Triboelectrification Of Polypropylene Shoe Sliding Against Polyethylene Cover

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***Abstract*—In order to provide a sterile environment, operating rooms require certain restrictions that will prevent the reproduction and spread of harmful microorganisms. The use of protective footwear (shoe covers) may reduce the bacterial transfer into operating room. Electric static charges generated from friction of engineering materials have a negative effect in their applications. The increased use of polymeric materials raised the importance of studying that effect. Electric static charges building up on human skin and hair as well as clothes in direct contact with human body are very harmful and can create serious health problems. The present study investigates the friction coefficient as well as the electric static charge generated from the dry and water wet sliding of polypropylene shoe sliding against polyethylene cover of people who are working in hospitals. This behavior would occur when the shoe cover is strongly adhered to the floor and relative motion would proceed between shoe sole and cover.**

It was found that voltage generated on the shoe sole from contact and separation as well as sliding against polyethylene cover at dry and water wet conditions decreased as the normal load increased. The voltage values observed during sliding were enough high to create serious health problems. As a consequence, it can be proposed to select materials of relatively low electric static charge. At water wet surfaces, voltage generated on the shoe sole showed relatively lower values due to the ability of water to conduct the charge out of the contact surfaces. The friction values guaranteed quite good adhesion of the shoe sole with the cover. They were enough for safe use at dry and water wet sliding condition. Comparing the frictional behavior of the tested materials with their ability to generate electric static charge, it seems that friction coefficient critically depended on the value of the generated voltage. This behavior can be explained on the basis that, generation of equal electric static charges on the sliding surfaces of different signs increased the attractive force between the two surfaces and consequently the adhesion increased leading to friction increase.

***Keywords*—electric static charge; voltage; contact and separation; sliding; dry; water wet; polypropylene shoe; polyethylene cover**

I. INTRODUCTION

The use of shoe covers may decrease the risk of surgical site infection and decrease the bacterial counts of the operating room floors, where they protect the footwear and feet from exposure to blood and body fluids, [1, 2]. In the operating room, shoe covers help to protect the patient against harmful contaminants, where wearing disposable shoe covers ensures that no bio hazardous materials are taken from the operating room out to the unprotected world. Besides, visitors to the hospital have to wear some to protect their patients from any outside contaminations. Due to the footwear and footwear cover of being polymeric materials, the electric static charges generated from their friction have a negative effect in their applications, where they are built up on human skin and can create serious health problems. The electric static charge generated from the dry and water wet contact and sliding of surgical gloves and the covers of the cloths of people who are working in hospitals was investigated, [3]. It was concluded that materials of both glove and cover generated very high electric static charge values. It is therefore necessary to select the materials of low electric static charge.

The electric static charge generated from the dry and water wet sliding of propylene shoe against floor of people who are working in hospitals was investigated, [4]. It was found that dry sliding of shoe against floor generated much higher electric static charge measured on the shoe. This observation can confirm the necessity to develop new materials to be applied as shoe of low electric static charge. At sliding, the charge value was higher than that recorded for contact and and separation. The electric static charge generated from the dry sliding of hair against disposable cap and face mask as well as skin against face mask of people who are working in hospitals was tested, [5]. Relatively high voltage (- 4000 volts) was generated from the sliding of the disposable cap on hair. The electric static charge generated on the disposable cap showed negative and much higher values. Sliding of disposable cap against hair generated much higher charge than that measured in contact and separation. The contact and separation of the mask with hair displayed very high voltage. Electric static charge of face mask generated from its contact and separation with skin displayed much higher values than that observed for skin. This observation can confirm the necessity to develop new materials to be applied as face mask of low electric static charge and the careful selection of the materials used in that application.

