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TRIBOELECTRIFICATION OF THE DIAPERS

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ABSTRACT
The extensive use of polymeric materials in diapers necessitates to study their electrification when they rubbing other surfaces. The electrostatic charge (ESC) generated from the friction of diapers sliding against cotton, polyester and wool textiles (clothes), as well as skin and ceramic tiles (floor) is discussed in the present work. Experiments have been carried out to measure the electrostatic charge generated and friction coefficient under different values of load.

The results of the experiments can confirm the necessity to develop new materials to be applied as back sheet of the diaper of low ESC. Sliding of the back sheet of the diaper against skin can give specific information about the triboelectrification of diaper material when the kid touches his diaper and when the adult carries the kid. It is necessary that friction coefficient should have reasonable values so that the slip of the hand of adult carrying the kid can be avoided to prevent accidents. It was found that the friction values at light loads do not guarantee the good adhesion of the skin and diaper.

The high values of ESC generated from the sliding of diaper against wool reflect the severity of ESC values when the kid wears woolen clothes contacting the back sheet of the diaper. Based on that observation, it is recommended to propose alternative materials of the back sheet of the diaper of low ESC. Also, ESC generated on the wool textiles generated relatively high values reached to 820 volts at 38 N. ESC gained by the diaper can migrate to the kid body. After more rubbing, the clothes gain more charge. Then the kid will be subjected to electrical field during wearing the conventional diapers.

KEYWORDS
Electrostatic charge, friction coefficient, diapers, textiles, skin, ceramic floor.

INTRODUCTION
In 1973, polymeric materials were extensively used in the industry of diapers, [1]. Until 1970 the cotton diapers were used. They are soft, comfortable, and of natural materials, but they have poor absorbency and have to be laundered. The first disposable diapers used wood pulp fluff, cellulose wadding and fluff cellulose as the absorbent material.

Therefore, they were extremely bulky, [2]. The function of a diaper is to absorb and retain moisture. Polymers made of fine particles of sodium or potassium acrylate act as tiny sponges that retain many times their weight in water, [3]. The absorption capacity is due to the absorbent pad found in the core of the diaper.

The outer layers of the diapers are waterproof made of polyurethane laminate and thermoplastic polyurethane. The back sheet of the diaper is made of polyethylene or cloth-like film to prevent the liquids from leaking out of the diaper. Thin polypropylene non-woven sheet is adhered to back sheet to give the cloth-like look. Mixture of resins, oils and tackifiers are used to glue the different components of the diaper, such as the pad and the elastics. Phthalates are are most likely used on the waterproof back sheet. It was found that, [4, 5], "phthalates are leading to exposure through ingestion, dermal transfer, and inhalation. Children are uniquely vulnerable to phthalate exposures given their hand-to-mouth behaviors, floor play, and developing nervous and reproductive systems."

The electrostatic charge generated from the friction of polytetrafluoroehylene (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, [6]. 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. Ultra surface DC Voltmeter was used to measure the electrostatic charge of the tested textile composites. 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, [7]. Materials can be assessed for risks from static electricity by measurement of charge decay and by measurement of capacitance loading, [8]. Tribology is the science and technology of two interacting surfaces in relative motion and of related subjects and practices. The popular equivalent is friction, wear, and lubrication, [9]. Tribological behavior of polymers is reviewed since the mid-20th century to the present day. Surface energy of different coatings is determined with contact adhesion meter. Adhesion and deformation components of friction were discussed. It was shown how load, sliding velocity, and temperature affect friction. Different modes of wear of polymers and friction transfer were considered, [10]. The ability to engineer a product's tactile character to produce favorable sensory perceptions has the potential to revolutionize product design. Another major consideration is the potential for products to produce friction-induced injuries to skin such as blistering, [11, 12]. Sports activities may cause different types of injuries induced by friction between the skin and sport textiles. Focusing on runners who are often bothered with blisters, the textile–foot skin interface was studied in order to measure and predict friction. The characteristics of mechanical contacts between foot, sock and shoe during running were determined. It was found that textiles with conductive threads did not give ignitions provided they were adequately earthed, [13]. 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, [14]. 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, [15]. 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. Generally, at higher loads, the difference in friction values was insignificant. African hair displayed relatively higher voltage. Nylon displayed relatively higher friction coefficient than polyester when slid against human hair, while cotton proposed the highest friction coefficient especially at lower loads. The nylon head scarf showed slight decrease in friction coefficient compared to scarf. The decrease might be from the difference in the weave form although the both two textiles are made of nylon. The weaves form has significant effect on friction coefficient and voltage generated.

Little attention has been devoted so far to the electrostatic properties of hair although these properties are very sensitive to the friction between hair and head scarf textiles. Hair has a tendency to develop static charge when rubbed with dissimilar materials like human skin, plastic and textiles. Human hair is a good insulator with an extremely high electrical resistance. Due to this high resistance, charge on hair is not easily dissipated, especially in dry environments. Many studies have looked at the static charging of human hair, [16 - 18]. Most of these studies include rubbing hair bundles with various materials like plastic combs, teflon, latex balloons, nylon, and metals like gold, stainless steel and aluminum. Hair in these cases is charged by a triboelectric interaction between the surface and the rubbing element. The kinetics of the charging process and the resulting charge are then measured using modified electrometers.

Friction coefficient displayed from the sliding of headscarf of different textiles materials against hair and skin was investigated, [19]. Test specimens of headscarf of common textile fibres were tested by sliding under different loads against skin, African, Caucasian and Asian hairs. It was found that, skin showed higher friction coefficient than hair. African hair displayed relatively higher friction when sliding against cotton, flax and inner lining of headscarf. Asian hair showed higher friction for polyester, polyacrylonitrile, crape, jil, chiffon and satin head scarves. Caucasian hair exhibited the lowest friction coefficient.

