDPE) and low density polyethylene (LDPE) against synthetic rubber, HDPE, polypropylene (PP) and polytetrafluoroethylene (PTFE), [1]. It was found that voltage generated from the sliding of aluminium oxide, copper, aluminium, iron and silicon oxide against rubber generated the lowest voltage, while PTFE showed the highest one. Generally, 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. Besides, it was observed that the maximum level of the voltage generated from the materials is dependent on their position in the triboelectric series relative to the counterface. The triboelectric series can be used to determine the charge polarity of the materials. This series can be used to evaluate the relative charging capacity of many polymeric materials.

Experiments were carried out to measure the electric static charge generated from the friction of different polymers sliding against stainless steel, [2]. 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.

It is well known that when two different materials contact each other, they may get charged. This tribocharging phenomenon is also known as triboelectrification when materials rub against each other, [3]. The mechanism of charge transfer in tribocharging can be explained by three mechanisms: electron transfer, ion transfer, and material transfer, [4]. The metal-metal contact electrification successfully explained by electron transfer mechanism. The electrostatic charging of unstrained and strained latex rubber sheets contacted with a series of materials such as polytetrafluoroethylene (PTFE), polyurethane (PU) and stainless steel (SS) was studied, [5]. For PTFE, strain causes a reversal in the direction of charge transfer. For PU, the direction of charge transfer is reversed after repeated contacts due to material transfer, and strain increases the number of contacts needed for this reversal. For SS, strain reduces the frequency of electrical discharges occurring. These effects may be explained by strain either changing material properties relevant to triboelectric charging, or changing the nature of contact between the surfaces. It was found that material strain can strongly influence triboelectric charging. Besides, straining a material can produce charged species, including ions, electrons, and radicals that can react to form charged species.

Silicon carbide is electrically semiconducting. The friction and wear behaviour of silicon carbide based materials may be influenced by electric potentials applied to the tribological system, [6, 7]. Also, it was found that the surface state of SiC ceramics can be influenced by electric potentials.

Triboelectrification and triboluminescence were measured from the sliding or rolling frictional contacts between polymers of PA66, POM, ABS, PET, PP, PVC, PE, and PTFE in various humidity conditions, [8]. As compared to the rolling friction, triboluminescence intensity was higher in sliding friction. However, the saturation values of triboelectrification were almost the same in both friction types. The saturation charges of all the sliding couples showed their maxima at the humidity from 10 to 30%. It is attributed to the humidity effect; it enhanced charge transfer which resulted in the increase or decrease of electrification.

Therefore, the physical processes during friction should be high-lighted to better understand subsequent reactions and surface layer formation. The contact/separation process leads to the charge transfer between dissimilar materials. When charges are accumulated, they are measured as triboelectrification, [9]. When a bond is broken by the shear stress, it generates dangling bonds. The bond breakage also induces the electron emission from the insulator. The emitted electrons are accelerated by the electric field between charged surfaces which originated from tribolectrification. When electrons attack surrounding molecules, they induce electron avalanche and photon emission from surrounding gases. The charge relaxation model was developed, [10], to account for the charge accumulation including the relaxation process after charge transfer.

Charge and discharge associated with the rubbing between shoes and carpet are less experienced in summer rather than in winter. It indicates that the charge is suppressed in higher humidity. Experimental data have exemplified this tendency [11]. However, other data show that water molecules on the surfaces convey charges in the form of ions to enhance charge separation between two surfaces [12, 13]. These contradictory results require precise measurement of the effect of humidity on charge generation. Charge generation is affected by discharge.

Dielectric and friction behaviour of unidirectional glass fibre reinforced epoxy (GFRE) were studied, [14]. It was found that the glass fibre/matrix interfaces play the role of diffusion path and, then, allow the trapping of electric charges, inducing the formation of defects outside the friction track. The importance of fibre/matrix interface on the trapping/diffusion of the electric charges was previously discussed, [15]. Tribological studies to correlate friction coefficient and wear with the role of the electric charges were carried out. Polymers are characterized by a low mobility leading to a strong localization of the electric charges, and consequently to their trapping on structural defects inducing local variations of the dielectric susceptibilities, [16]. Then, an external stress can permit the detrapping of trapped charges.