Static charge includes potentially dangerous electrical shocks which can cause fires and explosions. It can also cause severe damage to sensitive electronic components. Triboelectric charging is the transfer of electrons which occurs when two materials are in contact and are then separated. One material gains an excess of negative ions and the other an excess of positive ions. The charge generated can be more than 25,000 volts. 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, [6 - 8]. The mechanism of charge transfer in tribocharging can be explained by three mechanisms: electron transfer, ion transfer, and material transfer, [9 – 11]. The metal to metal contact electrification successfully explained by electron transfer mechanism. When two different materials come to contact, electrons transfer happens until their Fermi level equals. Difference in work functions between them is the main driving force, [12]. As for insulators, the electron transfers only happen on the surfaces of insulators, where electrons move from the filled surface of one insulator to the empty surface of the other insulator, [13 – 15]. Few researchers have drawn up triboelectric series to predict the polarity of the charge that is transferred from one surface to another, [16]. When two kinds of materials contact each other, the upper one in the triboelectric series will get positively charged and the other one will be negatively charged. It is becoming increasingly evident that more than one of these mechanisms may occur simultaneously, [17].

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, [18]. For SS, strain reduces the frequency of electrical discharges occurring. It was found that material strain can strongly influence triboelectric charging. Besides, straining a material can produce 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, [19 – 22]. 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, [23]. Triboluminescence intensity was higher in sliding friction. The saturation charges of all the sliding couples showed their maxima at the humidity from 10 to 30%. It was found that the humidity enhanced charge transfer which resulted in the increase or decrease of electrification, [24]. The contact and separation process leads to the charge transfer between dissimilar materials. When charges are accumulated, they are measured as triboelectrification.

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 [25 - 27]. However, other data show that water molecules on the surfaces convey charges in the form of ions to enhance charge separation between two surfaces [28, 29]. These contradictory results require precise measurement of the effect of humidity on charge generation.

Dielectric and friction behaviour of unidirectional glass fibre reinforced epoxy (GFRE) were studied, [30]. It was found that the glass fibre/matrix interfaces allow the trapping of electric charges. The diffusion of electric charges through the fibre–matrix interfaces permits a stabilization of the friction coefficient and a limitation of the wear, where a localized trapping of charges on the interfaces is a source of damage and wear. The importance of fibre/matrix interface on the trapping/diffusion of the electric charges was previously discussed, [31]. 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, [32]. Then, an external stress can permit the detrapping of trapped charges, [33], and, consequently, the release of the stored polarization energy, inducing catastrophic effects, such as dielectric breakdown, rupture or wear.

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, [34]. The materials tested showed different trend with increasing load. The contact and separation of the tested against polyamide textiles generated negative voltage, where voltage increased down to minimum then decreased with increasing load. The variance of the voltage with load was much pronounced. Remarkable voltage increase was observed for contacting synthetic rubber. This observation can limit the application of synthetic rubber in tailoring clothes. Materials of high static electricity can be avoided and new materials of low static electricity can be recommended.

The wide use of polymer fibers 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, [35]. 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. 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 fibers 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, [36]. Researches on electrostatic discharge (ESD) ignition hazards of textiles are important for the safety of astronauts. The likelihood of ESD ignitions depends on the environment and different models used to simulate ESD events, [37, 38]. Materials can be assessed for risks from static electricity by measurement of charge decay and by measurement of capacitance loading.

The present study investigated the effect of the relative motion of the shoe cover with shoe sole when the cover was adhered to the floor. Friction coefficient and electric static charge, generated from the contact and separation as well as the sliding of polypropylene shoe against shoe cover for people who are working in hospitals, were discussed.

II. EXPERIMENTAL

The present work investigated the measurement of electric static charge generated by the contact and separation as well as sliding of dry polypropylene shoe sliding against polyethylene shoe cover for people who are working in hospitals. The electrostatic fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens. Tests were carried out at room temperature under varying normal loads. The test specimens were polypropylene shoe pressing the polyethylene shoe cover adhered to the wooden base supported by two load cells, the first can measure the horizontal force (friction force) and the second can measure the vertical force (normal load), Fig. 1. The cover was pressed by the shoe, where the load was applied by foot. During test, horizontal and vertical load cell connected to two monitors detected normal and friction load respectively. Friction coefficient is the ratio between friction load and normal load. Each run was replicated five times, and the mean value of the friction coefficient was considered. Friction tests were carried out at different loads ranging from 0 - 800 N. The tested shoe and cover are shown in Fig. 2.

