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PROPER SELECTION OF INDOOR FLOOR BASED ON FRICTION COEFICIENT AND ELECTRIC STATIC CHARGE

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ABSTRACT
The present study investigates the friction coefficient and electric static charge generated from sliding of foot wearing socks against indoor flooring tiles. The static friction coefficient displayed by foot wearing socks of different textile materials under dry sliding was investigated. Floor tiles of ceramics, flagstone, parquet, parquet ceramics, marble, porcelain and rubber were tested as floor materials.

The experimental results showed that, there is an increasing demand to establish codes for the intensity of electric static charge generated from the friction of floors. Rubber floor displayed the highest friction values, while marble showed the lowest ones. Porcelain generated the highest electric static charge followed by ceramic, rubber, flagstone, parquet, parquet ceramic and marble. When mixing polyamide of positive charge with lycra of relatively negative charge as socks textiles, the intensity of the electric static charge generated from friction decreased. Finally, it can be recommended that further experiments should be carried out to determine the position of the floor materials in the triboelectric series in order to properly select the material of the socks to avoid generation of excessive electric static charge.

KEYWORDS
Friction coefficient, electric static charge, socks, floor.

INTRODUCTION
There is an increasing demand to avoid slip accidents indoor through paying attention to the proper selection of socks and floor materials. The effect of the cotton content of socks on the frictional behaviour of foot during walking was investigated, [1 – 3]. It was found that friction coefficient increased with increasing the cotton content in socks, where polyamide socks displayed the lowest friction and cotton socks displayed the highest one.

Friction between the insole, sock and foot has significant impact on the perception of comfort and the risk of injury of the wearers. Low friction allows the foot to move easily in the shoe. However, excessive movement can result in feeling of insecurity and may generate pressure and rubbing between the top and upper part of the foot and the shoe, [5]. Rubbing in shoe includes friction between the foot and the inner surface of sock, and

that between the outer surface of sock and shoe. Too low friction in the both interfaces may lead to excessive movement of foot in shoe and induces discomfort feeling of insecurity. It was found that the difference of friction coefficient among interfaces provide insight into where slip occurs, [6]. It was predicted that slip would be expected at the interface of lower friction coefficient rather than the interface of higher friction coefficient. It was recommended to set low friction on one side to allow foot sliding, and high friction on the other side to provide appropriate level of resistance to avoid excessive movement.

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, [7]. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [8, 9]. Relatively higher static and dynamic friction coefficient values may be required for safe walking when handling loads. The subjective ranking of floor slipperiness was compared with the static coefficient of friction (μ) and found that the two measures are consistent, [10, 11]. Many state laws and building codes have established that a static $\mu \geq 0.50$ represents the minimum slip resistance threshold for safe floor surfaces. Furthermore, the Americans Act Accessibility Guidelines for Disabled, [12, 13], contain advisory recommendations for static coefficient of friction of $\mu \geq 0.60$ for accessible routes (*e.g.* walkways and elevators) and $\mu \geq 0.80$ for ramps.

In the present work, friction coefficient and electric static charge generated from sliding of foot wearing socks against indoor flooring tiles are investigated. Socks of different textile materials as well as floor tiles of ceramic, flagstone, parquet, parquet ceramics, marble, porcelain and rubber are tested under dry sliding condition.

EXPERIMENTAL

Experiments were carried out using a test rig designed and manufactured to measure the friction coefficient between the foot and the tested flooring tiles through measuring the friction and normal forces. The tested flooring materials are placed in a base supported by two load cells, the first could measure the horizontal force (friction force) and the second could measure the vertical force (normal force). Friction coefficient is determined by the ratio between the friction and the normal force. The arrangement of the test rig is shown in Fig. 1. The flooring tiles were thoroughly cleaned with soap water to eliminate any dirt and dust and carefully dried before the tests. Socks of different textile materials, Table 1, were loaded against the tested flooring tiles. The tested flooring tiles were in form of a quadratic sheet of 0.4 m × 0.4 m and 5 mm thickness. Friction test was carried out at different values of normal load exerted by foot.

Electric static charge generated by the sliding of foot wearing socks against floor is measured. The experiments simulate the walking of people indoors. The electrostatic fields (voltage) measuring device (Ultra Stable Surface DC Voltmeter) was used to measure the electrostatic charge (electrostatic field) for test specimens, Fig. 2. 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.

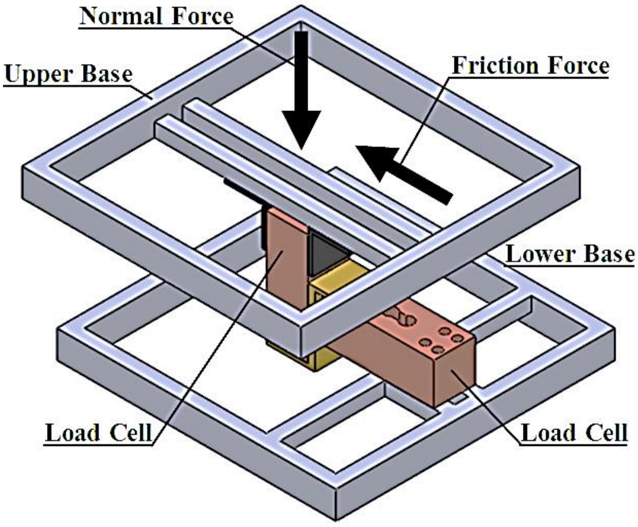

Fig. 1 Arrangement of test rig.

Fig. 2 Electrostatic field measuring device.

Table 1. Textile materials of the tested socks.