Electrostatic charge generated from the friction of hair and skin against head scarf of different textiles materials was measured, [20, 21]. Friction between Caucasian hair and polyester scarf generated the highest electrostatic charge followed by African and

Asian hairs when slid against cotton. Besides, sliding of polyacrylonitrile against skin displayed higher voltage than that generated from cotton and polyester. While, sliding of African hair against polyacrylonitrile textiles recorded the highest values of voltage which increases the risk of sparks of high energy enough to ignite flammable gases and vapors.

The possibility of having minimum electrostatic charge generated from the friction between the proposed polymeric composites consisting of polytetrafluoroethylene, (PTFE) and polyamide, (PA) fibres when sliding against cotton textiles was investigated, [22]. Based on the fact that, PTFE gaines negative charge and PA gaines positive charge, the resultant voltage would depend on the combination of both PTFE and PA. It was observed that fibre diameter of PA had critical effect on the generated voltage. The measure of the comfort of clothes is the friction coefficient displayed by the sliding against skins or other textiles. As the friction coefficient increased the comfort of the clothes decreased.

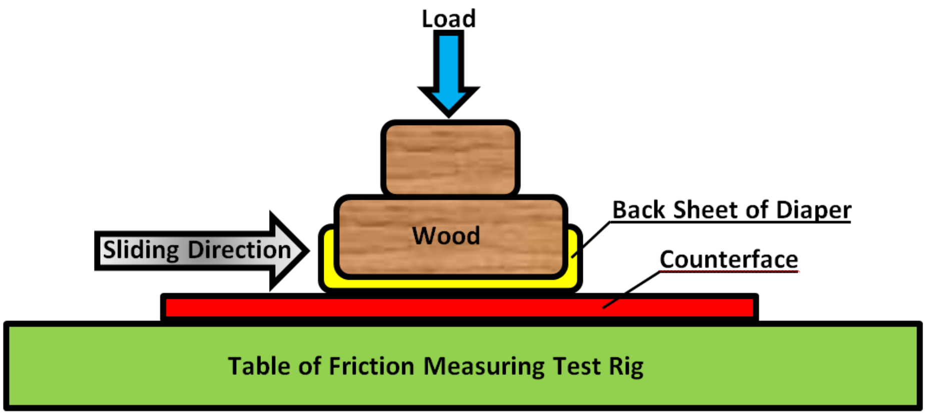
From the medical point of view, the electrostatic field effect of synthetic floorings on kindergarten children was studied, [23]. Their study concluded that the deteriorated thermos-protective properties of the synthetic floorings affected the serum level of immunoglobulins IgG, IgA and IgM, which in turn doubled the morbidity of those children than children going to kindergartens with wood floorings. Moreover, it was reported that doubling of the risk of childhood leukemia with exposures to magnetic fields above 0.3/0.4 mT may occur, [24]. It was proposed that the power frequency magnetic fields suppress the nocturnal production of melatonin in the pineal gland, which accounts for the observed increased risk of childhood leukemia. Substances reducing melatonin production are genotoxic because of the reduced antioxidant effect allowing free radicals to cause more genetic damage that not only increase the risk and incidence of cancer, but also increase the risk of cardiac, neurological and reproductive diseases and death, [25]. All the previous health hazards necessitate the use of a new material as back sheet for the diaper with reduced friction rub, in order to decrease the electro-magnetic field generated around the body of the infant.

In the present work, the electrostatic charge generated from the relative motion between surface of diaper sliding against floor as well as different types of textiles will be measured. Besides, friction coefficient will be investigated.

EXPERIMENTAL

Fig. 1 Electrostatic field measuring device.

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



The specimens, of polymeric textiles, have been prepared in strips of 100 mm width and 300 mm length. They have been fastened on the surface of wooden plate of 400 × 400 mm^2, Table 1. The back sheet of the diaper has been adhered to the wooden block of 50 × 50 mm^2. Tests were carried out at room temperature under varying loads up to 40 N. The sliding velocity has been controlled manually to be approximately to be 100 mm/sec. The sliding distance was 200 mm. Experiments were carried out by sliding the diaper test specimens against the textiles, skin and ceramic tiles. ESC was measured by DC voltmeter, while friction coefficient was determined by test rig shown in Fig. 2.

RESULTS AND DISCUSSIONS

The results, of experiments measuring friction coefficient and electric static charge at dry sliding of the tested diaper against cotton, polyester and wool textiles which represent the materials of the clothes as well as skin and ceramic tiles which represents the floor, are illustrated in Figs. 5 – 16. Friction coefficient is considered as the main factor in evaluation contacting materials. The measure of safety is the friction coefficient displayed between the back sheet of the diaper and the floor. As the friction coefficient increases, the safety of crawling and sitting on the floor increases. Friction coefficient displayed by dry sliding of diaper against ceramic tile is shown in Fig. 5. Friction coefficient slightly increases with increasing the load. The lowest friction value was 0.27 at 6 N load, while the maximum value was 0.33 at 38 N. The values of friction were not enough to prevent slip accidents.

ESC generated on the back sheet of the diaper from sliding against ceramic floor is shown in Fig. 6. The values ranged between 420 and 560 volts. As the load increased ESC charge decreased. This behaviour might be attributed to increase of the contact area with increasing load. ESC generated on the ceramic floor, Fig. 7, showed values ranging from 40 to 72 volts. ESC generated on diaper surface was much higher than that measured of ceramic tile. This observation can confirm the necessity to develop new materials to be applied as back sheet of the diaper of low ESC. The relatively low voltage values of generated on the floor can explain the decrease in the friction coefficient which critically depends on ESC. This behaviour can be explained on the

basis that, generation of ESC 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.