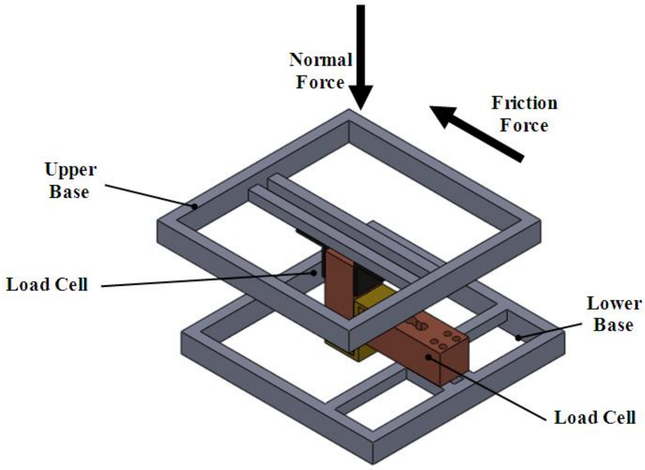

Fig. 1. *Arrangement of the test rig.*

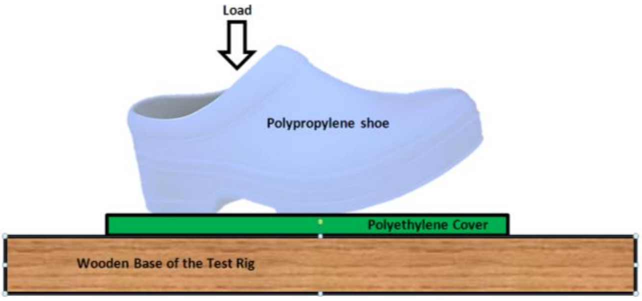

Fig. 2. *Illustration of the test procedure.*

III. RESULTS AND DISCUSSION

The relationship between friction coefficient and normal load is illustrated in Fig. 3. Friction coefficient displayed by sliding of polypropylene shoe sole against polyethylene cover at dry condition slightly decreased with increasing normal load. The values were reasonable to avoid slip accidents. The lowest friction value was 0.8 at 680 N, while the highest value was 1.32 at normal load of 100 N. The friction values guaranteed the good adhesion of the shoe sole with the cover. They are enough for safe walking at dry sliding condition.

Electric static charge generated on the shoe sole from contact and separation against shoe cover at dry condition and measured in volts is shown in Fig. 4. Voltage decreased as the normal load increased. The maximum value was -350 volts measured on the surface of the shoe sole. The electric static charge generated on the polyethylene cover, Fig. 5, showed positive values ranging from 4800 to 1100 volts. As the load increased, electric static charge drastically decreased due to the increased interference between the shoe and polyethylene, where the charge transfer became easier. Due to the nature of the electric static charge the scatter in the values measured during experiments was relatively high.

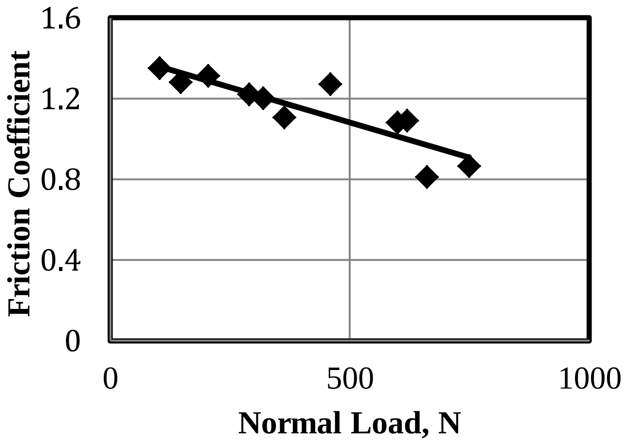

Fig. 3. *Friction coefficient displayed by sliding of shoe against dry cover.*

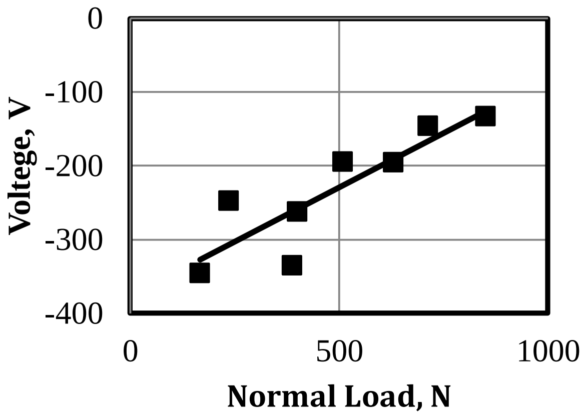

Fig. 4. *Electric static charge of shoe generated from its contact and separation against dry cover.*

