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FRICTION BEHAVIOR OF CARBON FIBRES REINFORCED EPOXY FLOOR COATED BY POLYURETHANE

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ABSTRACT
The present work discusses the effect of reinforcing epoxy by carbon fibres (CF) and coated by polyurethane on the generation of electrostatic charge (ESC) from contact and separation as well as sliding when bare foot and foot wearing rubber contacting epoxy. The relationship between ESC and friction coefficient will be discussed.

It was found that contact and separation as well as sliding of the tested composites against rubber showed that epoxy surface gave the highest ESC followed by PU. The same trend was observed for friction coefficient especially at higher loads. Based on the quantification of floor slip-resistance, the static friction coefficient of 0.5 has been recommended as the slip resistant standard for normal walking conditions. For all the tested composites, friction coefficient fulfills that recommendation at relatively higher loads, which confirms that the floor made of the tested composites will be very safe for walking. Concerns should be directed to the amount of ESC generated during contact and separation as well as sliding of the tested materials against both bare foot and rubber footwear.

KEYWORDS
Friction coefficient, bare foot, rubber footwear, epoxy reinforced by carbon fibres, polyurethane coating, electrostatic charge.

INTRODUCTION

Friction of footwear on floor coverings is responsible of the occurrence of slips and falls. Floor slip-resistance is quantified by the static friction coefficient. In the USA, the static friction coefficient of 0.5 has been recommended as the slip-resistant standard for unloaded, normal walking conditions [1]. Higher the static friction coefficient values may be required for safe walking when handling loads. In Europe, [2], it was suggested that a floor was ''very slip-resistant'' if the friction coefficient was 0.3 or more. The subjective ranking of floor slipperiness was compared with the static friction coefficient (μ) and found that the two measures were consistent, [3, 4]. It was concluded that human

subjects could discriminate floor slipperiness reliably. Many state laws and building codes have established that a static μ ≥ 0.50 represents the minimum slip resistance threshold for safe floor surfaces. Furthermore, the Americans with Disabilities Act Accessibility Guidelines [5] contain advisory recommendations for static friction coefficient of μ ≥ 0.60 for accessible routes (e.g. walkways and elevators) and μ ≥ 0.80 for ramps.

Friction coefficient of rubber sliding against different indoor floor materials of different surface roughness was investigated under the following conditions: dry, water, water and soap, oil, water and oil, [6 - 12]. It was found that, at dry sliding, the friction coefficient decreased with increasing surface roughness and applied load. At water lubricated sliding, the friction coefficient increased up to maximum then decreased with increasing surface roughness. Maximum friction values were observed at surface roughness ranging from 1.5 and 2.0 μm Ra. At water–soap lubricated sliding, the friction coefficient drastically decreased with increasing the surface roughness. At oil lubricated sliding, the maximum friction values were noticed at 4.0 μm Ra surface roughness. At water and oil lubricated sliding, smooth floor surface displayed very low values of friction coefficient (0.08) close to the ones observed for mixed lubrication where the two sliding surfaces are partially separated by a fluid film. Glazed floor tiles, Fig. [13], of different roughness ranging from 0.05 to 6.0 μm were tested. The test results showed that, friction coefficient decreased down to minimum then increased with increasing the surface roughness of the ceramic surface. Recycled rubber mats filled by polyurethane of different hardness showed the highest friction in all the sliding conditions, [14]. Surface roughness had insignificant effect on the frictional behavior, 15]. Friction coefficient slightly increased with increasing the tile thickness. For tested tiles wetted by water and contaminated by sand particles, rough surface displayed relatively higher friction than smooth one. Hard floors such as marble and ceramic showed friction increase with increasing surface roughness, [16]. Parquet and cement tiles showed the highest friction. In the presence of water on the sliding surface, rough surface displayed higher friction values than the smooth one, [17]. Friction coefficient increased for rough surface and decreased for smooth one with increasing the tile thickness when the contact surfaces are covered by sand particles.

Static friction coefficient displayed by rubber disc fitted by single groove sliding against ceramics was investigated, [18 – 21]. For soft rubber, load had no effect on the values of friction coefficient. It was found that, at dry sliding, dust particles caused drastic decrease in friction coefficient, [22]. In this condition, it is recommended to use circular protrusion in the rubber surface. Water wet square protrusions are recommended to have relatively higher friction values. For surfaces lubricated by detergent and soap, flat rubber embedded by dust particles gave higher friction than surfaces of protrusions, while dust particles embedded in rubber lubricated by oil showed higher friction values. Circular protrusions gave higher friction than flat and square protrusions. The effect, of rectangular and cross treads introduced in the rubber mats on friction coefficient when sliding against footwear, was investigated, [23]. It was found that friction coefficient displayed slightly decreased with increasing tread groove at dry, detergent wetted and oily sliding due to the decreased contact area accompanied to the increased groove width

of the rubber. At water wetted sliding friction coefficient remarkably increased with increasing the tread groove. As the tread width decreased the friction values decreased due to the decrease of the contact area. At sliding against water wet floor, friction coefficient significantly increased with increasing both of the width of the tread and the groove due to the easier water escape from the contact area, where the groove volume was relatively higher. The friction behavior, of ceramic tiles as floor materials when soft and hard rubbers slide against them, was described, [24]. At dry and wet sliding, soft rubber slid against ceramic tiles showed higher friction coefficient than hard one. The difference might be attributed to the extra deformation offered by soft rubber. The porous recycled rubber tiles were inspected to be used for architectural applications as floor tiles, [25]. It was found that friction coefficient displayed by bare foot sliding against dry recycled rubber tiles slightly increased with increasing force reduction ratio. It seems that the presence of pores inside the rubber matrix is responsible for the extra deformation displayed by the porous recycled rubber and consequently the contact area between the foot and the tested floor materials increased. When rubber shoe slid against dry rubber tiles friction coefficient significantly increased with increasing the force reduction ratio due to the increased deformation of the rubber tiles. The effect, of the hardness and thickness of recycled rubber floor tiles on the friction coefficient when sliding against the rubber sole, was tested, [26]. Based on the experimental observations, it was found that friction coefficient, displayed by sliding of rubber sole against dry floor tiles, drastically decreased with increasing the hardness of the tested floor tiles, while increased with increasing normal load.

The increase of polymeric materials in floors industry necessitates the study of their triboelectrification during friction. Experiments were carried out to measure the ESC and friction coefficient of bare foot and rubber footwear sliding against epoxy and polyvinyl chloride (PVC) floors were investigated under dry sliding condition, [27]. ESC generated from the sliding of rubber footwear against PVC floor displayed higher values than epoxy floor. Rubber footwear sliding against epoxy floor displayed consistent trend of friction coefficient with increasing load. The highest friction coefficient value was 0.86, while the lowest was 0.58. Sliding against PVC floor experienced lower friction coefficient than that observed on epoxy one. The highest friction value reached 0.82, while the lowest was 0.4. The effect of hardness and thickness on ESC generated from the sliding of the rubber sole against recycled rubber tiles was studied, [28]. Voltage decreased with increasing the hardness. At sand contaminated sliding, soft tiles showed very high voltage values. Voltage generated significantly increased with increasing the thickness of the tested tiles. The effect, of floor materials on the generation of ESC and friction coefficient, was discussed, [29]. Based on this observation it can be suggested to select floor materials according to their resistance to generate electric static charge.