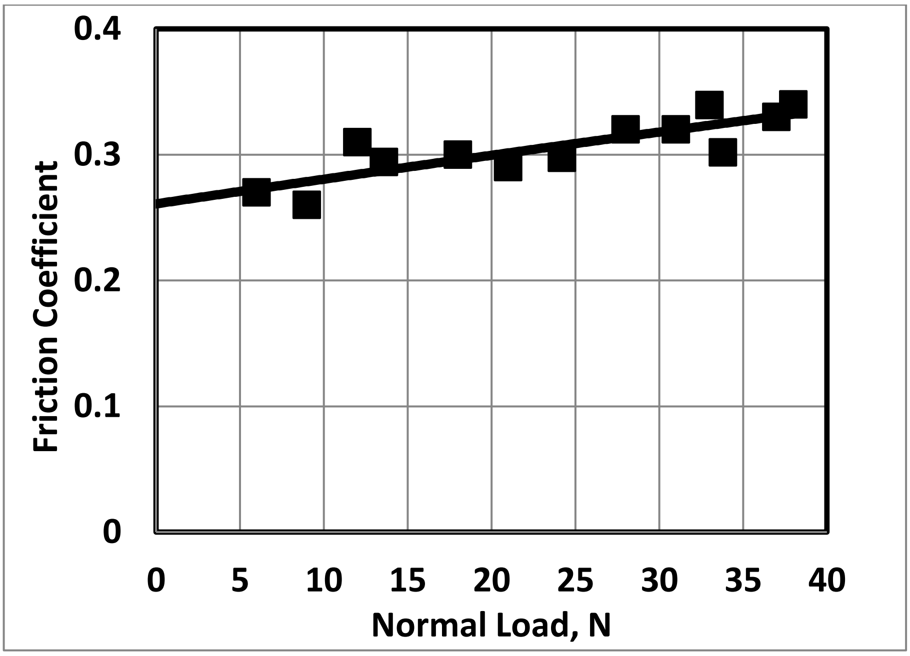


Fig. 5 Friction coefficient displayed by the sliding of diaper against ceramic tile.

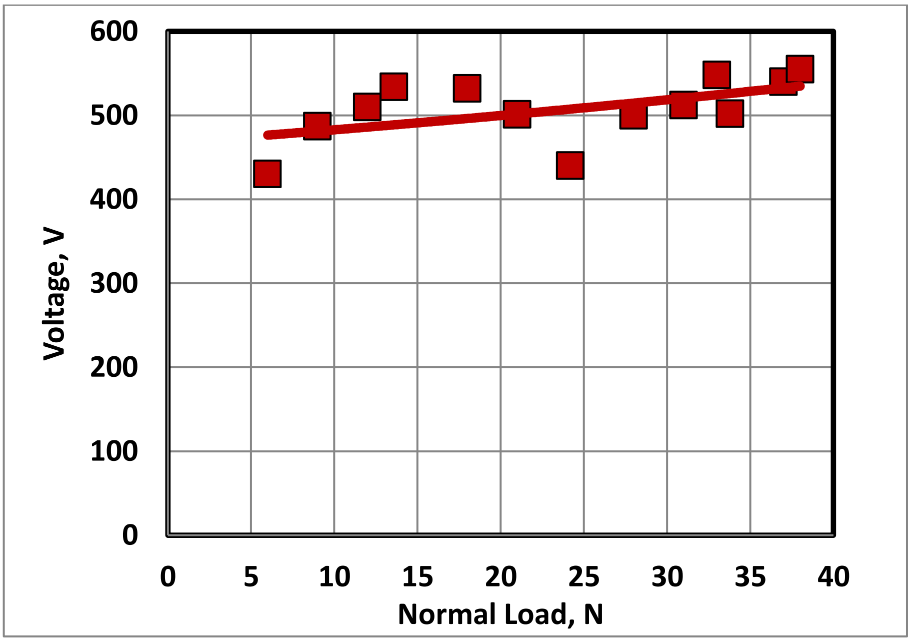


Fig. 6 ESC generated on the surface of the diaper sliding against ceramic tile.

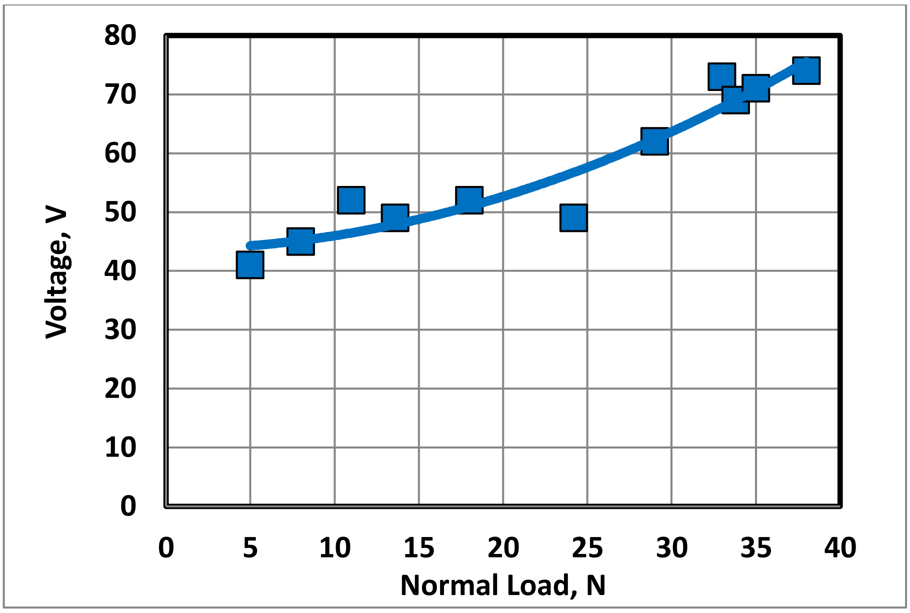


Fig. 7 ESC generated on the surface of the ceramic tile.

Sliding of the back sheet of the diaper against skin can give specific information about the triboelectrification of diaper material when the kid touches his diaper and when the adult carries the kid. Friction coefficient displayed by sliding of diaper against skin, Fig. 8, significantly increased with increasing normal load. It is necessary that friction coefficient should have reasonable values so that the slip of the hand of adult carrying the kid should be avoided to prevent accidents. The lowest and highest friction values were 0.21 and 0.49 at 6 and 38 N load respectively. The friction values at light loads do not guarantee the good adhesion of the skin and diaper.