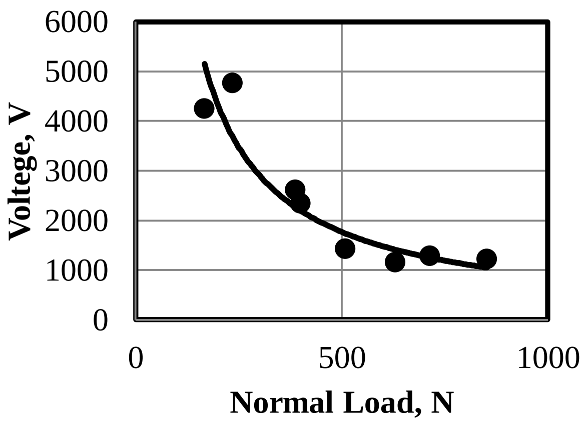

Fig. 5. *Electric static charge of dry cover generated from its contact and separation against shoe.*

Electric static charge of shoe generated from its sliding against dry polyethylene cover is shown in Fig. 6. It was observed that, at sliding, the charge value reached -6000 volts at 830 N. This value was much higher than that recorded at contact and and separation. Electric static charge of dry polyethylene generated from its sliding against shoe recorded higher positive voltage than that observed for shoe sole, where the value approached 8000 volts at 820 N, Fig. 7. The voltage values observed during sliding were enough high to create serious health problems. As a consequence, it can be proposed to select materials of relatively low electric static charge, where the materials selection depends on their triboelectrification. It is known that when two materials contact each other, the upper one in the triboelectric series will get positively charged and the other one will be negatively charged. As the difference in the rank of the two materials increases the generated voltage increases. It is expected that shoe sole (polypropylene) gains negative charge when rubs polyethylene cover, while polyethylene gains positive charge, Fig. 8. The intensity of the electric charge depends on the contact area and load. It is therefore necessary to select the materials based on their triboelectric charging. Comparing the frictional behavior of the tested materials with their ability to generate electric static charge, it seems that friction coefficient critically depended on the value of the generated voltage. This behaviour can be explained on the basis that, generation of equal electric static charges on the sliding surfaces of different signs would increase the attractive force between the two surfaces and consequently the adhesion increased leading to friction increase.

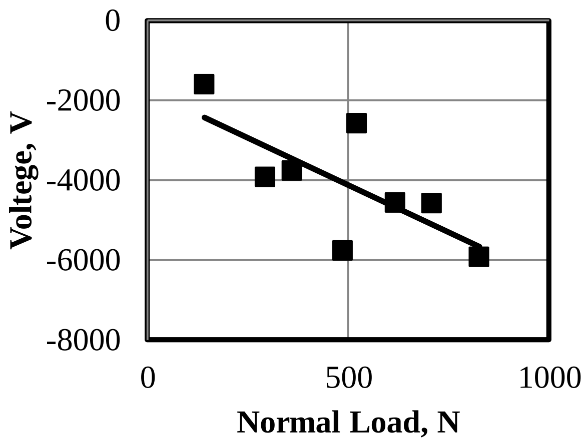

Fig. 6. *Electric static charge of shoe generated from its sliding against dry cover.*

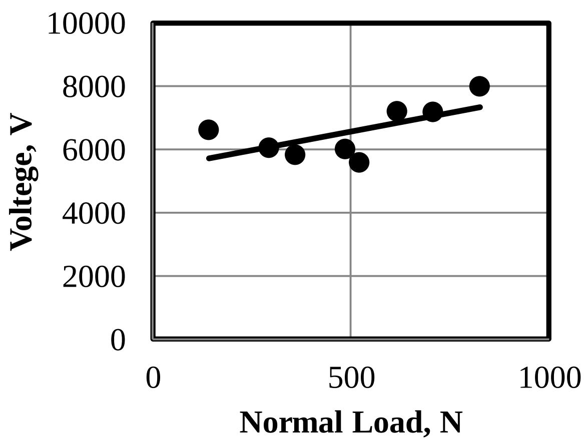

Fig. 7. *Electric static charge of dry cover generated from its sliding against shoe.*