It was found that voltage generated by the contact and separation of the tested upholstery materials of car seat covers against the materials of clothes showed great variance according to the type of the materials, [17]. Voltage generated from polyester textiles showed reasonable values. Remarkable voltage increase was observed for contacting synthetic rubber. This observation can limit the application of synthetic rubber in tailoring clothes. Based on the experimental results the materials of car seat covers can be classified according to their electric properties. Materials of high static electricity can be avoided and new materials of low static electricity can be recommended.

The wide use of polymer fibres in textiles necessitates to study their electrification when they rubbing other surfaces. The electric static charge generated from the friction of different polymeric textiles sliding against cotton textiles, which used as a reference material, was discussed, [18]. Experiments were carried out to measure the electric static charge generated from the friction of different polymeric textiles sliding against cotton under varying sliding distance and velocity as well the load. It was found that increase of cotton content decreased the generated voltage. Besides, as the load increased voltage generated from rubbing of 100 % spun polyester specimens increased. Besides, mixing polyester with rayon (viscose) showed the same behavior of mixing it with cotton. Generally, increasing velocity increased the voltage. The voltage increase with increasing velocity may be attributed to the increase of the mobility of the free electrons to one of the rubbed surfaces. The fineness of the fibres much influences the movement of the free electrons.

The electrostatic charge generated from the friction of polytetrafluoroethylene (PTFE) textiles was tested to propose developed textile materials with low or neutral electrostatic charge which can be used for industrial application especially as textile materials, [19]. Test specimens of composites containing PTFE and different types of common textile fibers such as cotton, wool and nylon, in a percentage up to 50 vol. % were prepared and tested by sliding under different loads against house and car padding textiles. The results showed that addition of wool, cotton and nylon fibers remarkably decreases the electrostatic discharge and consequently the proposed composites will become environmentally safe textile materials. Research on electrostatic discharge (ESD) ignition hazards of textiles is important for the safety of astronauts. The likelihood of ESD ignitions depends on the environment and different models used to simulate ESD events, [20]. It was found that textiles with conductive threads did not give ignitions provided they were adequately earthed, [21]. When isolated, all textiles were capable of causing ignitions regardless of the anti-static strategy employed.

Friction coefficient displayed by clothes sliding against car seat covers was discussed, [22]. The frictional performance of two groups of covers, the first contained five different types of synthetic leather and the second contained nine different types of synthetic textiles, was measured. Measurement of friction coefficient is, therefore, of critical importance in assessing the proper friction properties of car seat covers and their suitability to be used in application to enhance the safety and stability of the driver. Less attention was considered for the triboelectrification of the textiles. Friction coefficient and electrostatic charge generated from the friction of hair and head scarf of different textiles materials were measured, [23]. Test specimens of head scarf of common textile fibres such as cotton, nylon and polyester were tested by sliding under different loads against African and Asian hair. The results showed that friction coefficient generated from the sliding of the cotton head scarf against hair displayed higher values than that showed by polyester head scarf. The nylon head scarf when sliding against hair showed relatively lower friction coefficient than that observed for polyester and cotton scarf. Electric static charge measured in voltage represented relatively lower values. This behaviour may be attributed to the ranking of the rubbing materials in the triboelectric series where the gap between human hair and nylon is smaller than the gap between hair and cotton as well as hair and polyester.

In the present work, it is aimed to study the influence of insulating the sliding surfaces on the friction coefficient for PMMA and PE spheres sliding on PTFE and steel at dry and water as well as salt water wetted sliding conditions.