The influence of heat treatment processes such as annealing, tempering and quenching on friction coefficient and wear resistance of polyurethane coatings were investigated, [30]. Polyurethane coating of double layers showed the lowest friction coefficient values compared to single and triple layers. Quenched coatings represented the highest values, while annealed ones showed the lowest ones. Annealed coatings showed the lowest wear. Wear displayed by triple layers (0.8 mm) polyurethane represented the lowest values

compared to single and double layers coatings. Annealed coatings showed the lowest wear values. Polyurethane coatings reinforced by copper wires were proposed to defeat erosion wear of surfaces such buildings and tanks by sand during dusty storms. It was found that erosion wear decreases with increasing wire diameter, where the wire strengthens the eroded area. Besides, minimum value of wear of polyurethane coating reinforced by copper wires is observed when the substrate was coated by two layers, [31]. Sand erosion of steel sheets coated by polyurethane and reinforced by steel wires of different diameters was discussed, [32, 33]. The tested polyurethane composite coatings are proposed to defeat sand erosion during dusty storms. Experiments have been carried out using sand blast test rig. The experimental results showed that wear of polyurethane coatings reinforced by steel wires decreased drastically with increasing wire diameter due to the strengthening effect of the steel wires. When the distance between the wires decreased, wear decreased. As the polyurethane coating thickness increased, wear increased. Besides, wear of polyurethane reinforced by gridded steel wires decreased with increasing wire diameter. At lower values of wire diameter, wear recorded relatively lower values than that displayed by longitudinal wires. It seems that gridded wire reinforcement strengthened the coating and increased the bonding force between polyurethane and steel wires. Sand erosion of steel sheets coated by polyurethane and reinforced by nickel chrome (Ni Cr) wires of different diameters was investigated.

The aim of the present work is to investigate the effect of ESC generated from the contact and separation as well as the sliding of bare foot and rubber footwear against epoxy floor reinforced by carbon fibres and coated by polyurethane on friction coefficient.

EXPERIMENTAL

Experiments were carried out using test rig which shown in Fig. 1. It consists, mainly, of two load cell one places in horizontal position and other places in vertical position (horizontal load cell measured normal load while vertical one measured friction load). Also it consists of upper base that will covered by the flooring surface, and lower base used to make test rig fixed on floor and not move during test running. Two monitors are connected to two load cell for reading normal and friction force.

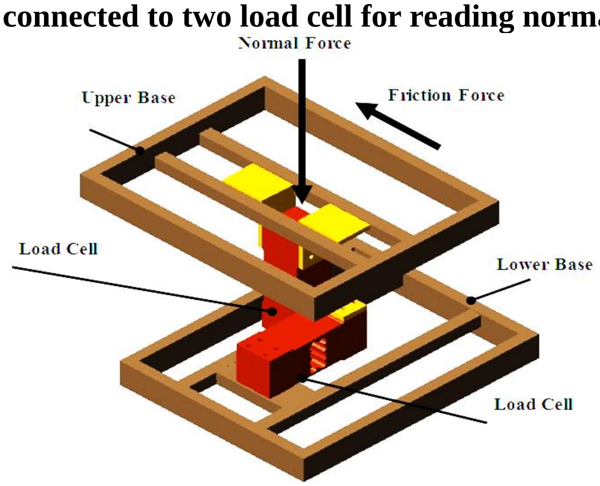

Fig. 1 Details of the test rig.

Fig. 2 ESC measurement device.

The effect of the tested parameters on friction coefficient of epoxy reinforced by carbon fibres (CF) and coated by polyurethane of 0.5 mm thickness has been investigated. Epoxy test specimens have been prepared in the form of square sheets of 50 × 50 mm. The values of CF content used in experiment are 0, 2, 4, 6, 8 wt. % as illustrated in Fig. 3. ESC measurement has been carried out. First, epoxy specimens have been adhered on wooden block then cleaned to eliminate any dirt and dust and carefully dried before the test. The epoxy test specimens have been loaded against human skin and rubber at contact and separation as well as sliding conditions. During test running, horizontal and vertical load cell connected to two monitors read normal and friction load respectively. Friction coefficient is the ratio between friction and normal load. By taking five values for each test the values of friction coefficient can be calculated.

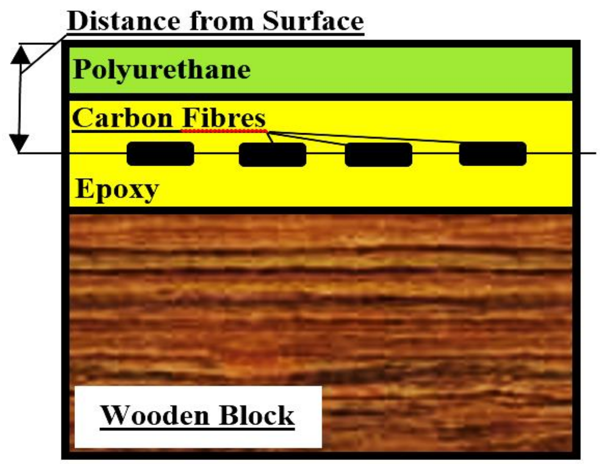

Fig. 3 Epoxy test specimens with different CF contents.

The effect of the tested parameters on friction coefficient of epoxy reinforced by carbon fibres (CF) such as content and distance from epoxy surface and coating of epoxy by polyurethane has been investigated. Epoxy test specimens have been prepared in the form of square sheets of 50 × 50 mm. The values of CF content used in experiment are 0, 2, 4, 6, 8 wt. % as illustrated in Fig. 3. ESC measurement has been carried out. First, epoxy specimens have been adhered on wooden block then cleaned to eliminate any dirt and dust and carefully dried before the test. The epoxy test specimens have been loaded against human skin and rubber at contact and separation as well as sliding conditions. During test running, horizontal and vertical load cell connected to two monitors read normal and friction load respectively. Friction coefficient is the ratio between friction and normal load. By taking five values for each test the values of friction coefficient can be calculated.

RESULTS AND DISCUSSION

The results of experiments measuring ESC are illustrated in Figs. 4 – 6. ESC generated on the surfaces of the tested composites coated by polyurethane (PU) from its contact and separation with bare foot recorded higher values than that shown by epoxy surface. Voltage values were 205 and 240 volts at 40 and 160 N load respectively. This observation confirms that, the intensity of ESC depends on load. It is clearly shown that,

increasing CF caused significant ESC increase. Increasing normal load increased ESC due to increasing contact area. Slight difference was observed in ESC values recorded at 1.0 and 5.0 mm distance from the friction surface.