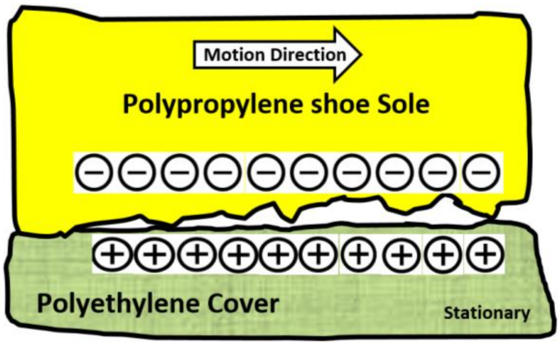

Fig. 8. *Illustration of generation of electric static charge on the sliding surfaces.*

At water wet surfaces, the results of experiments measuring friction coefficient and electric static charge are shown in Figs. 9 – 13. Friction coefficient displayed by sliding of shoe sole against polyethylene cover at water wet sliding is shown in Fig. 9. Friction coefficient slightly decreased with increasing the load. The lowest friction value was 0.52, while the maximum value was 0.7. The values of friction were acceptable for safe walking but they were lower than that observed for dry contact. Because friction coefficient is considered as main factor in the evaluation of safe walking it is necessary to increase its value.

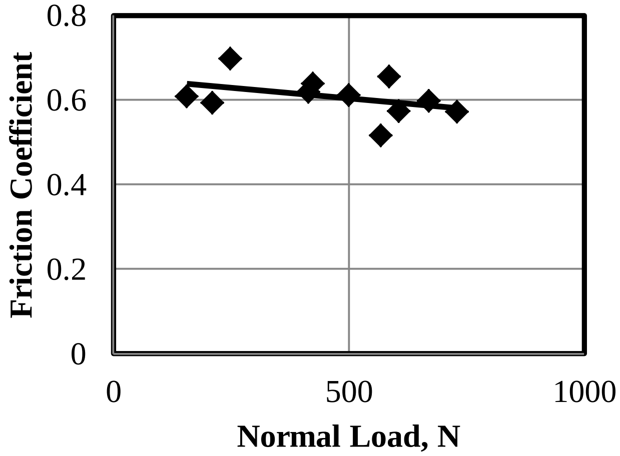

Fig. 9. *Friction coefficient displayed by sliding of shoe against water wet cover.*

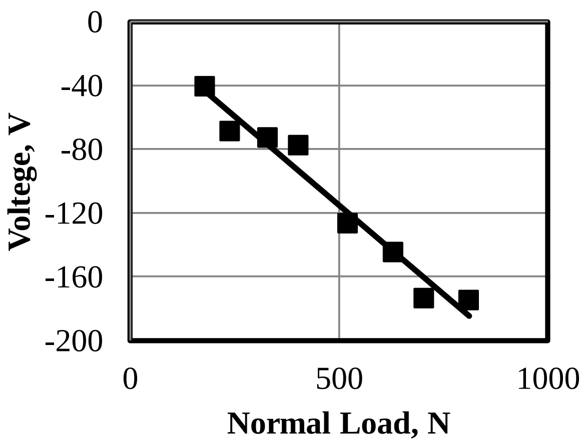

Fig. 10. *Electric static charge of shoe generated from its contact and separation against water wet cover.*

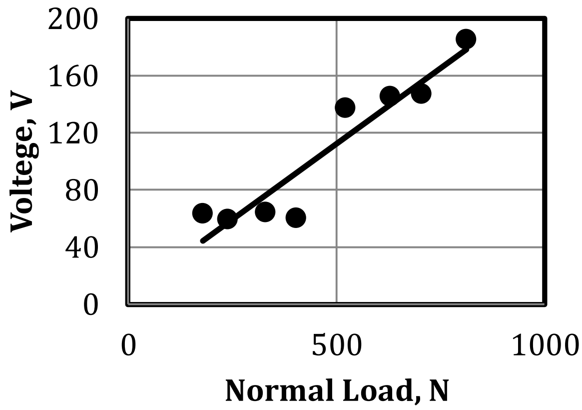

Fig. 11. *Electric static charge of water wet cover generated from its contact and separation against shoe.*

