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# FRICTION COEFFICIENT AND ELECTROSTATIC CHARGE GENERATED FROM RUBBER FOOTWEAR SLIDING AGAINST FLOORING MATERIALS

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## ABSTRACT

**The present work discusses the effect of flooring materials on the generation of electric static charge and friction coefficient. The electric static charge and friction coefficient of smooth rubber footwear sliding against different types of flooring materials were investigated under dry sliding condition. The tested flooring materials were ceramic, marble, parquet ceramic, porcelain and flagstone.**

**It was observed that voltage generated from sliding against ceramic flooring slightly. The measured voltage values showed significant scatter as well known for the generated electric static charge, where the maximum and minimum values reached 850 and 360 volts respectively. It is expected that electrical field will be formed due the electric charge formed on the footwear and floor surfaces. Marble flooring displayed higher values than that observed for ceramic flooring. As the load increased, voltage increased. Based on this observation it can be suggested to select flooring materials according to their resistance to generate electric static charge. Voltage generated from sliding of footwear against parquet ceramic flooring was lower than marble and higher than that generated from smooth ceramic. It seems that surface topography of the parquet ceramic was responsible for that behaviour. Voltage presented significant increase when footwear slid against porcelain flooring, where the maximum value reached 5995 volts. This behaviour can be an obstacle in using porcelain as flooring material, while flagstone flooring showed the lowest generated voltage, especially at low loads. This observation can confirm the use of the flooring materials.**

**The values of friction coefficient displayed by sliding against ceramic flooring displayed decreasing trend of friction coefficient with increasing load. Footwear sliding against marble flooring experienced relatively lower friction coefficient than that observed on ceramic one. Sliding against parquet ceramic flooring showed relatively higher friction values than that observed for ceramic and marble. The highest friction value was 0.82, while the lowest one was 0.47. Porcelain flooring showed relatively lower friction values**

**than that observed for ceramic and parquet ceramic, while higher than that shown for marble. Friction coefficient displayed by sliding against flagstone flooring represented significant increase in friction coefficient.**

**KEYWORDS**
**Friction coefficient, electrostatic charge, ceramic, marble, parquet ceramic, porcelain, flagstone tiles.**

## INTRODUCTION

**Safe walking on the floor was evaluated by the static friction coefficient. Few researches paid attention to the electric static charge generated during walking on the floor. It is well known that walking and creeping on flooring can generate electric static charge of intensity depends on the material of flooring. The materials of the floors as well as footwear can affect the generated charge. The electrostatic charge and friction coefficient of bare foot and foot wearing socks sliding against different types of flooring materials were investigated under dry sliding condition, [1]. The tested flooring materials were ceramic, marble, parquet, moquette and rubber. It was found that rubber flooring showed the highest generated voltage among the tested floorings. The highest voltage values were displayed by polyester socks, while cotton socks showed the lowest one. This observation can confirm the necessity of careful selection of the flooring materials. Parquet flooring showed the lowest voltage among the all tested flooring. Charge generated from rubbing between shoes and carpet were discussed, [2, 3]. The effect of humidity was explained on the basis that water molecules on the surfaces convey charges in the form of ions to enhance charge relaxation, [4, 5]. The effect of the static charge generation on the environment is influenced by electrical conductivity of the sliding surfaces.**

**Friction coefficient is the major scale to quantify floor slipperiness. The friction coefficient of rubber sliding against polymeric indoor flooring materials of different surface roughness was investigated, [6]. 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. At water–detergent 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 $R_a$ surface roughness. At water and oil lubricated sliding, smooth flooring 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. At dry sliding, friction coefficient of bare foot and polymeric socks, friction coefficient decreased down to minimum then increased with increasing the surface roughness, [7]. In water lubricated sliding, cotton socks showed the highest friction coefficient. Friction coefficient drastically decreased with increasing surface roughness at water and detergent lubricated sliding. For the tested flooring materials lubricated by oil, bare foot displayed drastic reduction in friction coefficient, while cotton socks showed the highest values.**

**The changes in the surface properties and frictional characteristics of flooring materials are expected in practical use due to mechanical wear, ageing, soiling and maintenance, [8]. In the sport halls the flooring surfaces are probably changed mainly through mechanical wear, periodic cleaning processes and material transfer from shoe soles (elastomer abrasions and contaminating particles). Coefficients of friction were measured periodically over a period of 30 months on the surfaces of five types of floor coverings in a new sport complex, [9]. Surface changes through mechanical wear range from smoothing to roughening, [10, 11], depending on flooring material and surface characteristics.**

**Surface roughness is known to be a key factor in determining the slip resistance of floors. The effect of surface roughness of ceramic on the friction coefficient, when sliding against rubber and leather, was investigated, [12]. Glazed floor tiles of different roughness ranging from 0.05 and 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.**