II. EXPERIMENTAL

The test rig is shown in Fig. 1. The PE and PMMA spheres were assembled in a holder fastened in the loading lever. A counter weight was used to balance the loading lever before loading. Vertical load was applied by weights of 2, 4, 6, 8, 10, 12, 14, 16 and 18 N. The counterfaces (PTFE and steel) in form of sheets of 100 × 100 × 5 mm3 were fixed in the moving table of the test provided by manual driving mechanism to move specimens in a straight direction. Friction force was measured using a load cell mounted to the loading lever and connected to a digital monitor. The friction force was measured during the test and used to calculate friction coefficient. The test was conducted under dry and water as well as salt water wetted sliding conditions at the room temperature.

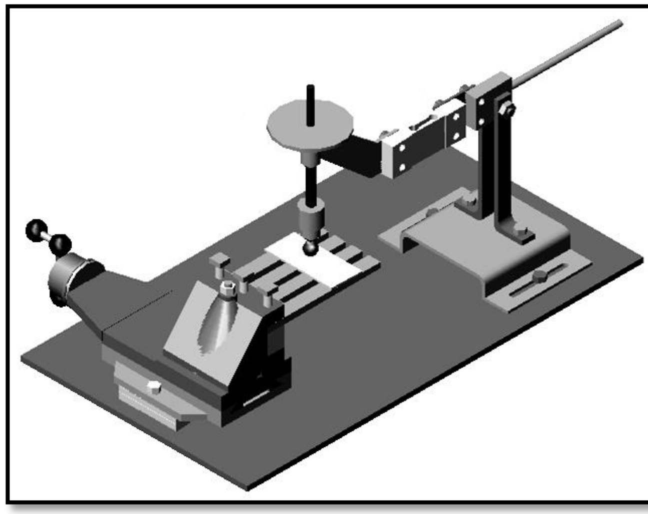

Fig. 1 Arrangement of the test rig.

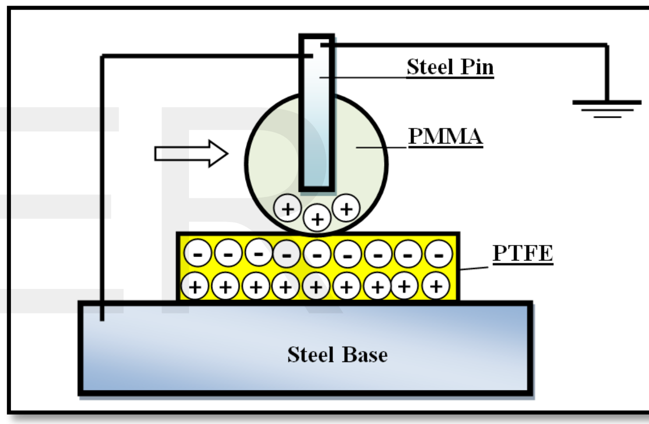

Fig. 2 Distribution of the generated electric static charge on the sliding surfaces.

III. RESULTS AND DISCUSSION

The results of the experiments carried out in the present work are illustrated in Figs. 3 – 14. The effect of isolating the sliding surfaces on the friction coefficient is discussed for PMMA and PE spheres sliding on PTFE and steel at dry and water as well as salt water wetted sliding conditions. Friction coefficient of PMMA sphere sliding against dry PTFE is shown in Fig. 3, where the connected test specimens showed relatively higher friction coefficient than that observed for the isolated ones. This behaviour can be explained on the basis that sliding of PMMA sphere on PTFE surface generated positive charge on the PMMA surface and negative charge on PTFE surface, Fig. 2. The lower surface of PTFE sheet would be charged by positive charge which in condition of connecting the steel sheet by the grounded steel pin would move to the steel pin and increase the positive charge generated on its surface. As a result of that, the electric static charge would increase and consequently the attractive force would increase leading to an increase in friction coefficient. The friction difference was significant at the lowest values of the load. As the applied load increased friction difference decreased due to PTFE transfer into PMMA surface. Generally, friction values were relatively higher than that expected for PMMA/PTFE, where the values should be lower than 0.1 due to the well known sliding properties of PTFE. As for isolated test specimens, the electric static charge on the contact would be lower and consequently the attractive force would decrease causing slight decrease in friction coefficient.