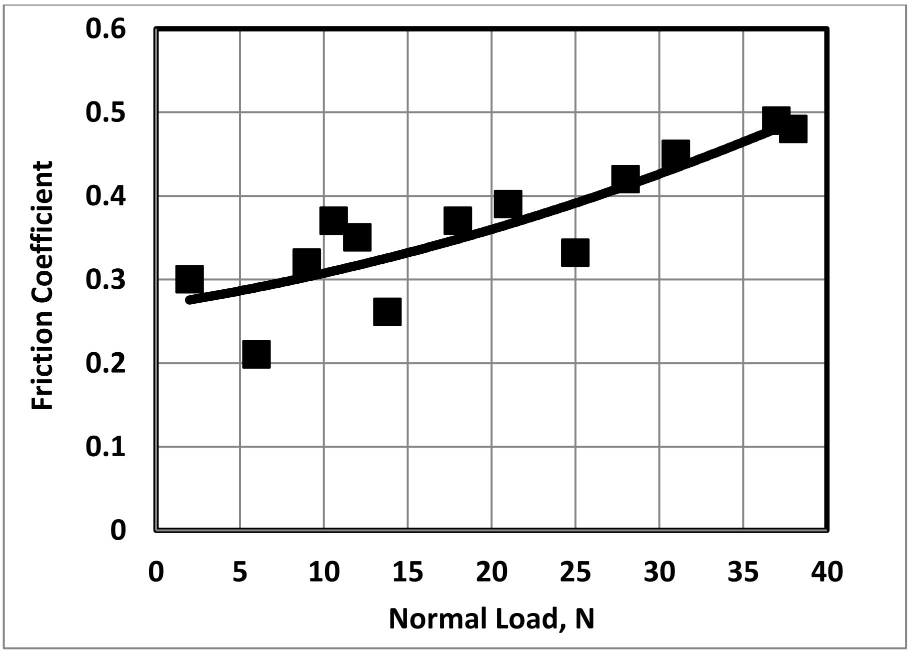


Fig. 8 Friction coefficient displayed by the sliding of diaper against skin.

It was observed that, ESC values were lower than that recorded for sliding against ceramic floor, the highest ESC values reached 500 volts at 38 N, Fig, 9. This behavior can be attributed to the fact that the skin is good conductor so that most of ESC leaked to the earth during

measurement. Voltage generated on the skin from its sliding against diaper is shown in Fig. 10. Voltage values were 21 and 61 volts at 6 and 38 N load respectively. This observation confirmed that, the amount of ESC depends on the load. It seems that, the low values of charge were from the ability of skin to conduct away the charge from the contact surfaces.

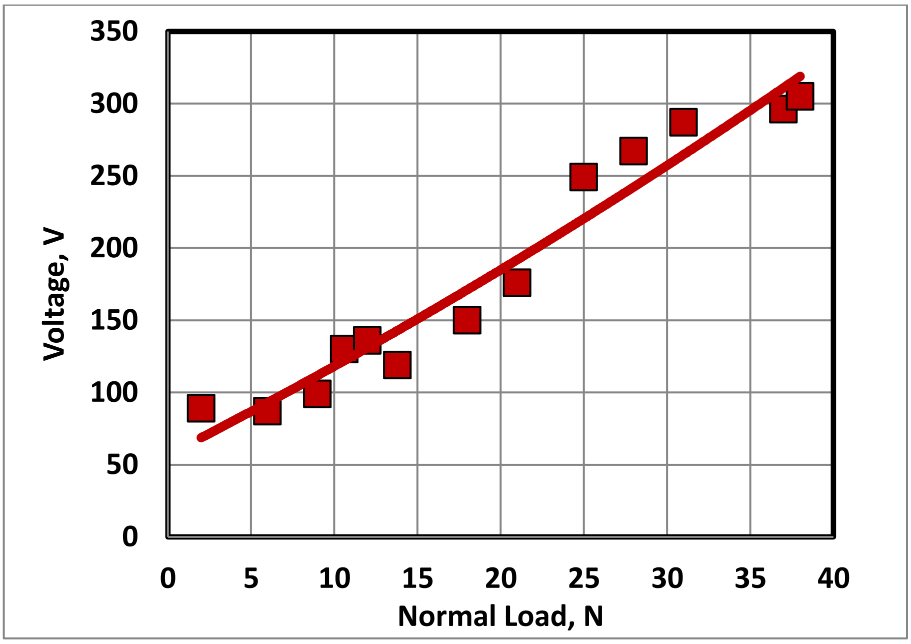


Fig. 9 ESC generated on the surface of the diaper sliding against skin.

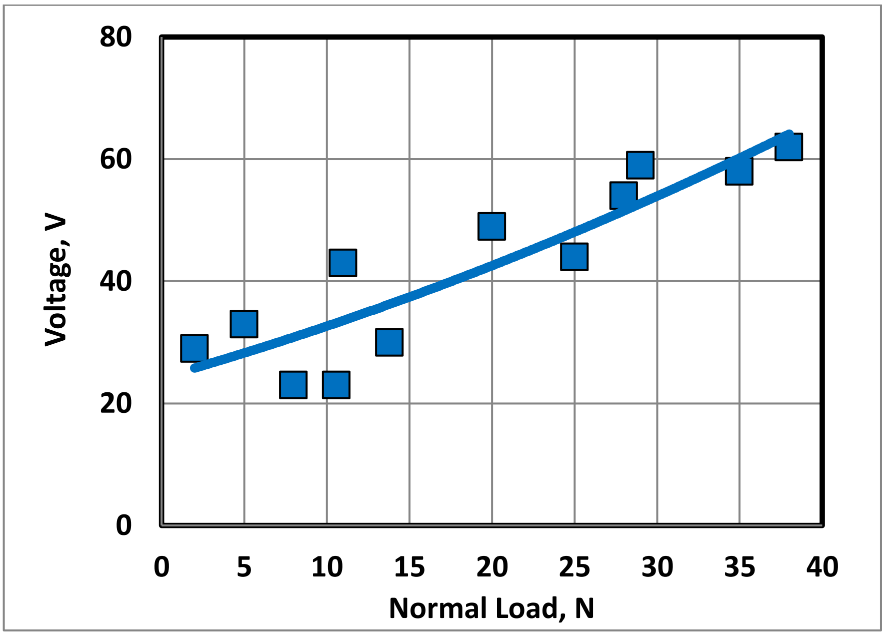


Fig. 10 ESC generated on the skin.