**Slip resistance of flooring materials is one of the major environmental factors affecting walking and materials handling behaviors. Floor slipperiness may be quantified using the static and dynamic friction coefficient, [13]. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [14, 15]. Relatively higher static and dynamic friction coefficient values may be required for safe walking when handling loads.**

**Researches revealed significant correlations between surface roughness of shoes and friction coefficient for a given floor surface, [16 - 19]. Abrasion of rubber soling in steps with increasingly coarse grit gradually raised the roughness in parallel with a rise in the friction coefficient on water wet surfaces. Dense rubbers never developed the same order of roughness, and they became smooth and polished when worn on ordinary floors or with mechanical polishing.**

**In the present work, friction coefficient and electrostatic charge of rubber footwear sliding against different types of flooring materials were investigated under dry sliding condition.**

## EXPERIMENTAL

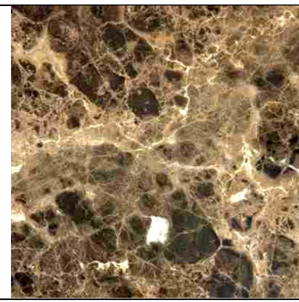
**Experiments were carried out to measure the friction coefficient displayed by the sliding of bare foot and foot wearing socks against different types of flooring materials, under dry sliding condition through measuring the friction force and applied normal load. The tested materials are placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second measures the vertical force (applied load). Friction coefficient was determined by the ratio between the friction force and the normal load.**

**The tested flooring materials were ceramic, parquet ceramic, marble, porcelain and flagstone tiles in form of a quadratic sheet of 0.4 m × 0.4 m, Fig. 1. The sliding surfaces**

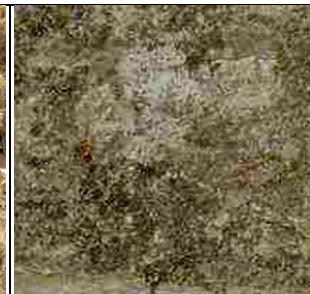
**were thoroughly cleaned with soap water to eliminate dirt as well as dust and carefully dried before the tests. Rubber footwear was loaded against the tested flooring materials. The rubber footwear was smooth of 75 Shore A hardness. Friction test was carried out at normal load varying from 0 to 800 N at dry sliding condition. After each measurement, all contaminants were removed from the flooring materials and the rubber footwear using absorbent papers.**

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

**Ceramic**

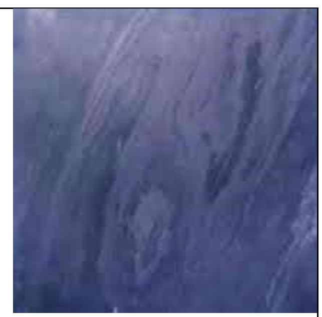


**Marble**



**Porcelain**

**Parquet Ceramics**



**Flagstone**

**Fig. 1 The tested flooring materials.**

## RESULTS AND DISCUSSION

**The results of the experimental work are illustrated in Figs. 2 – 11. Voltage generated from sliding against ceramic flooring slightly decreased with increasing load, Fig. 2. The measured voltage values showed significant scatter as well known for the generated electric static charge, where the maximum and minimum values reached 850 and 360 volts respectively. It is expected that electrical field will be formed due the electric charge formed on the footwear and floor surfaces.**

**Safety of walking on flooring materials can be enhanced by increasing friction coefficient. The values of friction coefficient displayed by sliding against ceramic flooring is shown in Fig. 3, where rubber footwear displayed decreasing trend of**

**friction coefficient with increasing load. The highest friction coefficient value was 0.58, while the lowest value was 0.33. The scatter in the friction values was attributed to that rubber exhibits unusual sliding friction. When rubber is slid on a hard, rough substrate, the surface asperities of the substrate exert oscillating forces on the rubber surface leading to energy "dissipation" via the internal friction of the rubber. I estimate this contribution to the friction force and compare the results with the experimental data of low elastic modulus of rubber, where the adhesion of the rubber to the substrate was relatively high. Consequently, adhesion force will deform the rubber at the rubber–substrate interface, where the rubber completely followed the short-wavelength surface roughness profile. This gives an additional contribution to the friction force.**