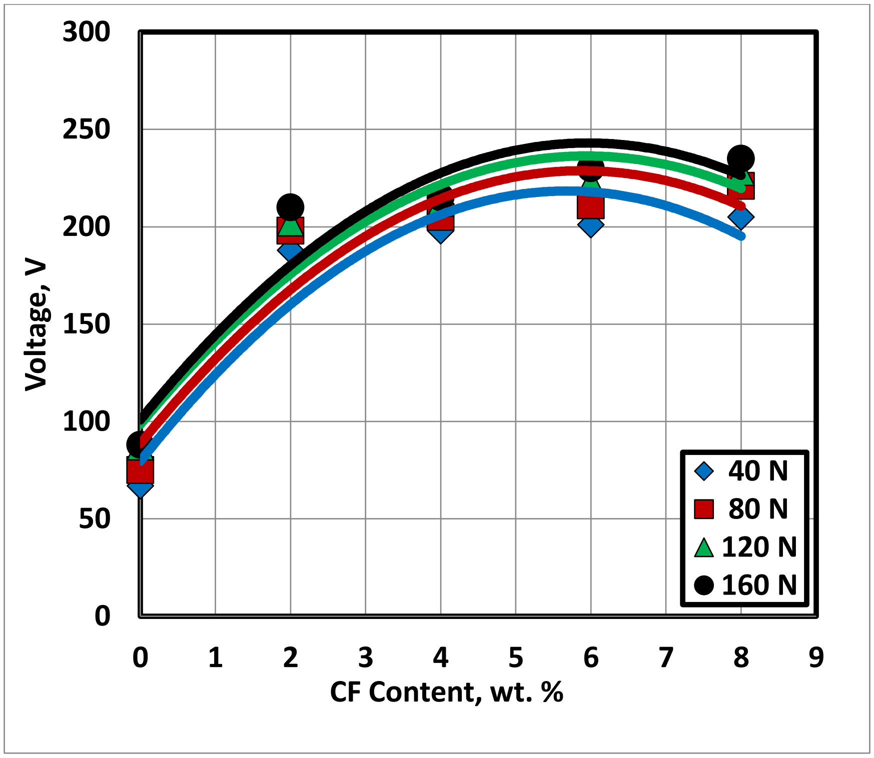

Fig. 4 ESC generated from contact and separation of bare foot and test specimens at 1 mm close to the surface.

ESC generated on the PU coated test composites from sliding against bare foot is shown in Figs. 7 and 8. ESC values increased up to 1280 volts. As the load increased ESC increased. This behaviour might be attributed to increase of the contact area with increasing load. Sliding of PU against bare foot generated much higher ESC than that observed in contact and separation measured on PU surface. This observation can confirm the necessity to develop new materials to be used as floor coating of low ESC. The relatively high ESC values is attributed to the difference in the rank of the bare foot and PU that increases the generated ESC. It is known that bare foot is ranked above PU, so that bare foot was positively charged and the gap is relatively long in the triboelectric series which increases ESC difference. It is therefore necessary to select the materials based on their triboelectric ranking. Drastic decrease in ESC was observed as the distance of CF from friction surface increased as shown in Fig. 9.

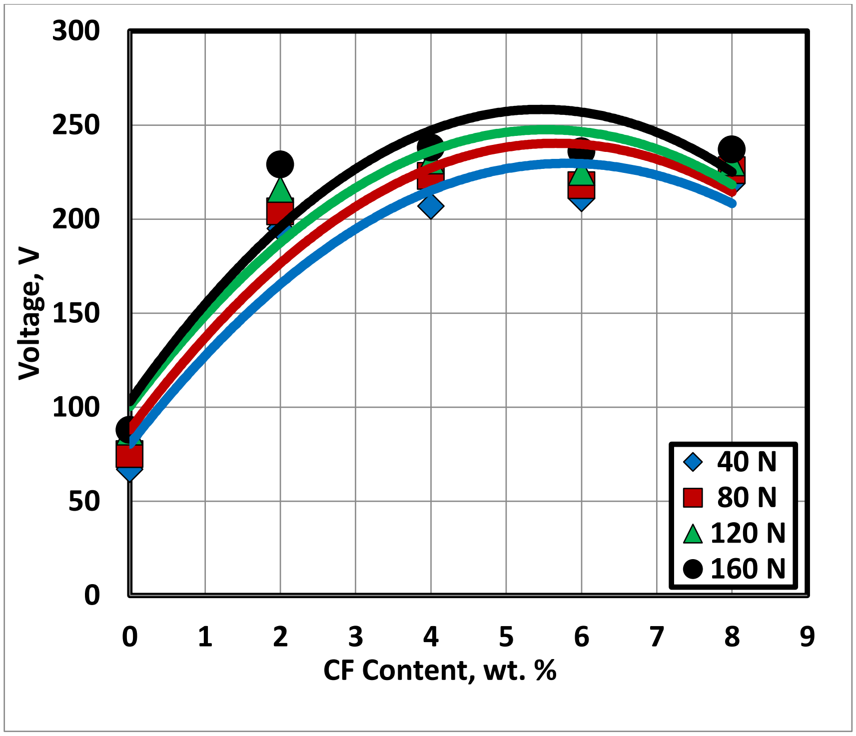

Fig. 5 ESC generated from contact and separation of bare foot and test specimens at 5 mm close to the surface.

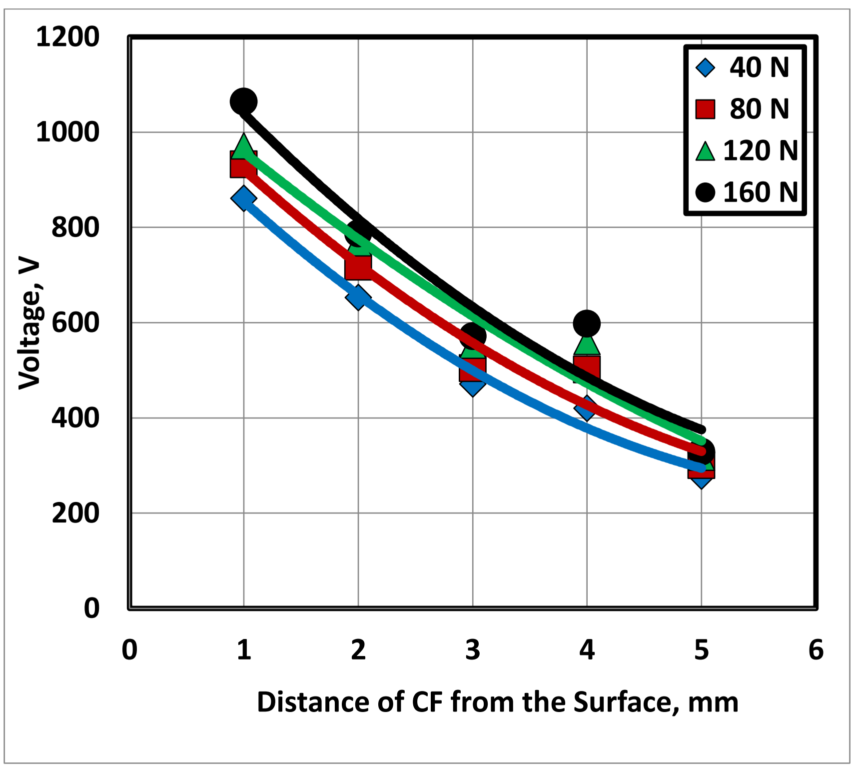

Fig. 6 Effect of the distance of CF from the surface on the electrostatic charge generated from contact and separation of bare foot and test specimens.