Friction coefficient, of PMMA sphere sliding against steel, recorded relatively higher values than that displayed by PMMA/PTFE. Based on the triboelectric series the charge formed on the sliding surfaces would be lower than that formed on PMMA and PTFE surfaces. The friction increase might be from the PMMA transfer into steel surface. Connected sliding surfaces displayed relatively higher friction than isolated ones. This was due to the positive charge transfer from the lower surface of steel into the steel pin which increased the positive charge on the PMMA sphere.

In the presence of the water film covering the sliding surfaces, friction coefficient displayed drastic decrease, Fig. 5. This behaviour could be from the ability of water to distribute the electric static charge homogeneously on the PMMA and PTFE surfaces. Besides, a fraction of the contact area would be covered by water film, where the charge generation would be in the contact area. Load slightly decreased with increasing the load. Friction coefficient of PMMA sphere sliding against steel wetted by water recorded very high values, Fig. 6. Connected test specimens showed higher friction than isolated ones. It seems that water film covering the PMMA sphere well distributed the electric static charge formed on the contact area. When the steel sheet was connected to steel pin holding PMMA sphere an excess positive charges would be superimposed on the PMMA sphere. The electric force generated from the sliding would be enough high to attract and increase the adhesion between the two sliding surfaces. Isolated sliding surfaces showed lower friction due to the low electric force.

The difference in friction coefficient between connected and isolated test specimes represented relatively high values, Fig. 7. This behaviour might be attributed to the increase of electric static charge on the sliding surfaces, where connected test specimens showed higher friction coefficient than that observed for the isolated ones.

Friction coefficient of PMMA sphere sliding against steel wetted by salt water displayed higher friction than sliding against PTFE, Fig. 8. The friction contact between PMMA and steel sheet incorporated PMMA transfer into steel surface in such way that the contact was partially PMMA/PMMA and PMMA/steel. Load increase caused drastic friction decrease due to the formation of salt water film in the contact area.

The frictional performance of PE sphere sliding against PTFE and steel surfaces is shown in Figs. 9 – 14. Isolated test specimens showed the lowest values of friction coefficient, where the minimum value (0.065) was displayed at 18 N when PE sphere slid against dry PTFE surface, Fig. 9. Comparing the results illustrated in Fig. 9 with that in Fig. 3, it can be seen that significant reduction was observed in friction coefficient. This behaviour might be attributed to the intensity of electric static charge generated on the contact area. It is well known that charge generated from sliding of PMMA against PTFE is much higher than that displayed by PE sliding on PTFE due to their ranking in the triboelectric series.

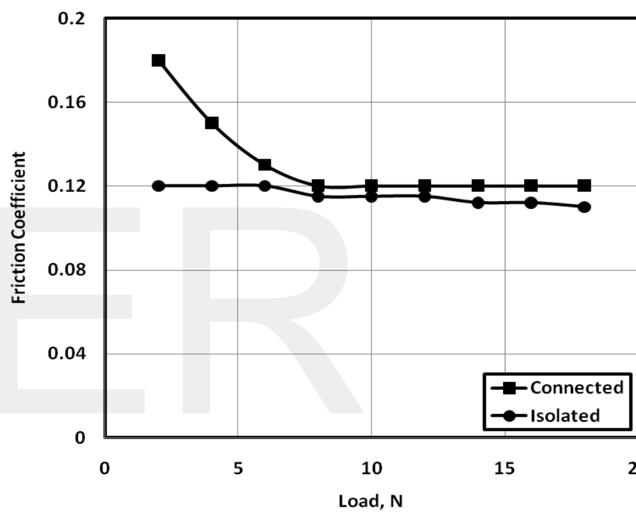

Fig. 3 Friction coefficient of PMMA sphere sliding against PTFE.