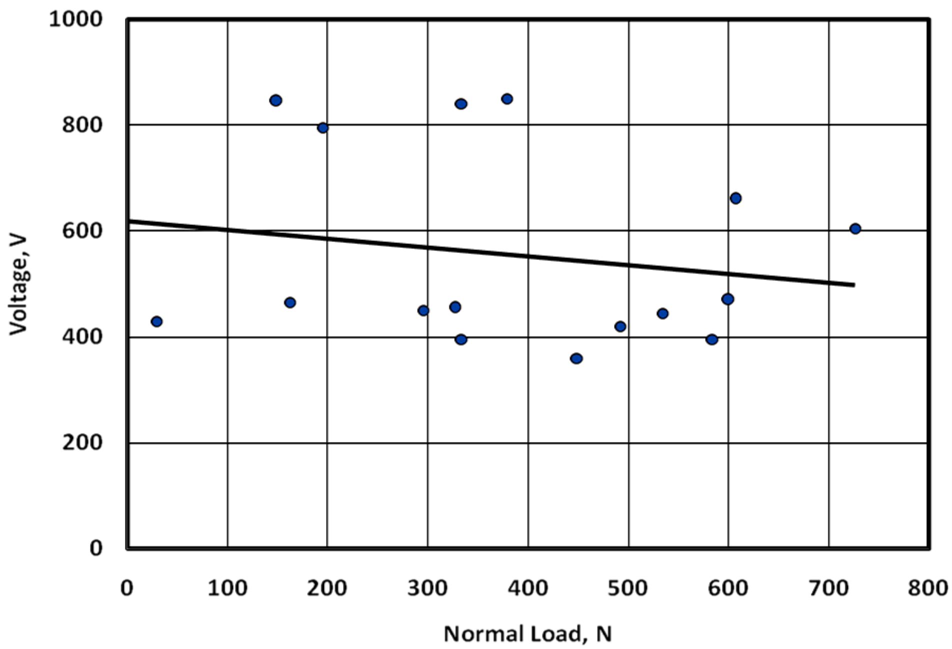



**Fig. 2 Voltage generated for sliding against ceramic floor.**

**Voltage generated from sliding against marble flooring displayed higher values than that observed for ceramic flooring, Fig. 4. The highest value was 1800 volts generated from the sliding of the rubber footwear. As the load increased, voltage increased due to the increase of the contact area. Based on this observation it can be suggested to select flooring materials according to their resistance to generate electric static charge.**

**Footwear sliding against marble flooring, Fig. 5, experienced relatively lower friction coefficient than that observed on ceramic one. The highest friction value reached 0.48, while the lower one was 0.29. Based on the American and European standards those values are not high enough for safe walking.**

**Voltage generated from sliding of footwear against parquet ceramic flooring is illustrated in Fig. 6. Voltage values were lower than marble and higher than that generated from smooth ceramic. It seems that surface topography of the parquet ceramic was responsible for that behaviour.**