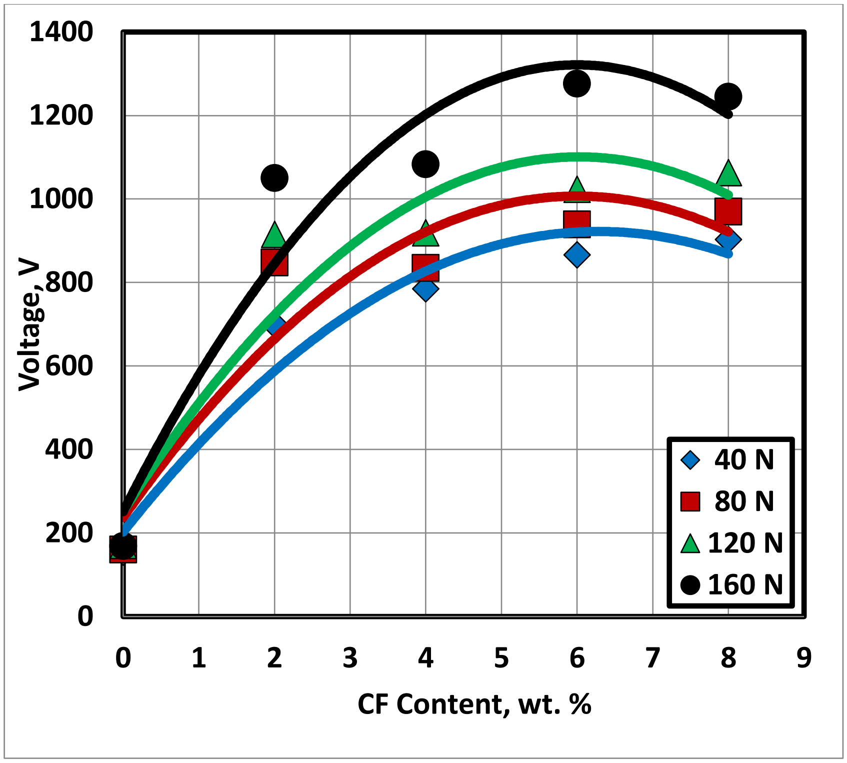

Fig. 7 ESC generated from sliding of bare foot and test specimens at 1 mm close to the surface.

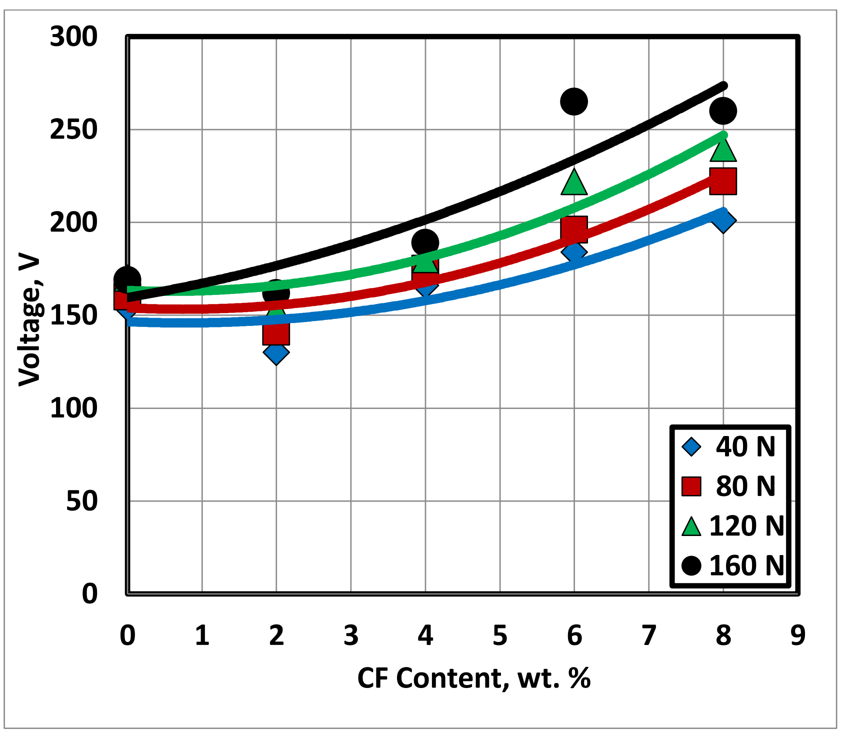

Fig. 8 Electrostatic charge generated from sliding of bare foot and test specimens at 5 mm close to the surface.

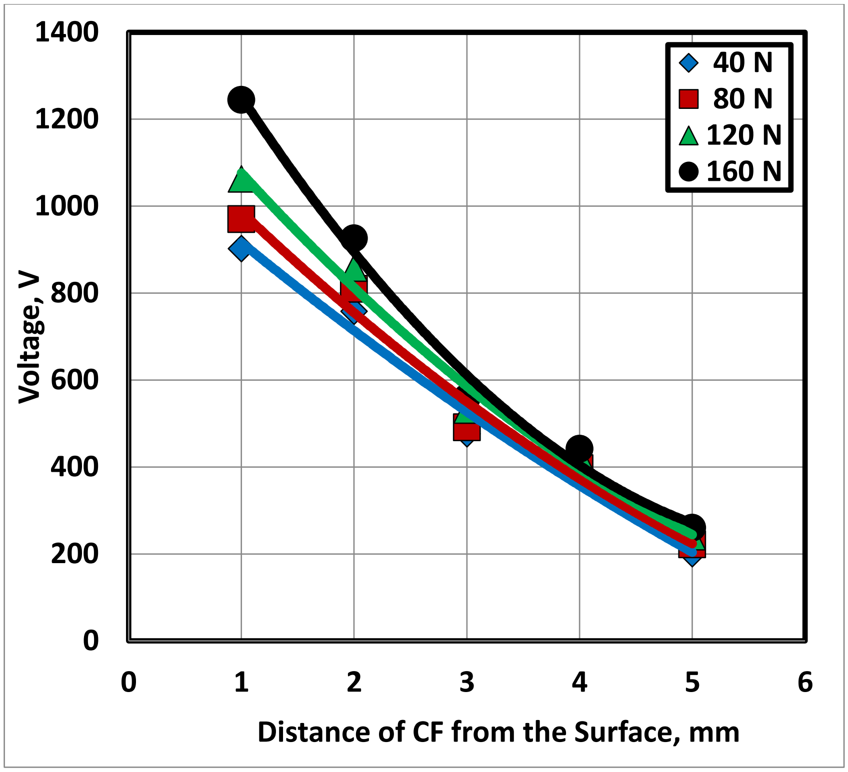

Fig. 9 Effect of the distance of CF from the surface on the ESC generated from sliding of bare foot and test specimens.