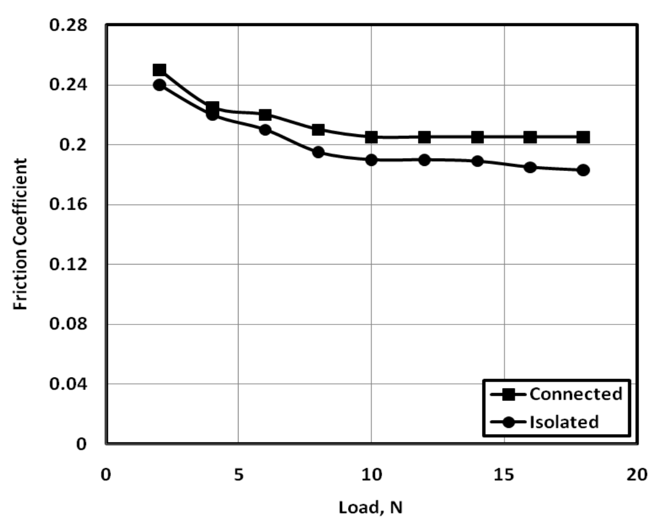

Fig. 4 Friction coefficient of PMMA sphere sliding against steel.

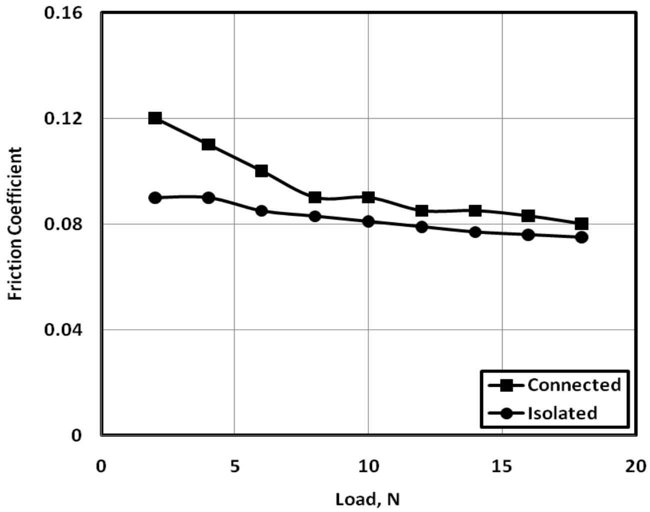

Fig. 5 Friction coefficient of PMMA sphere sliding against PTFE wetted by water.

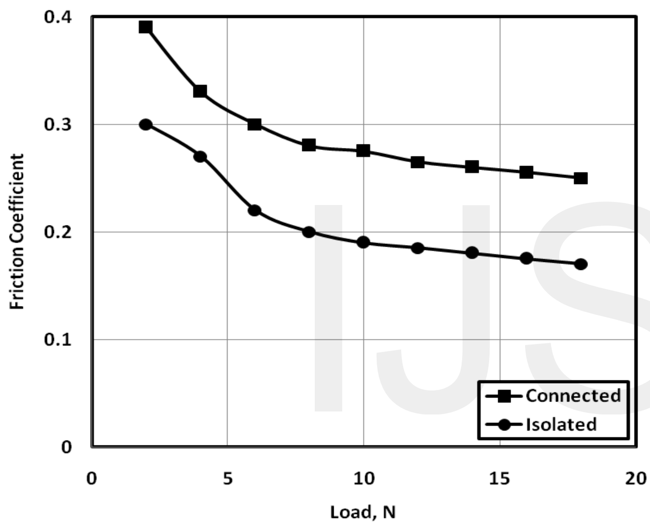

Fig. 6 Friction coefficient of PMMA sphere sliding against steel wetted by water.