The results of experiments measuring friction coefficient and ESC at dry sliding of diaper against cotton textiles are illustrated in Figs. 11 – 13. Friction coefficient displayed by sliding of diaper against cotton textiles is shown in Fig. 9. Friction coefficient slightly decreased with increasing the load. The lowest friction value was 0.48, while the maximum value was 0.63. The values of friction were higher than that observed for skin and ceramic tiles. The friction values at light loads satisfied the European standards for safe use at dry sliding condition, where the safety increased with increasing applied load. The luxury of textiles depends on the slipperiness and smoothness. The touch by the human skin is considered an important factor that qualifies the use of textiles, [18 - 20]. Friction coefficient specifies the slipperiness or smoothness of the textiles. It seems that, as the load increases the pressure applied on the fibre fringes increases, flattens the fringes and makes their surface smoother. In consequence, friction coefficient decreases,

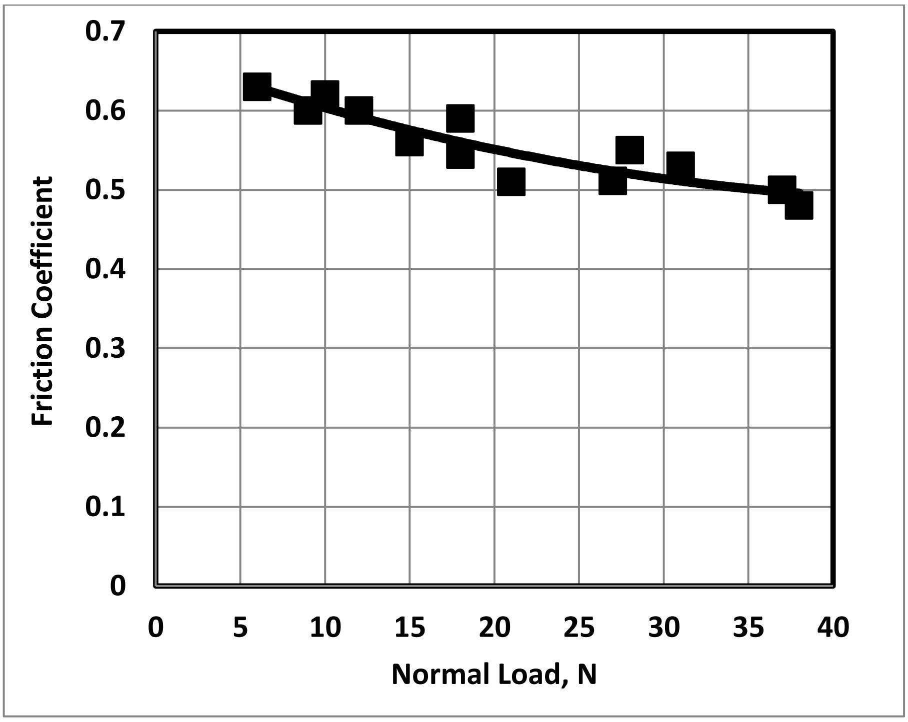


Fig. 11 Friction coefficient displayed by the sliding of diaper against cotton textiles.

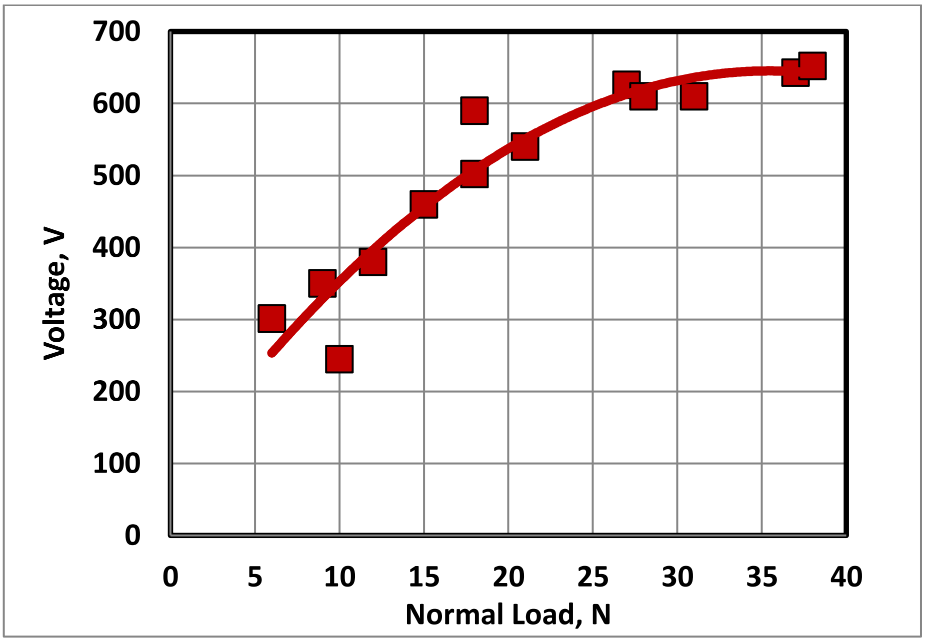


Fig. 12 ESC generated on the surface of the diaper sliding against cotton textiles.