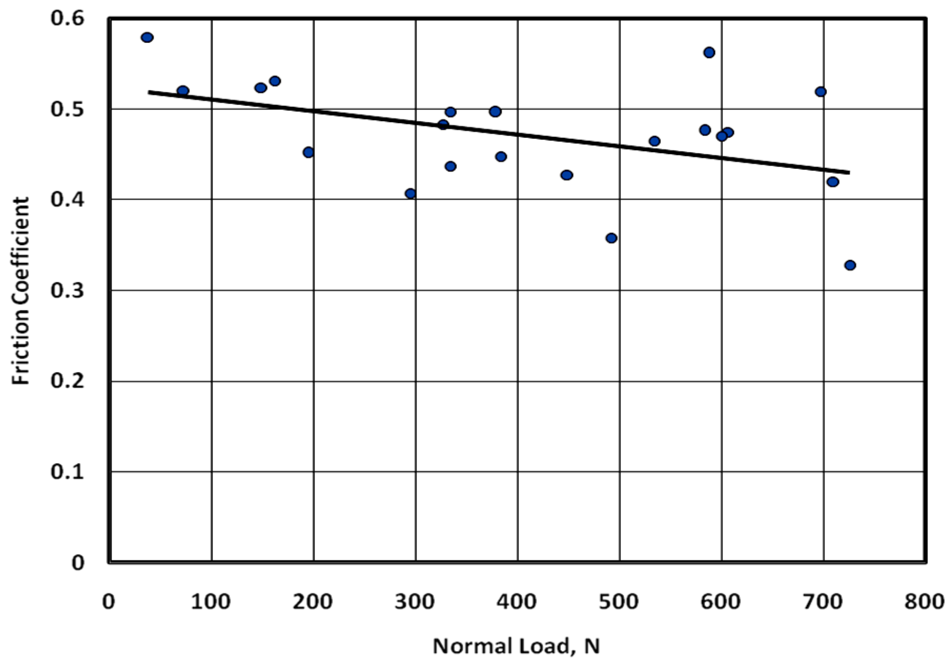



**Fig. 3 Friction coefficient displayed for sliding against ceramic floor.**

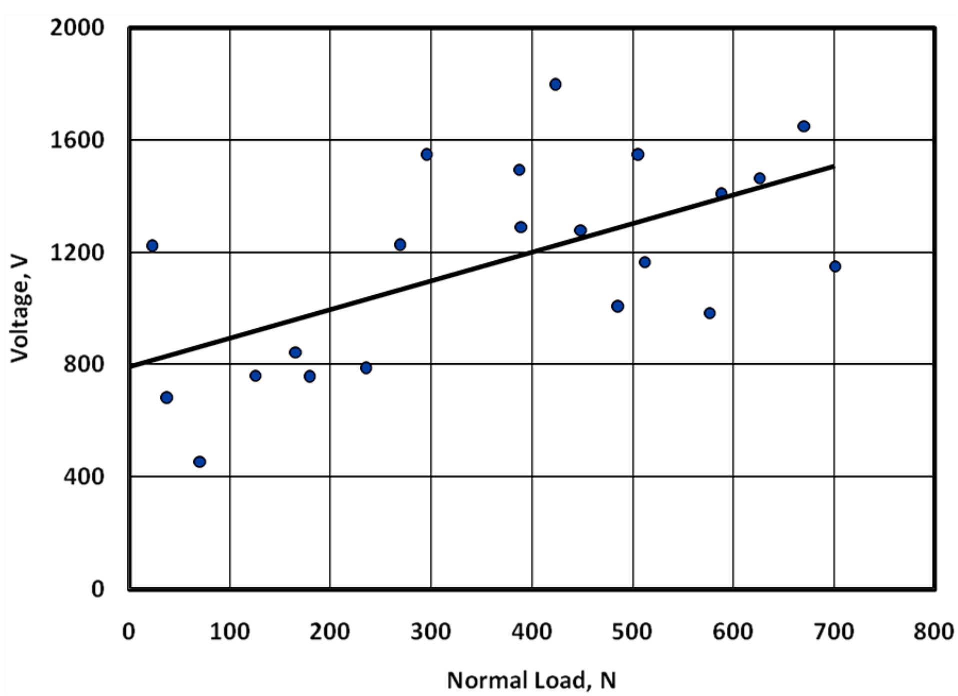



**Fig. 4 Voltage generated for sliding against marble floor.**

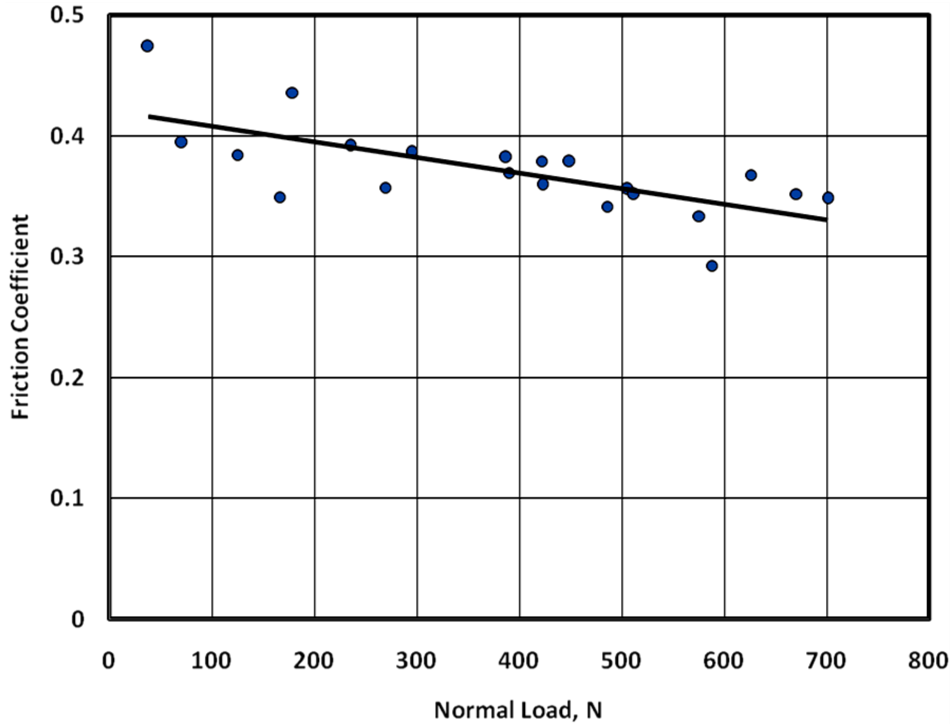



**Fig. 5 Friction coefficient displayed for sliding against marble floor.**

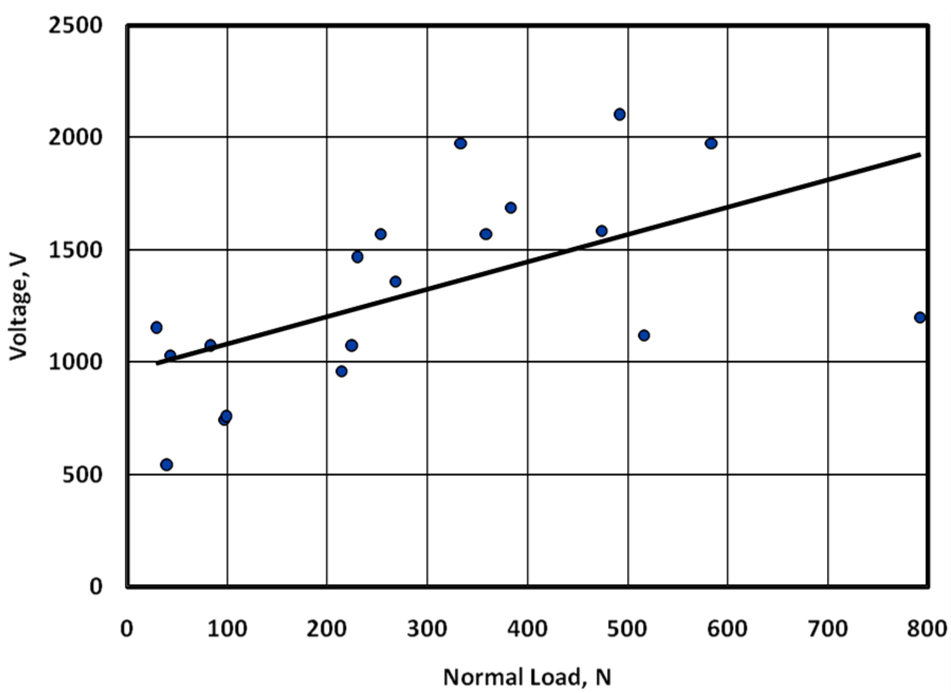



**Fig. 6 Voltage generated for sliding against parquet ceramic floor.**

**Sliding against parquet ceramic flooring showed relatively higher friction values than that observed for ceramic and marble, Fig. 7. The highest friction value was 0.82, while the lowest one was 0.47. The difference in the values generated from slip and stick behaviour accompanied to friction process. Voltage presented significant increase when footwear slid against porcelain flooring, where the maximum value reached 5995 volts, Fig. 8. This behaviour can be an obstacle in using porcelain as flooring material. Voltage increased with increasing normal load which resemble serious danger to those people of heavy weight.**

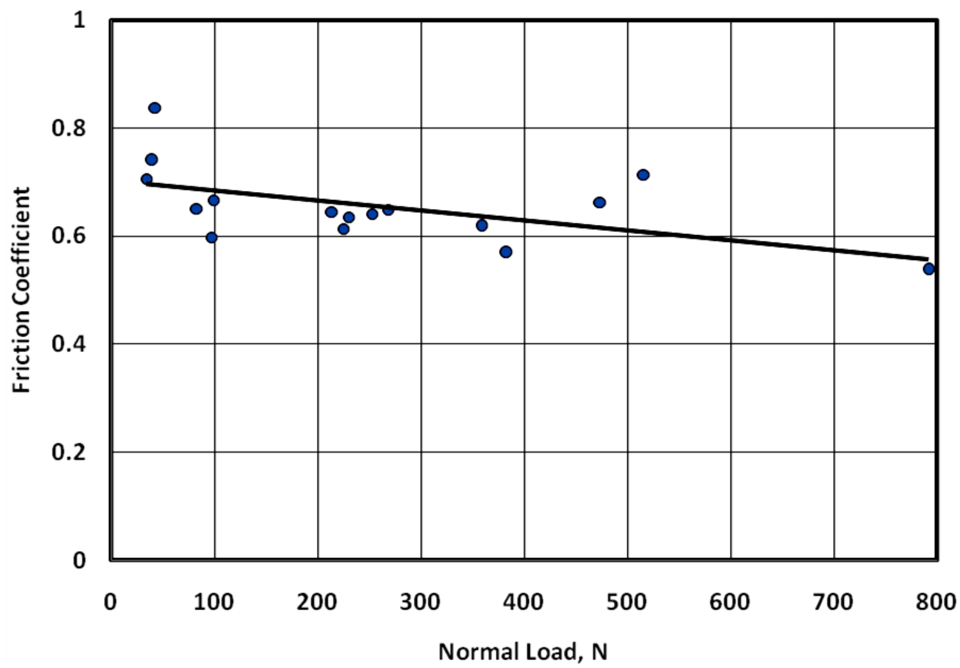



**Fig. 7 Friction coefficient displayed for sliding against parquet ceramic floor.**

**Friction coefficient displayed by sliding against porcelain flooring showed relatively lower values than observed for ceramic and parquet ceramic, while higher than shown for marble, Fig. 9. The friction values fulfill the European standards, where the static values of friction coefficient of 0.3 - 0.5 had been recommended as the slip-resistant standard for unloaded, normal walking conditions. Higher static coefficient of friction may be required for safe walking when handling loads, which is guaranteed by the American standards.**

**Flagstone flooring showed the lowest generated voltage, Fig. 10, especially at low loads. The highest voltage values reached 800 volts. Voltage significantly increased with load increase. This observation can confirm the use of the flooring materials.**

**Friction coefficient displayed by sliding against flagstone flooring represented the highest values of friction coefficient compared to the other tested floorings, Fig. 11. The highest value reached to 0.8, while the lowest value was 0.4.**