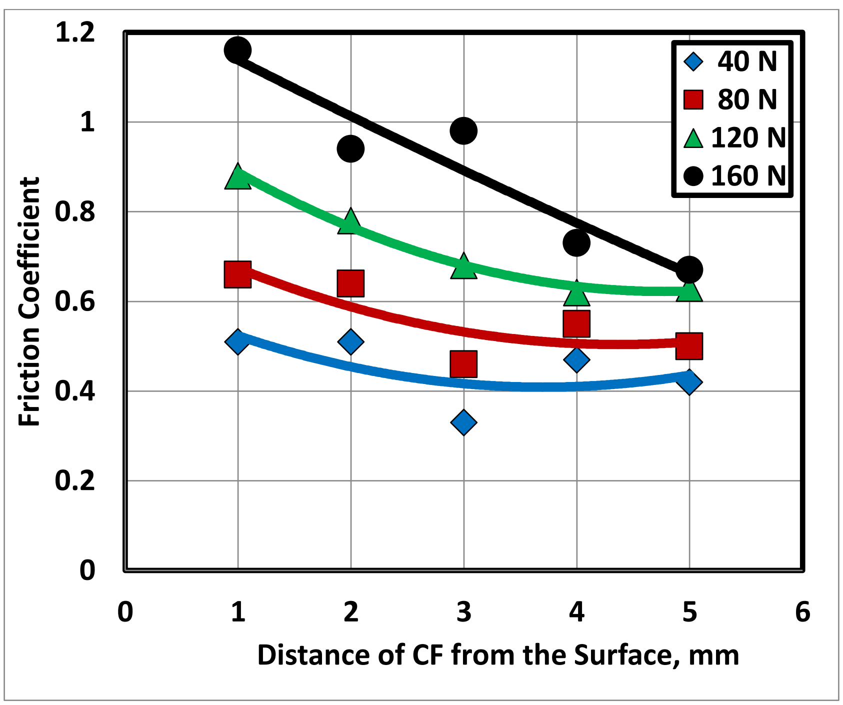

Fig. 10 Effect of the distance of CF from the surface on friction coefficient for sliding condition generated between bare foot and test specimens.

ESC generated on the PU coated test composites from sliding against bare foot is shown in Figs. 7 and 8. ESC values increased up to 1280 volts. As the load increased ESC increased. This behaviour might be attributed to increase of the contact area with increasing load. Sliding of PU against bare foot generated much higher ESC than that observed in contact and separation measured on PU surface. This observation can confirm the necessity to develop new materials to be used as floor coating of low ESC. The relatively high ESC values is attributed to the difference in the rank of the bare foot and PU that increases the generated ESC. It is known that bare foot is ranked above PU, so that bare foot was positively charged and the gap is relatively long in the triboelectric series which increases ESC difference. It is therefore necessary to select the materials based on their triboelectric ranking. Drastic decrease in ESC was observed as the distance of CF from friction surface increased as shown in Fig. 9.

The results of experiments carried out to measure friction coefficient displayed by PU coated tested composites sliding against bare are illustrated in Fig. 10, where friction values drastically decreased with increasing the distance of CF from the surface. Based on the quantification of floor slip-resistance, the static friction coefficient of 0.5 has been recommended as the slip resistant standard for normal walking conditions. For load value higher than 80 N, friction coefficient exceeded 0.5, which confirmed that the floor made of the tested composites will be safe for walking.

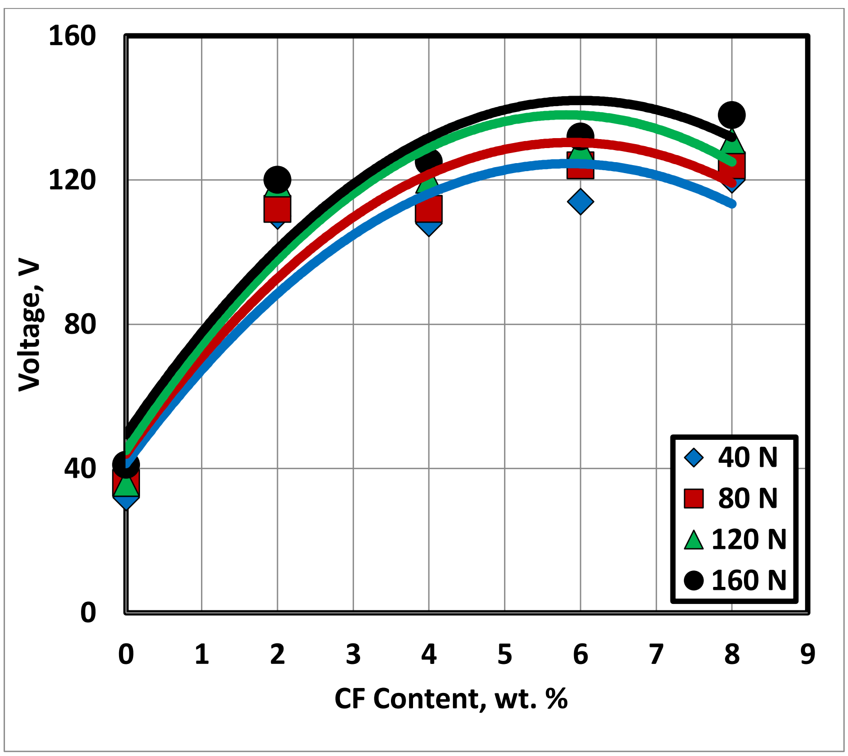

Fig. 11 ESC generated from contact and separation of rubber and test specimens at 1 mm close to the surface.

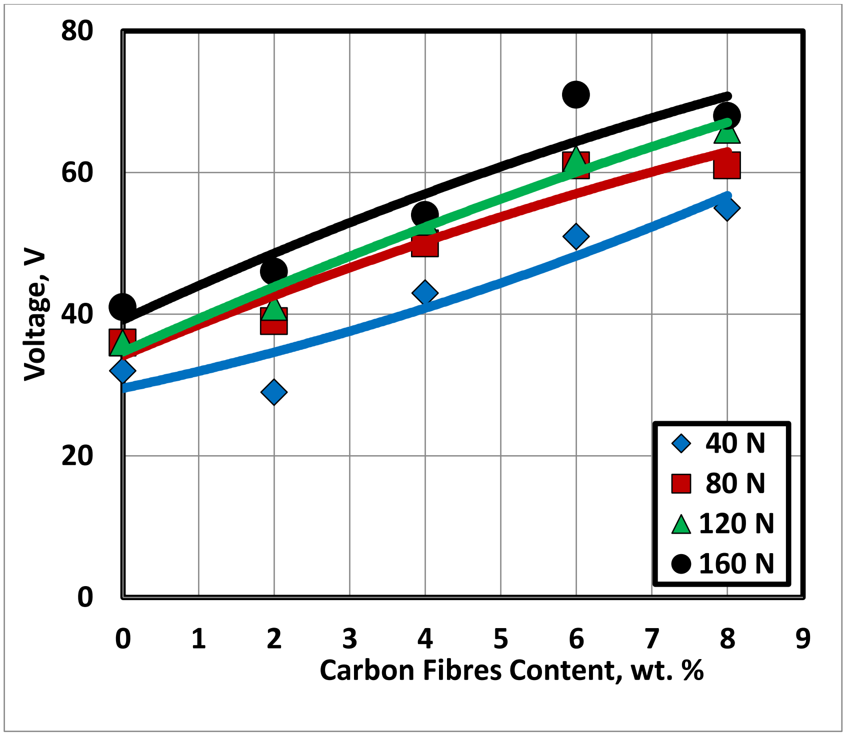

Fig. 12 ESC generated from contact and separation of rubber and test specimens at 5 mm close to the surface.