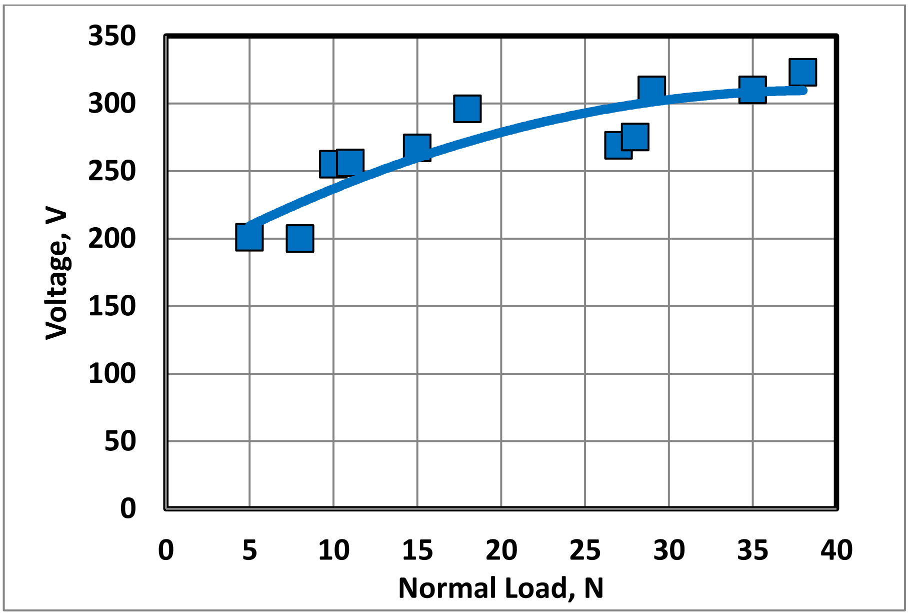


Fig. 13 ESC generated on the cotton textiles.

ESC generated on the surface of the diaper sliding against cotton textiles is shown in Fig. 12. The values were ranged between 230 and 640 volts. As the load increased the voltage increased. This behaviour might be attributed to the increase of the contact area as the load increased. The voltage generated at cotton textiles, Fig. 13, showed values ranging from 200 to 330 volts. As the load increased, voltage remarkably increased due to the increased interference between the diaper and cotton, where the charge generation became easier. Due to the nature of the voltage, the scatter in the values measured during experiments was relatively high.

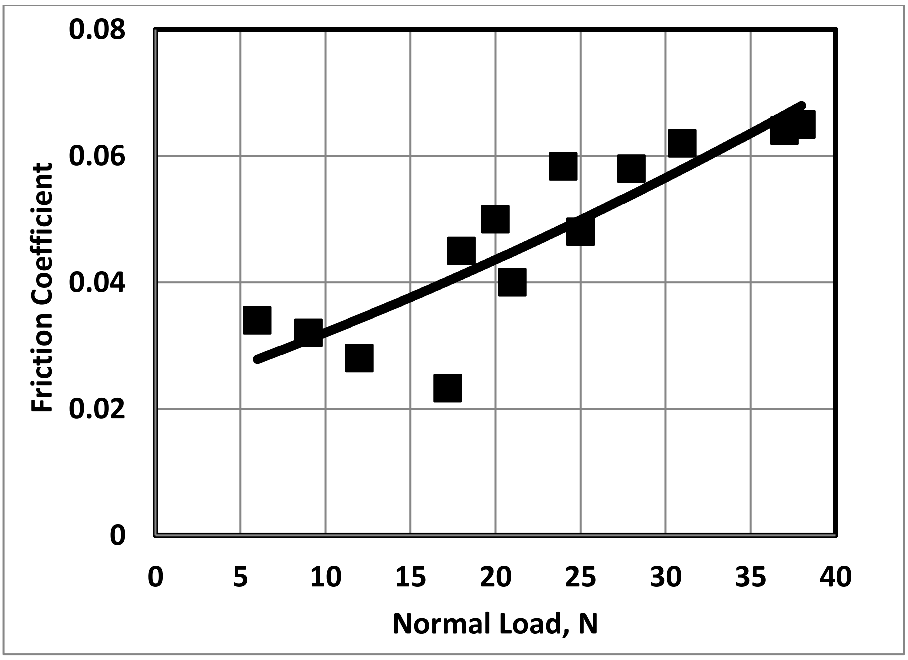


Fig. 14 Friction coefficient displayed by the sliding of diaper against polyester textiles.

Friction coefficient displayed by the sliding of diaper against polyester textiles, Fig. 14, displayed very low values, where the highest value did not exceed 0.062. The values of friction were lower than that observed for the above mentioned tested materials. The risk of accident slip increases due to that observation.

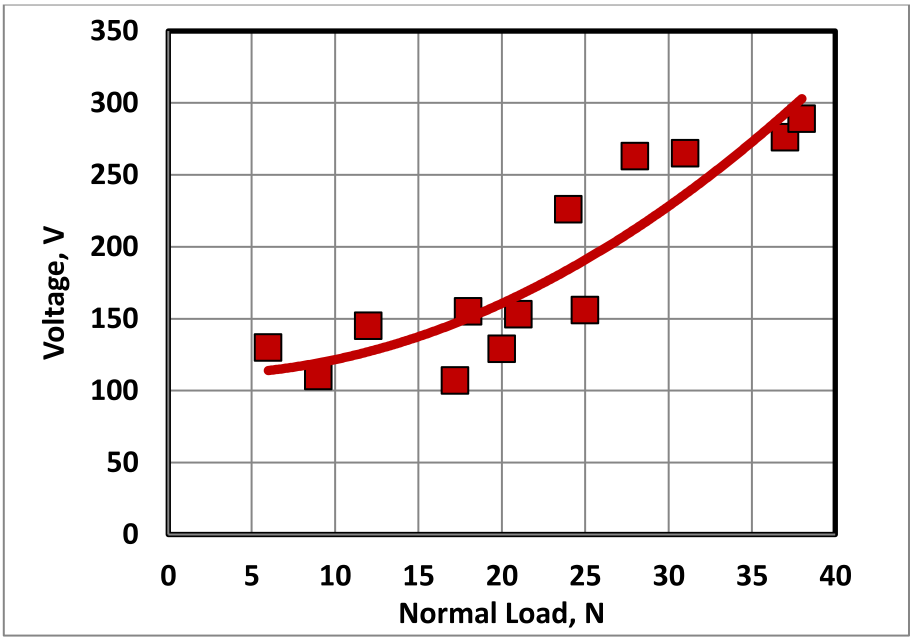


Fig. 15 ESC generated on the surface of the diaper sliding against polyester textiles.