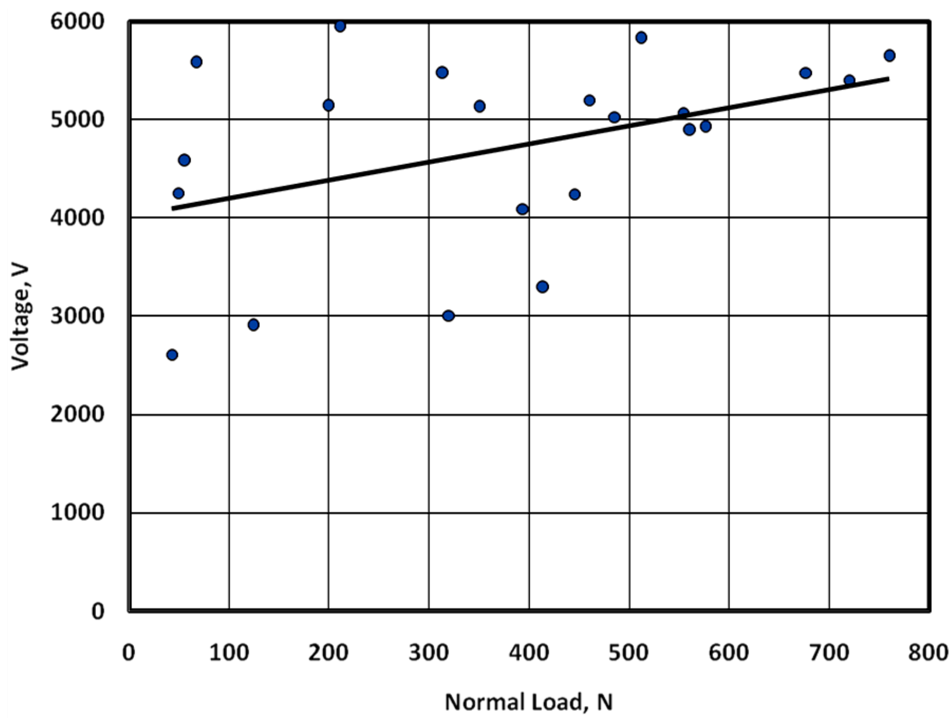



**Fig. 8 Voltage generated for sliding against porcelain floor.**

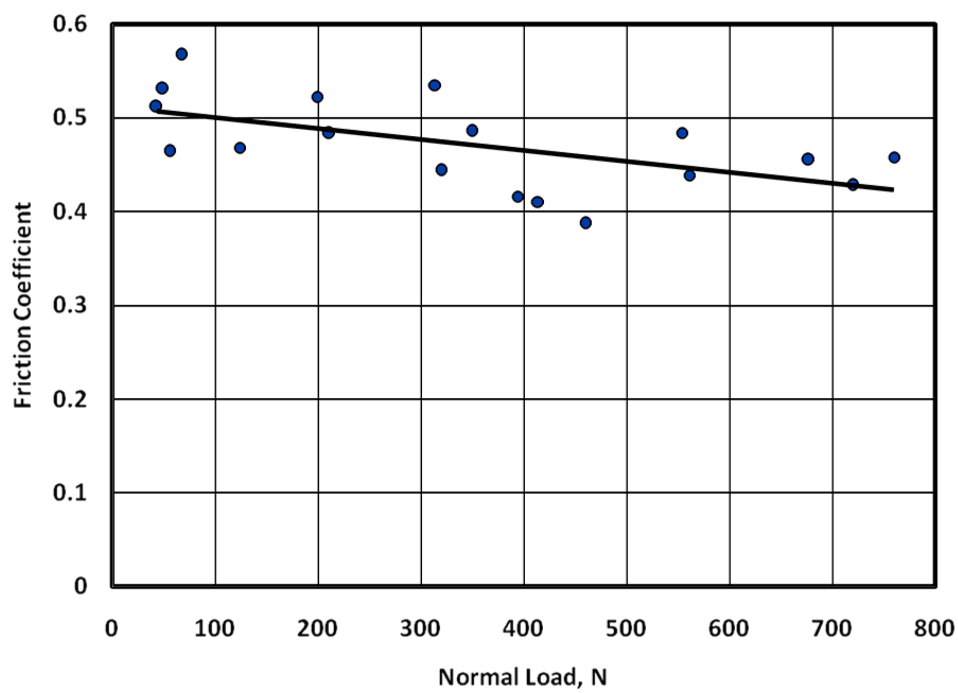



**Fig. 9 Friction coefficient displayed for sliding against porcelain floor.**

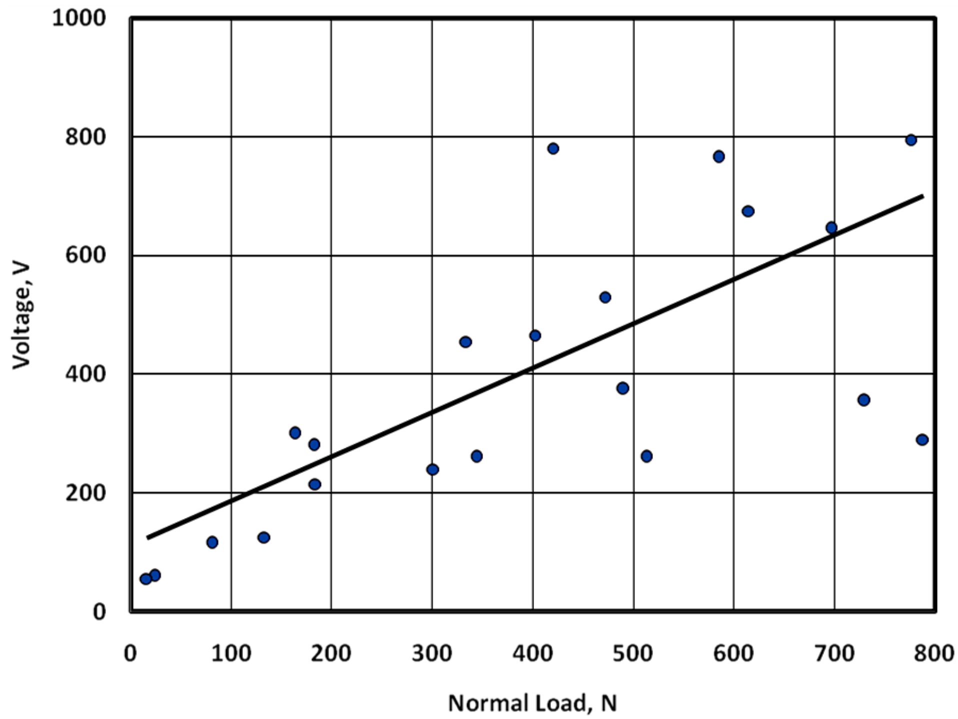



**Fig. 10 Voltage generated for sliding against flagstone floor.**

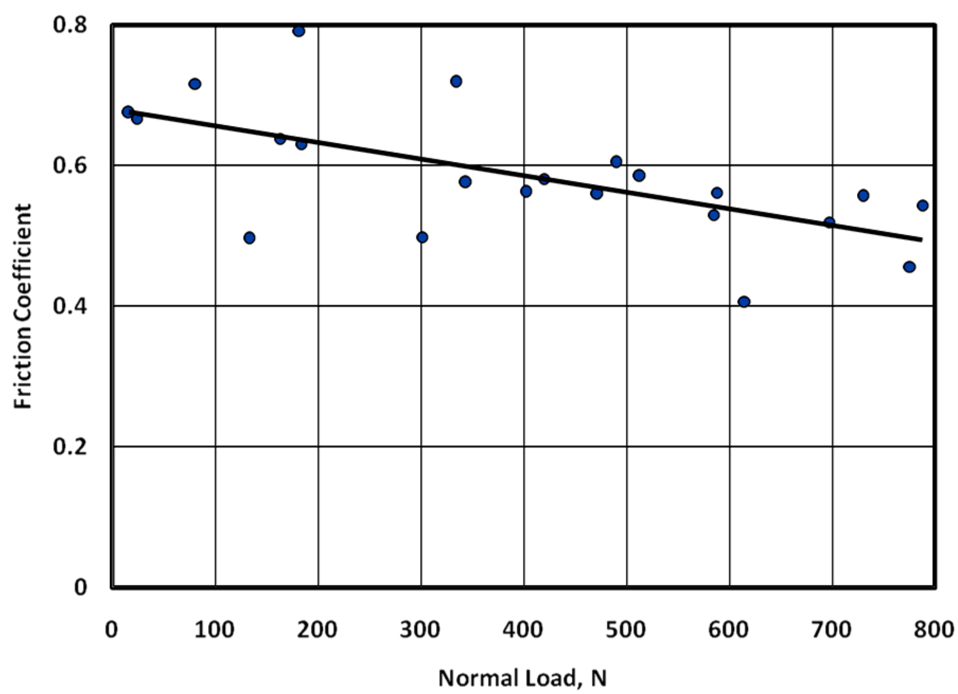



**Fig. 11 Friction coefficient displayed for sliding against flagstone floor.**

**CONCLUSIONS**

**1. Voltage generated from sliding against ceramic flooring slightly decreased with increasing load. Rubber footwear displayed decreasing trend of friction coefficient with increasing load. The highest friction coefficient value was 0.58, while the lowest value was 0.33.**

**2. Voltage generated from sliding against marble flooring displayed higher values than that observed for ceramic flooring. Sliding against marble flooring experienced relatively lower friction coefficient than that observed on ceramic one. The highest friction value reached 0.48, while the lower one was 0.29.**

**3. Voltage generated from sliding of footwear against parquet ceramic flooring showed lower values than that generated from marble and higher than observed for smooth ceramic. Parquet ceramic flooring showed relatively higher friction values than that observed for ceramic and marble. The highest friction value was 0.82, while the lowest one was 0.47.**