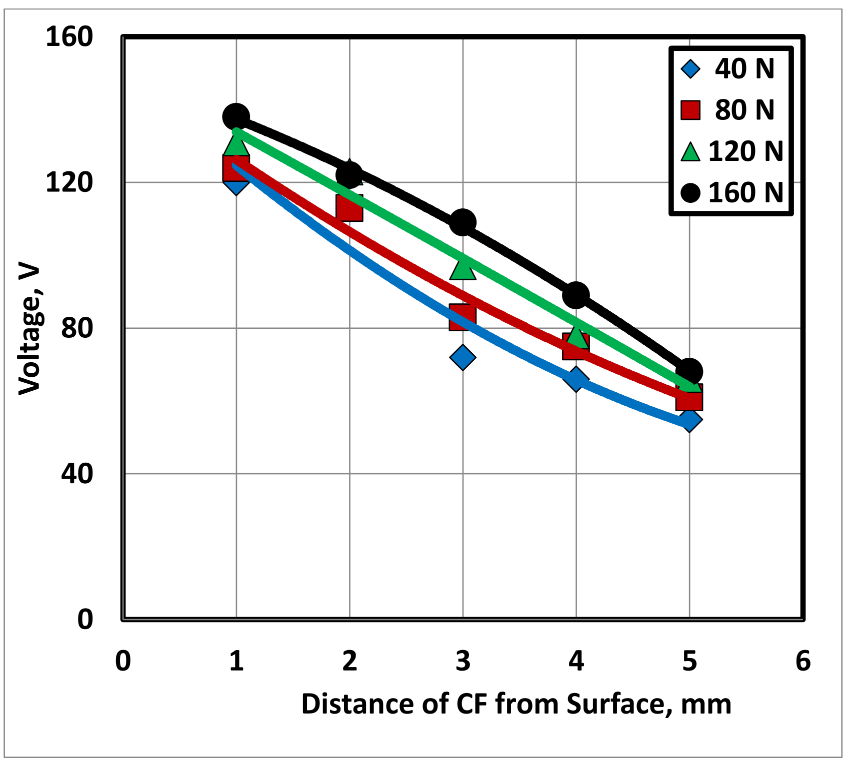

Fig. 13 Effect of the distance of CF from the surface on the ESC generated from contact and separation of rubber and test specimens.

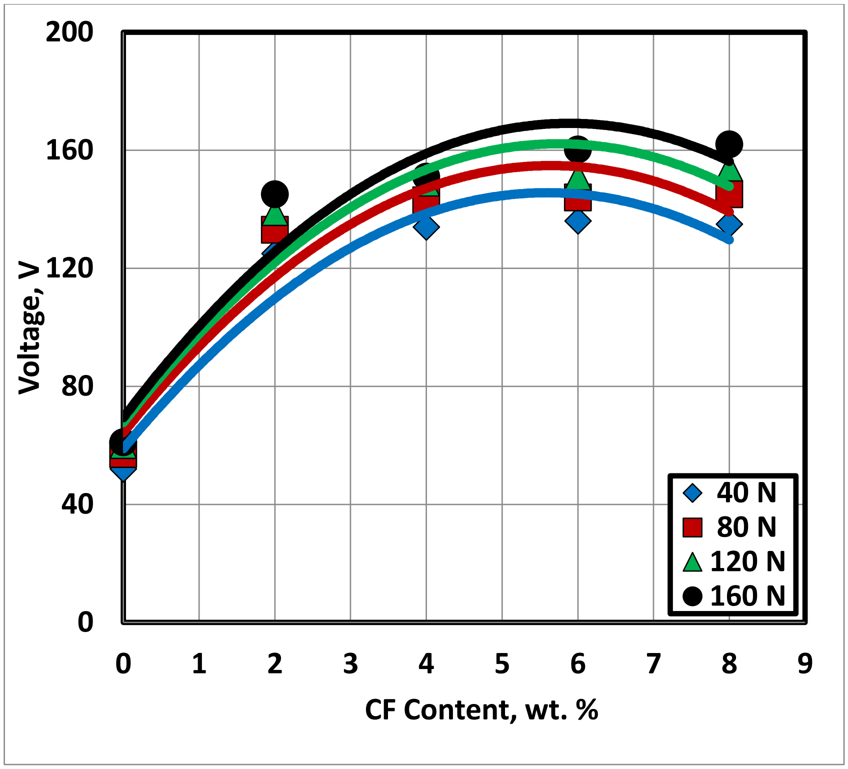

Fig. 14 ESC generated from sliding of rubber and test specimens at 1 mm close to the surface.

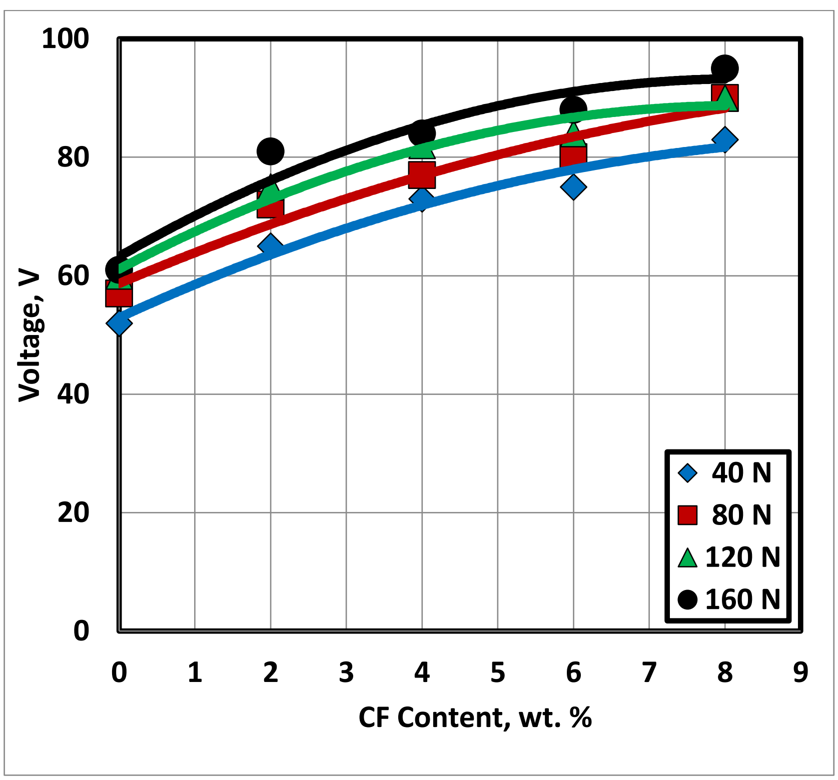

Fig. 15 ESC generated from sliding of rubber and test specimens at 5 mm close to the surface.