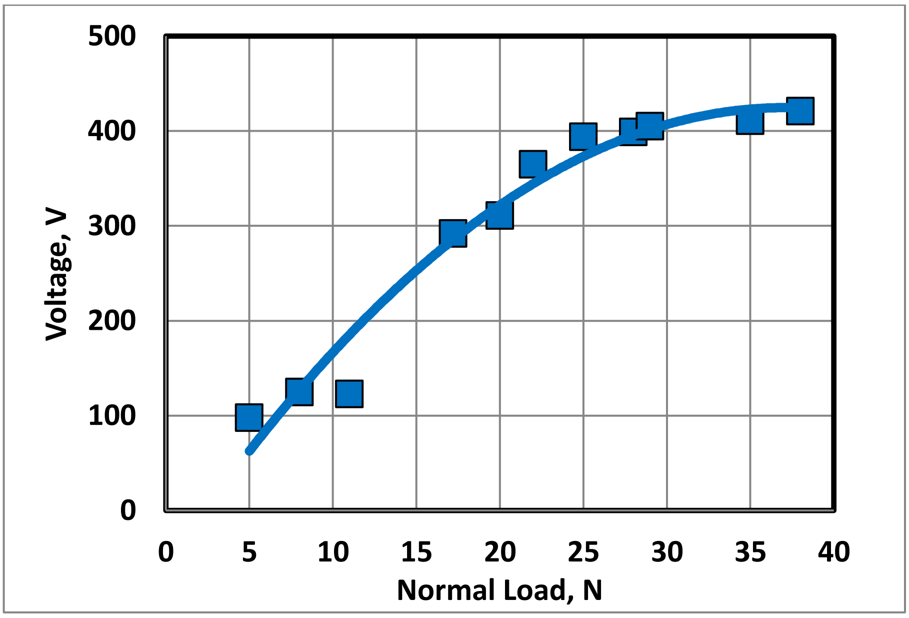


Fig. 16 ESC generated on the surface of the polyester textiles.

It is observed that, ESC value was lower than that recorded for cotton, skin and ceramic tiles, Fig. 15. When two materials contact each other, as the difference, in the rank of the two materials in the triboelectric series, increases the generated voltage increases. It is therefore necessary to select the materials based on their triboelectric charging. ESC

generated on the surface of the polyester textiles is shown in Fig. 16. ESC values were 100 and 420 volts at 5 and 38 N load respectively.

The results of experiments measuring friction coefficient and ESC for the sliding of diaper against wool textiles are illustrated in Figs. 17 – 19. Friction coefficient displayed by sliding of diaper against wool textiles is shown in Fig. 17, where friction coefficient slightly increased with increasing the load. The lowest friction value was 0.29, while the maximum value was 0.43. The values of friction were lower than that observed for cotton and higher than that observed for polyester.

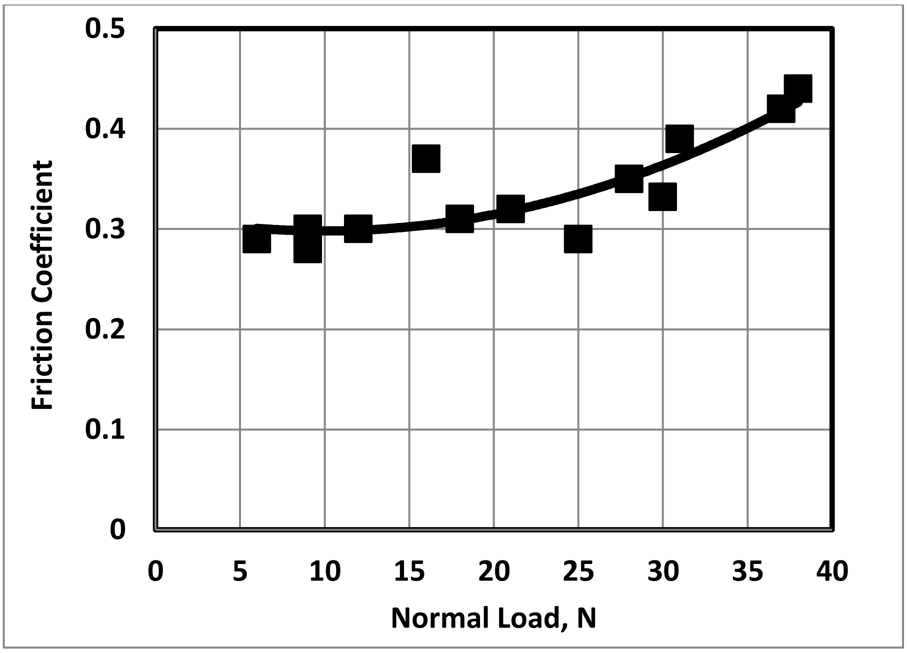


Fig. 17 Friction coefficient displayed by the sliding of diaper against wool textiles.