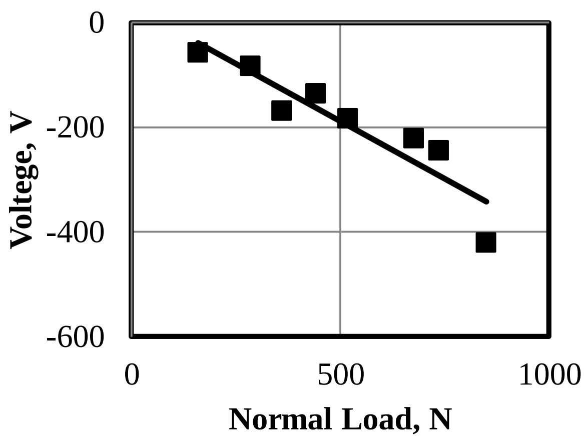

Fig. 12. *Electric static charge of shoe generated from its sliding against water wet cover.*

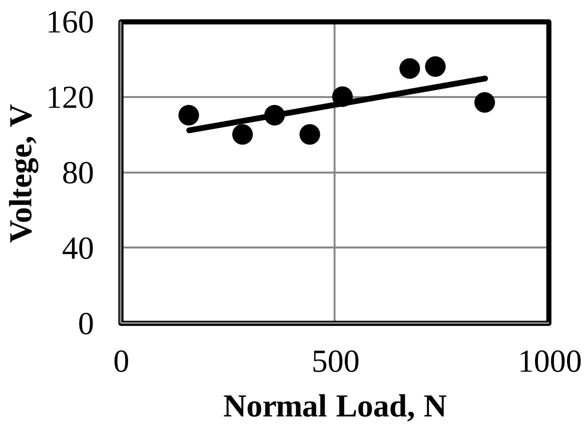

Fig. 13. *Electric static charge of water wet cover generated from its sliding against shoe.*

Voltage generated on the shoe sole from its contact and separation against water wet polyethylene cover is shown in Fig. 10. Voltage values were -175 and -40 volts at 810 and 180 N loads respectively. Voltage generated on polyethylene cover, Fig. 11, displayed positive voltage reached 182 volts. The values of electric static charge were approaching to that shown for the opposite counterface (shoe sole). The measured low values of voltage were from the ability of water to conduct the charge out of the contact surfaces.

Voltage generated on shoe sole from its sliding against shoe cover, Fig. 12, showed maximum voltage value of -440 volts at 860 N, while voltage generated on the polyethylene cover from its sliding against sole, Fig. 13, showed maximum value of 135 volts. The difference between the values of voltage generated on the two sliding surfaces was relatively lower than that measured for dry sliding due to the ability of water to redistribute the electric charge on the contact surfaces.

IV. CONCLUSIONS

1. Friction coefficient displayed by sliding of polypropylene shoe sole against polyethylene cover at dry condition slightly decreased with increasing normal load. The values were reasonable to avoid slip accidents and guarantee safe walking. At water wet sliding, the values of friction coefficient were acceptable for safe walking but they were lower than that observed for dry contact.

2. Voltage generated on the shoe sole from contact and separation against shoe cover at dry condition decreased as the normal load increased. The maximum value was -350 volts measured on the surface of the shoe sole, while that generated on the polyethylene cover showed positive values up to 4800 volts. Voltage generated on shoe sole from sliding against dry polyethylene cover voltage reached -6000 volts at 830 N, while voltage generated on dry polyethylene recorded higher positive voltage than that observed for shoe sole, where the value approached 8000 volts at 820 N. The voltage values observed during sliding were enough high to create serious health problems. As a consequence, it can be proposed to select materials of relatively low electric static charge.

3. At water wet surfaces, voltage generated on the shoe sole, from its contact and separation as well as sliding, against polyethylene cover showed relatively lower values due to the ability of water to conduct the charge out of the contact surfaces.

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