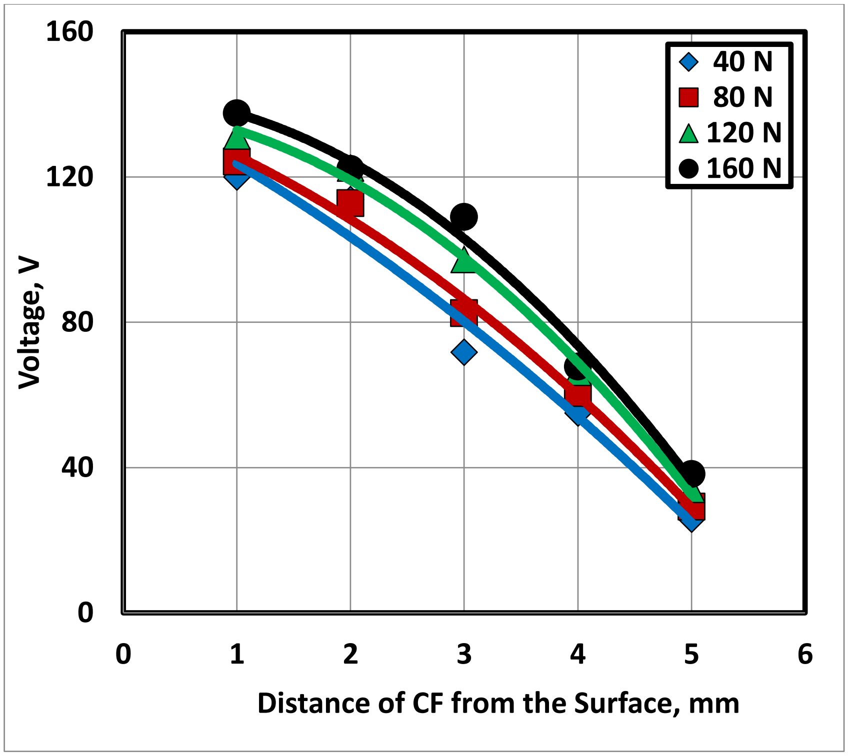

Fig. 16 Effect of the distance of CF from the surface on ESC generated from sliding of rubber against test specimens.

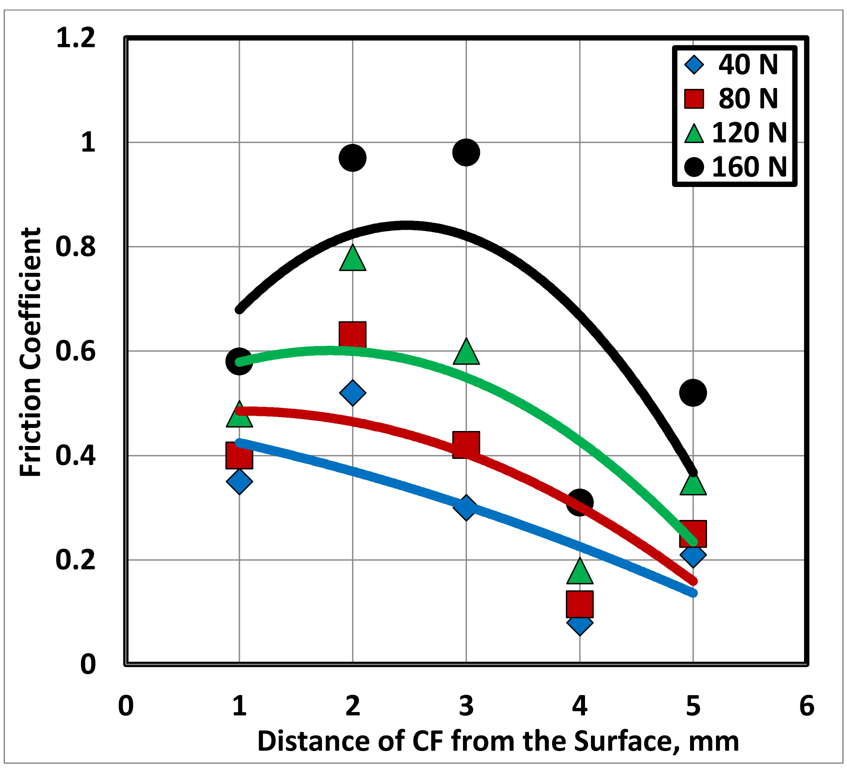

Fig. 17 Effect of the distance of CF from the surface on friction coefficient displayed by sliding of rubber against test specimens.

ESC generated from contact and separation of PU coated epoxy reinforced by CF and rubber is shown in Figs. 11 – 13. It is clearly shown that, increasing CF and normal load caused significant ESC increase. The same effect of CF location on ESC is illustrated, where the highest and lowest voltage values were recorded for CF located at 1.0 and 5.0 mm far from the friction surface respectively. This behavior is due to the influence of the generated electric field. ESC measured in volts represented relatively lower values. This behaviour may be attributed to the ranking of the rubbing materials in the triboelectric series where the gap between PU and rubber is smaller compared to the gap between bare foot and PU. It is commonly known that as the gap increases the amount of ESC increased. Significant decrease in ESC was observed as the distance of CF from friction surface increased. In case of sliding of polyurethane coated epoxy that reinforced by CF against rubber is shown in Figs. 14 – 16. It can be observed that values of ESC slightly exceeded those observed for contact and separation. ESC remarkably increased with increasing CF content. Value of ESC for epoxy free of CF was 60 volts at 160 N normal load, while the value reached to 160 volts for epoxy reinforced by 8 wt. % CF. This behaviour could be explained on the basis of the electric properties of the tested materials. As the load increases ESC slightly increased due to the increase of the contact area with increasing load so that increased interference between the footwear and floor, where ESC generation became easier. Significant decrease in ESC was observed as the distance of CF from friction surface increased. Friction of PU coated epoxy against rubber is accompanied by electrification. Based on that theory, one of the sliding surface gains positive ESC, while the other gains negative ones. As a result of that, an electrostatic force is generated and this force influences the adhesion between the two contact surfaces. The magnitude of the electrostatic force is proportional to ESC that depends on the rank of the rubbing surfaces in the triboelectric series. The double layer of the electric static charge generated on the sliding surfaces would generate an E-field inside the matrix of epoxy. Presence of CF inside epoxy matrix would generate extra electric static charge on the sliding surfaces leading to further increase in the adhesion force acting between the two sliding surfaces and causing significant increase in friction coefficient, Fig. 17. It is necessary that friction coefficient should have reasonable values so that foot slip should be avoided to prevent accidents.

CONCLUSIONS

1. ESC generated on PU coated epoxy from its contact and separation as well as sliding against bare foot recorded higher values than that shown by epoxy surface. Friction values drastically decreased with increasing the distance of CF from the surface.

2. Sliding of PU coated epoxy reinforced by CF against rubber generated values of ESC that exceeded those observed for contact and separation. Friction coefficient displayed values lower than that observed for rubber/bare foot sliding.

REFERENCES

1. Miller J. M., "‘‘Slippery’’ work surface: toward a performance definition and quantitative friction coefficient criteria", J. Saf. Res. 14, pp. 145 - 158, (1983).

2. Grönqvist R., "Mechanisms of friction and assessment of slip resistance of new and used footwear soles on contaminated floors", Ergonomics 38, pp. 224 - 241, (1995).