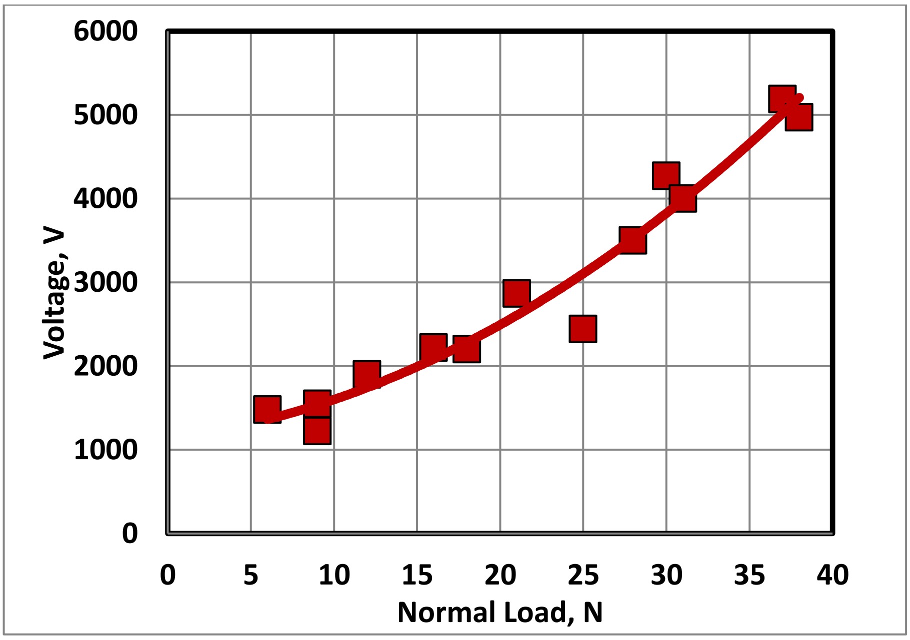


Fig. 18 ESC generated on the surface of the diaper sliding against wool textiles.

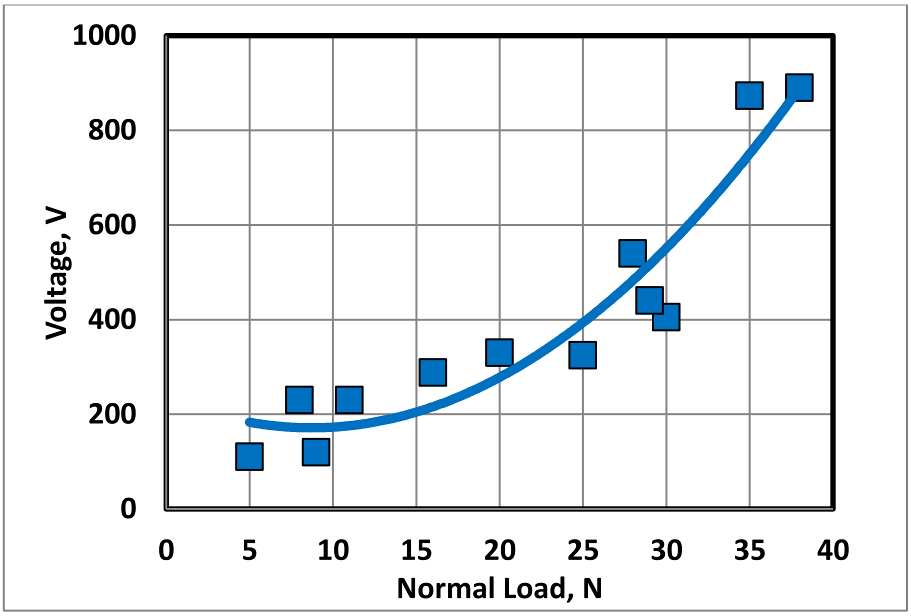


Fig. 19 ESC generated on the wool textiles.

Voltage generated on the back sheet of the diaper from its sliding against wool textiles is illustrated in Fig. 17. Voltage values recorded the highest values ranging from 1200 and 5200 volts at 8 and 37 N load respectively. This observation confirms that, the intensity of voltage depends on the load. The high values of ESC reflect the severity of ESC values when the kid wears woolen clothes contacting the back sheet of the diaper. Based on that observation, it is recommended to avoid the use of the material of the back sheet of the diaper and propose alternative materials of low ESC. Also, ESC generated on the wool textiles showed relatively high values reached to 820 volts at 38 N, Fig. 18. ESC gained by the diaper can migrate to the kid body. After more rubbing, the clothes gain more charge. Then ESC moves to the air by sparking or by flowing to earth if the charged volume touches ground.

CONCLUSIONS

1. Friction coefficient displayed by dry sliding of diaper against ceramic tile slightly increases with increasing the load. The values of friction were not enough to prevent slip accidents. ESC generated on the back sheet of the diaper from sliding against ceramic floor ranged between 420 and 560 volts. As the load increased ESC charge decreased. ESC generated on diaper surface was much higher than that measured of ceramic tile.

2. Friction coefficient displayed by sliding of diaper against skin significantly increased with increasing normal load. The friction values at light loads do not guarantee the good adhesion of the skin and diaper. It is necessary that friction coefficient should have reasonable values so that the slip of the hand of adult carrying the kid should be avoided to prevent accidents. ESC values were lower than that recorded for sliding against ceramic floor.

3. Friction coefficient displayed by sliding of diaper against cotton textiles was higher than that observed for skin and ceramic tiles. ESC values were ranged between 230 and 640 volts, while ESC generated at cotton textiles showed values ranging from 200 to 330 volts.

4. Friction coefficient displayed by the sliding of diaper against polyester textiles displayed very low values, where the highest value did not exceed 0.062. The risk of accident slip increases due to that observation. ESC value was lower than that recorded for cotton, skin and ceramic tiles.

5. Friction coefficient displayed by sliding of diaper against wool textiles was lower than that observed for cotton and higher than that observed for polyester. ESC recorded the highest values ranging from 1200 and 5200 volts at 8 and 37 N load respectively. The high values of ESC reflect the severity of ESC values when the kid wears woolen clothes contacting the back sheet of the diaper. Based on that observation, it is recommended to avoid the use of the material of the back sheet of the diaper and propose alternative materials of low ESC.

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