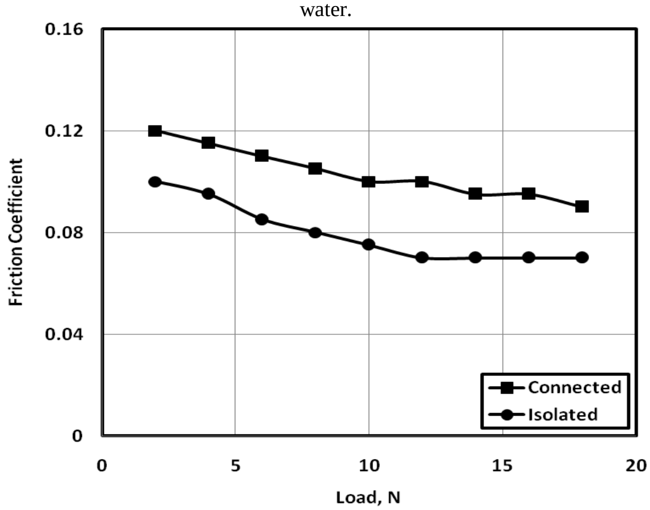

Fig. 7 Friction coefficient of PMMA sphere sliding against PTFE wetted by salt water.

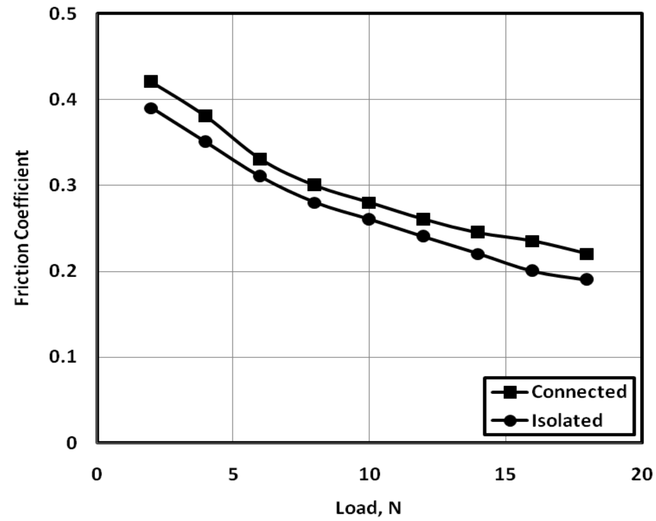

Fig. 8 Friction coefficient of PMMA sphere sliding against steel wetted by salt water.

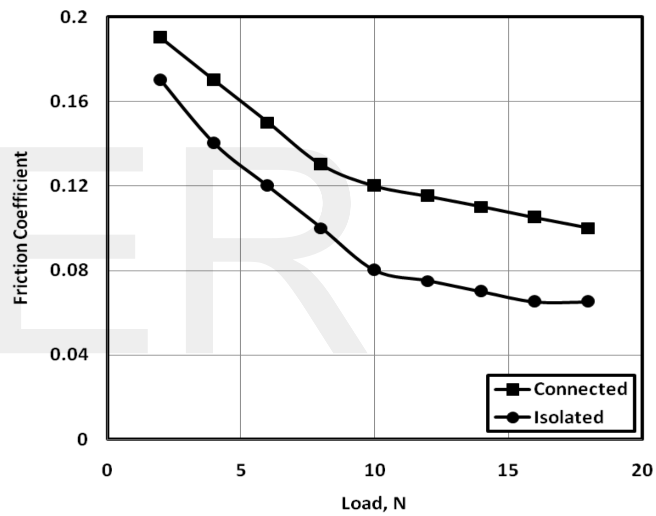

Fig. 9 Friction coefficient of PE sphere sliding against dry PTFE surface.

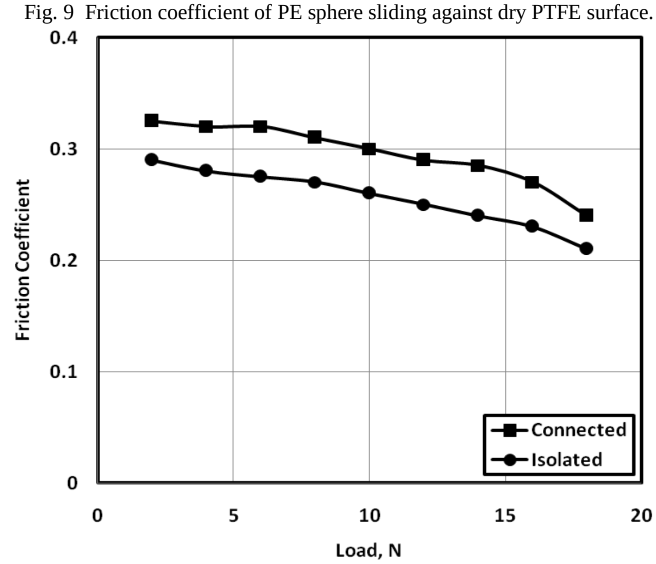

Fig. 10 Friction coefficient of PE sphere sliding against dry steel surface.