3. Myung R., Smith, J. L. and Leamon, T. B., "Subjective assessment of floor slipperiness", Int. J. Ind. Ergon. 11, pp. 313 - 319, (1993).
4. Kai W. L., Rui-feng Y., and Xiao L. H., "Physiological and psychophysical responses in handling maximum acceptable weights under different footwear–floor friction conditions", Applied Ergonomics 38, pp. 259 – 265, (2007).
5. Burnfield J. M., Tsai Y. J. and Powers Ch. M., "Comparison of utilized friction coefficientduring different walking tasks in persons with and without a disability', Gait & Posture 22, pp. 82 – 88, (2005).
6. Ezzat F. H., Hasouna A. T. and Ali, W., "Effect of Surface Roughness of Indoor Floor Materials on Friction Coefficient", KGK, January 2008, pp. 42 –49, (2008).
7. Ezzat F. H., Hasouna A. T. and Ali, W. Y., "Friction Coefficient of Rubber Sliding Against Polymeric Indoor Floor Materials of Different Surface Roughness", KGK Kautschuk Gummi Kunststoffe 61. Jahrgang, Nr 608, December 2008, pp. 638 – 641, (2008).
8. Ezzat F. H., Abdel-Jaber, G. T. and Ali, W. Y., "Dry Sliding of Rubber on Glazed Ceramic Tiles", Proceedings of the 7th International Conference of Tribology, EGTRIB 7, December 27 - 28, 2006, Faculty of Engineering, Cairo University, CI, 1-9 (2006).
9. El-Sherbiny Y. M., Mohamed M. K. and Ali W. Y., "Prevention of Slip Accidents by Using Rubber Floor Mat", KGK, 09 2012, pp. 39 – 44, (2012).
10. Elham B. R., Khashaba M. I. and Ali W. Y., "Effect of Surface Roughness on Friction Coefficient of Recycled Rubber Floors", Journal of the Egyptian Society of Tribology Vol. 10, No. 1, January 2013, pp. 13 – 25, (2013).
11. El-Sherbiny Y. M. Ramadan M. A. and Ali W. Y., "Frictional Behaviour of Rubber Floor Mat Fitted by Rectangular Treads", Journal of the Egyptian Society of Tribology, Vol. 11, No. 2, April 2014, pp. 39 – 52, (2014).
12. El-Sherbiny Y. M., Hasouna A. T. and Ali W. Y., "Friction Coefficient of Rubber Sliding Against Floor Materials", ARPN Journal of Engineering and Applied Sciences, VOL. 7, NO. 1, January 2012, pp. 1 – 7, (2012).
13. El-Sherbiny Y. M., Abdel-Jaber G. T. and Ali W. Y., "Friction Coefficient and Electrostatic Charge Generated From Rubber Footwear Sliding Against Floor Materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 4, October 2014, pp. 13 - 24, (2014).
14. Elham B. R., Khashaba M. I. and Ali W. Y., "Friction Coefficient of Smooth and Rough Recycled Rubber Floor Tiles", Journal of the Egyptian Society of Tribology Vol. 9, No. 3, July 2012, pp. 53 – 65, (2012).
15. El-Sherbiny Y. M., Abdel-Jaber G. T., Ali W. Y., "Proper Selection of Indoor Floor Based on Friction Coefficient and Electric Static Charge", EGTRIB Journal, Vol. 13, No. 1, January 2016, pp. 1 – 14, (2016).
16. Samy A. M., Khashaba M. I. and Ali W. Y., "Influence of Grooves on Friction Coefficient displayed by Rubber Disc Sliding against Ceramics", KGK Kautschuk Gummi Kunststoffe 11-12 2014, pp. 52 – 56, (2014).
17. Samy A. M., Khashaba M. I. and Ali W. Y., "Friction Coefficient of Grooved Rubber Disc Sliding Against Ceramics: I. Effect of Motion Direction", Journal of the Egyptian Society of Tribology, Vol. 11, No. 2, April 2014, pp. 1 – 20, (2014).
18. Samy A. M., Khashaba M. I. and Ali W. Y., "Friction Coefficient of Grooved Rubber Disc Sliding Against Ceramics: II. Effect of Load", Journal of the Egyptian Society of Tribology, Vol. 11, No. 2, April 2014, pp. 21 – 38, (2014).

19. Samy A. M., Khashaba M. I. and Ali W. Y., "Friction coefficient of grooved rubber disc sliding against ceramics: iii. effect of the grooves", Journal of the Egyptian Society of Tribology, Vol. 11, No. 3, July 2014, pp. 1 – 19, (2014).
20. El-Sherbiny Y. M., Samy A. M. and Ali W. Y., "Friction Coefficient of Rubber Sliding Against Dusty Indoor Floor", KGK Kautschuk Gummi Kunststoffe 62. Jahrgang, Nr 622, March 2012, (2012).
21. Mohamed M. K., ElKattan A. A. and Ali W. A., "Friction Coefficient Displayed by Rubber Sliding Against Floor Tiles", International Journal of Engineering & Technology IJET-IJENS Vol. 12 No. 06, pp. 144 – 149, (2012).
22. El-Sherbiny Y. M., Ibrahim R. A. and Ali W. Y., "Effect of sand on the friction coefficient displayed by rubber sliding against epoxy floors filled by iron nanoparticles", Journal of the Egyptian Society of Tribology, Vol. 11, No. 3, July 2014, pp. 45 – 59, (2014).
23. Elham B. R., Khashaba M. I. and Ali W. Y., "Effect of Filling Materials on the Friction Coefficient of Recycled Rubber Floor", Journal of the Egyptian Society of Tribology Vol. 10, No. 1, January 2013, pp. 1 – 12, (2013).
24. Samy A. M., El-Sherbiny Y. M. and Ali W. Y., "Friction Coefficient of Recycled Rubber Tiles of Different Porosity", Journal of the Egyptian Society of Tribology Vol. 10, No. 1, January 2013, pp. 38 – 49, (2013).
25. El-Sherbiny Y. M., Al-Qaham Y. G. and Ali W. Y., "Friction Coeficient of Semi-Spherical Rubber Protrusions Sliding Against Rubber", Journal of the Egyptian Society of Tribology Vol. 10, No. 3, July 2013, pp. 1 – 12, (2013).
26. Mai K. M., Khashaba M. I., Mousa M. O. and Ali W. Y., "Friction Coefficient Displayed by Sliding of Rubber Sole Against Recycled Rubber Floor Tiles", EGTRIB Journal, Vol. 12, No. 4, October 2015, pp. 28 – 39, (2015).
27. Ezzat F. H., Hasouna A. T. and Ali W. Y., "Friction Coefficient of Rough Indoor Floor Materials", JKAU: Eng. Sci., Vol. 19 No. 2, pp: 53 – 70, (2008).
28. Diaz AF, Felix-Navarro RM., "A semi-quantitative tribo-electric series for polymeric materials", Journal of Electrostatics, 62, pp. 277 - 290, (2004).
29. Mai K. M., Khashaba M. I., Mousa M. O. and Ali W. Y., "Electrostatic Charge generated from Sliding of Rubber Sole against recycled Rubber Tiles", KGK, 03 2017, pp. 32 – 36, (2017).
30. Mohamed M. K., Samy A. M. and Ali W. Y., "Influence of heat treatment on the friction and wear of polyurethane coatings", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 46 – 57, (2014).
31. Kassar M. H., Samy A. M., Khashaba M. Y. and Ali W. Y., "Wear Resistance of Steel Coated by Polyurethane Reinforced by Steel Wires", EGTRIB Journal, Vol. 13, No. 3, July 2016, pp. 46 – 56, (2016).
32. Kassar M. H., Samy A. M., Khashaba M. Y. and Ali W. Y., "Sand Erosion of Steel Coated by Polyurethane Reinforced By Metallic Wires", International Journal of Advanced Materials Research, Vol. 2, No. 4, 2016, pp. 66 - 71, (2016).
33. Kassar M. H., Samy A. M., Khashaba M. I. and Ali W. Y., "Wear resistance of Steel Sheets coated by Polyurethane reinforced by Nickel Chrome Wires", KGK, 03 2017, (2017).