**4. Voltage presented significant increase when footwear slid against porcelain flooring, where the maximum value reached 5995 volts. This behaviour can be an obstacle in using porcelain as flooring material. Voltage increased with increasing normal load which resemble serious danger to those people of heavy weight. Friction coefficient showed relatively lower values than that observed for ceramic and parquet ceramic, while higher than shown for marble.**

**5. Flagstone flooring showed the lowest generated voltage, Fig. 10, especially at low loads. The highest voltage values reached 800 volts. Friction coefficient represented the highest values of friction coefficient compared to the other tested floorings.**

**REFERENCES**

**1. El-Sherbiny Y. M., Samy A. M. and Ali W. Y., "Electrostatic charge generated from bare foot and foot wear sliding against flooring materials", Journal of the Egyptian Society of Tribology, Vol. 11, No. 1, January 2014, pp. 1 – 11, (2014).**

**1. Greason W. D., "Investigation of a test methodology for triboelectrification", Journal of Electrostatics, 49, pp. 245 - 56, (2000).**

**2. Nomura T., Satoh T., Masuda H., "The environment humidity effect on the tribocharge of powder", Powder Technology (135 - 136), pp. 43 - 49, (2003).**

**3. Diaz AF, Felix-Navarro RM., "A semi-quantitative tribo-electric series for polymeric materials", Journal of Electrostatics, 62, pp. 277 - 290, (2004).**

**4. Nemeth E, Albrecht V, Schubert G, Simon F, "Polymer tribo-electric charging: dependence on thermodynamic surface properties and relative humidity", Journal of Electrostatics, 58, pp. 3 - 16, (2003).**

**5. Al-Qaham Y., Mohamed M. K.and Ali W. Y., "Electric Static Charge Generated From the Friction of Textiles", Journal of the Egyptian Society of Tribology Vol. 10, No. 2, April 2013, pp. 45 – 56, (2013).**

**6. Ezzat F. H., Hasouna A. T. and Ali, W., "Effect of Surface Roughness of Indoor Flooring Materials on Friction Coefficient", KGK, December 2008, pp. 638 – 641, (2008).**

**7. Ezzat F. H., Hasouna A. T. and Ali, W., "Friction Coefficient of Rough Indoor Flooring Materials", JKAU: Eng. Sci., Vol. 19 No. 2, pp: 53 – 70, (2008).**

**8. Leclercq, S., Saulnier, H., "Floor slip resistance changes in food sector workshops: prevailing role played by fouling". Safety Science 40, pp. 659 - 673, (2002).**
**9. Derler S., Kausch F., Huber R., "Systematic patterns and random fluctuations in time series of coefficients of friction measured on floor surfaces", Safety Science 43, pp. 391 – 405, (2005).**
**10. Chang, W.-R., Kim, I.-J., Manning, D.P., Bunterngchit, Y., "The role of surface roughness in the measurement of slipperiness", Ergonomics 44, pp. 1200 - 1216, (2001).**
**11. Chang W. R., "The effects of surface roughness and contaminants on the dynamic friction between porcelain tile and vulcanized rubber", Safety Science 40, pp. 577 - 591, (2002).**
**12. Chang, W.-R., Li, K.W., Huang, Y.-H., Filiaggi, A., Courtney, T.K., "Assessing floor slipperiness in fast-food restaurants in Taiwan using objective and subjective measures", Applied Ergonomics 35, pp. 401 - 408, (2004).**
**13. Li K. W., Yu R., Han X. L., "Physiological and psychophysical responses in handling maximum acceptable weights under different footwear–floor friction conditions", Applied Ergonomics 38, pp. 259 – 265, (2007).**
**14. Miller J. M., "''Slippery'' work surface: toward a performance definition and quantitative coefficient of friction criteria", J. Saf. Res. 14, pp. 145 - 158, (1983).**
**15. 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).**
**16. Manning, D.P., Jones, C., Bruce, M., "A method of ranking the grip of industrial footwear on water wet, oily and icy surfaces", Safety Science, 14, pp. 1 – 12, (1991).**
**17. Manning, D.P., Jones, C., "The superior slip-resistance of soling compound T66/103", Safety Science, 18, pp. 45 – 60, (1994).**
**18. Manning, D.P., Jones, C., "High heels and polished floors: The ultimate challenge in research on slip resistance", Safety Science, 19, pp. 19 – 29, (1995).**
**19. Manning D. P., Jones C., Rowland F. J. Roff M., "The Surface Roughness of a Rubber Soling Material Determines the Coefficient of Friction on Water Lubricated Surfaces", Journal of Safety Research, Vol. 29, No. 4, pp. 275 - 283, (1998).**
**20. Miller J. M., "''Slippery'' work surface: toward a performance definition and quantitative coefficient of friction criteria", J. Saf. Res. 14, pp. 145 - 158, (1983).**