Friction coefficient of PE sphere sliding against dry steel surface showed slight increase compared to that observed for PMMA due to the position of PE and steel relative to each other in the triboelectric series, Fig. 10. The connected test specimens showed higher friction than isolated ones. This observation confirmed the influence of the triboelectrification on the frictional performance of the tested materials.

At water wetted sliding, PE sphere sliding against PTFE displayed slight friction increase compared to that given by PMMA/PTFE, Fig. 11. The water film distributed the electric static charge generated on the two sliding surfaces and consequently its local intensity in the contact area decreased. In this sliding condition, material transfer and transfer back were mainly controlling the friction values.

Sliding of PE sphere against steel wetted by water, Fig. 12, displayed higher friction than that observed for PE/PTFE. It seems that PE transfer to the steel surface was responsible for that behaviour. Besides, PE/steel sliding gave higher friction coefficient than that displayed by PMMA/steel, Fig. 6. The distance between the two sliding materials in the triboelectric series is longer for PE and steel than for PMMA and steel which alters the voltage generated from the electric static charge. Increasing the distance increases the generated voltage and consequently the electric force increases.

In the presence of salt water, Fig. 13, friction coefficient showed higher values than that shown for fresh water. It seems that the good electrical conductivity of salt water homogeneously distributed the electric formed on the contact surface, so that the controlling factor of friction was PTFE transfer into the surface of PE. The same trend was observed for sliding of PE/steel, Fig. 14, where values of friction coefficient were higher than given by PMMA/steel sliding.

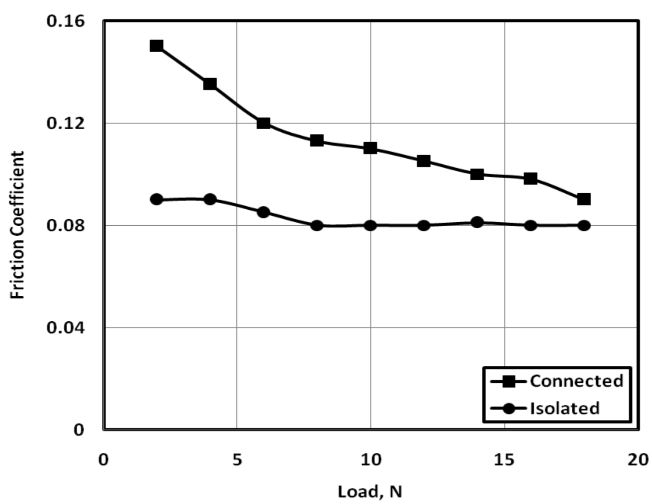

Fig. 11 Friction coefficient of PE sphere sliding against PTFE wetted by water.

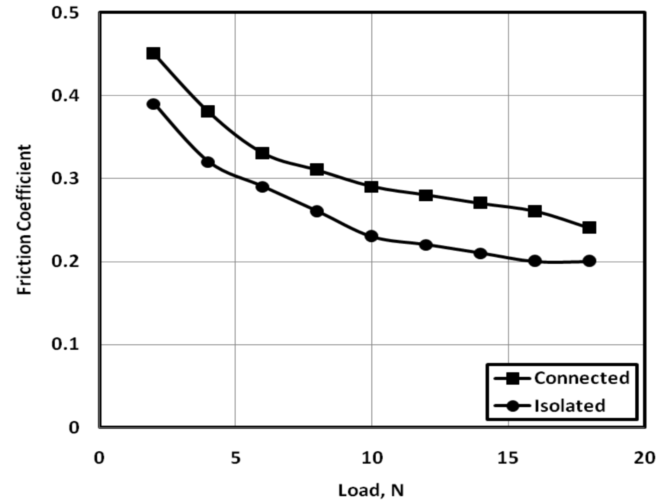

Fig. 12 Friction coefficient of PE sphere sliding against steel wetted by water.

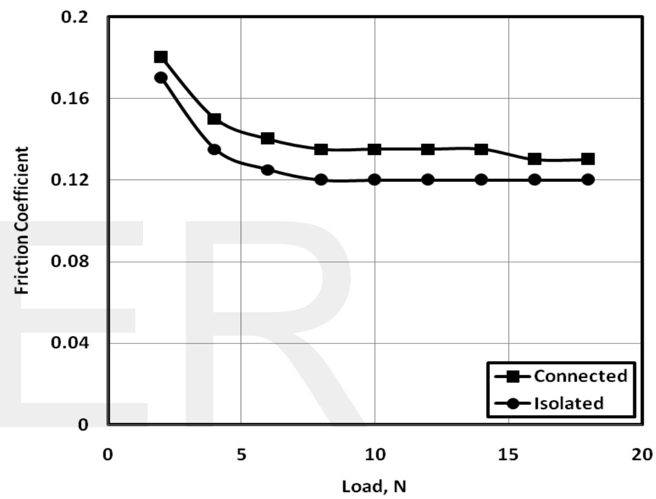

Fig. 13 Friction coefficient of PE sphere sliding against PTFE wetted by salt water.

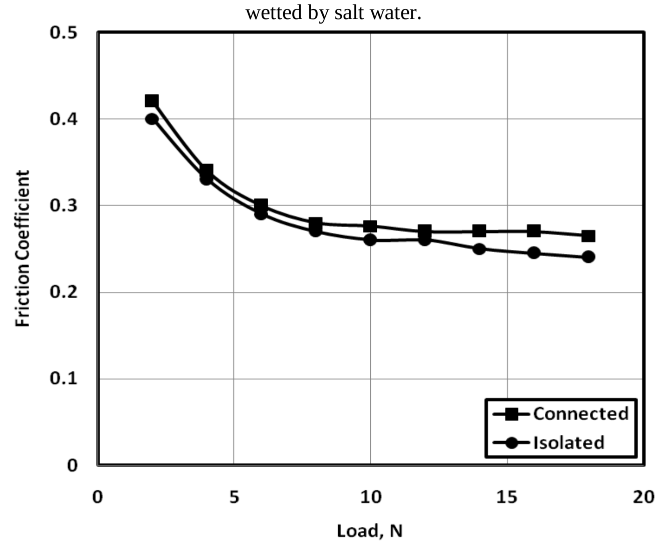

Fig. 14 Friction coefficient of PE sphere sliding against steel surface wetted by salt water.

V

IV. CONCLUSIONS

1. For all the tested materials and sliding conditions, the connected test specimens showed relatively higher friction coefficient than that observed for the isolated ones.
2. In the presence of water film covering the sliding surfaces, friction coefficient displayed drastic decrease, due to the ability of water to distribute the electric static charge homogeneously on the PMMA and PTFE surfaces.
3. Friction coefficient of PMMA sphere sliding against steel wetted by water recorded very high values. The electric force generated from the sliding was enough high to increase the adhesion and attract the two sliding surfaces.
4. Friction coefficient of PMMA sliding against steel wetted by salt water displayed higher friction than that given by sliding against PTFE.
5. Significant friction reduction was observed for PE sliding against PTFE due to their ranking in the triboelectric series.
6. PE/steel sliding gave higher friction coefficient than that displayed by PMMA/steel. The distance between the two sliding materials in the triboelectric series is longer for PE and steel than for PMMA and steel which alters the voltage generated from the electric static charge. Increasing the distance increases the generated voltage and consequently the electric force increases..

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