Code	Material
A	50 wt. % Polyester, 50 wt. % Cotton
B	80 wt. % Cotton, 20 wt. % Lycra
C	100 wt. % Polyester
D	50 wt. % Polyester, 50 wt. % Polyacrylonitrile
E	100 wt. % Cotton
F	100 wt. % Polyester-Polyurethane Copolymer
G	80 wt. % Polyamide, 20 wt. % Polyester-Polyurethane Copolymer (Lycra)
H	100 wt. % Polyamide

RESULTS AND DISCUSSION

In Europe, [7], it was suggested that a floor was ‘‘very slip-resistant’’ if the coefficient of friction was 0.3 or more. A floor with the coefficient of friction between 0.2 and 0.29 was ‘‘slip resistant’’. A floor was classified as ‘‘unsure’’ if its coefficient of friction was between 0.15 and 0.19. A floor was ‘‘slippery’’ and ‘‘very slippery’’ if the coefficient of friction was lower than 0.15 and 0.05, respectively, Fig. 3. Rubber tends to provide higher effective contact area and more pronounced microscopic deformations when mechanically interacting with the surface asperities of a rigid material, greater friction coefficients can be expected for rubber than for plastic. The above characteristic frictional behaviour of rubber was greatly disturbed when fluid film separating the two sliding surfaces.

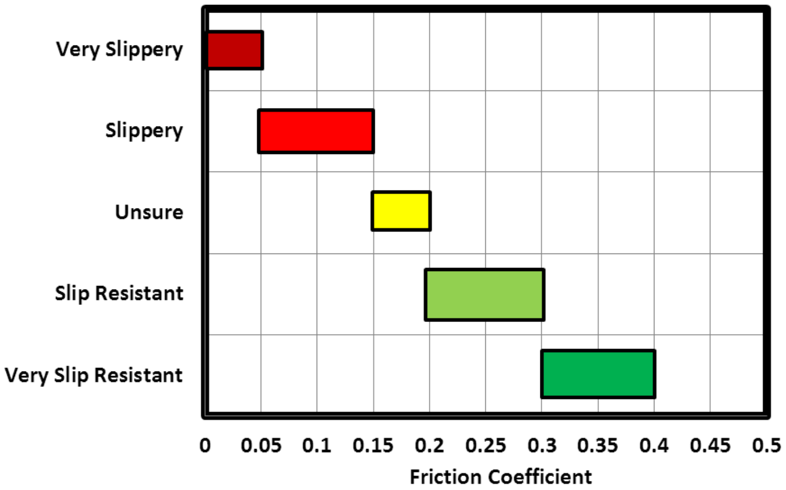

Fig. 3 Dependency of friction coefficient on the safety of walking, [7].

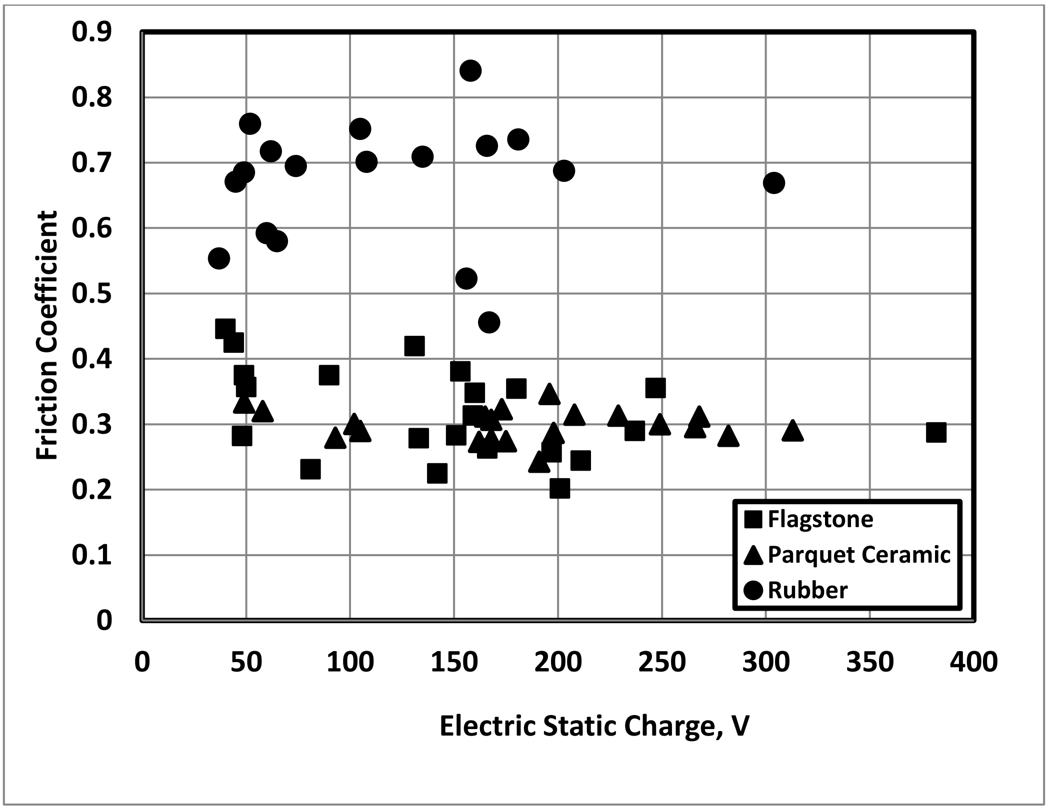

Fig. 4 Friction coefficient displayed by sliding of foot wearing sock (A) against the tested floor materials.

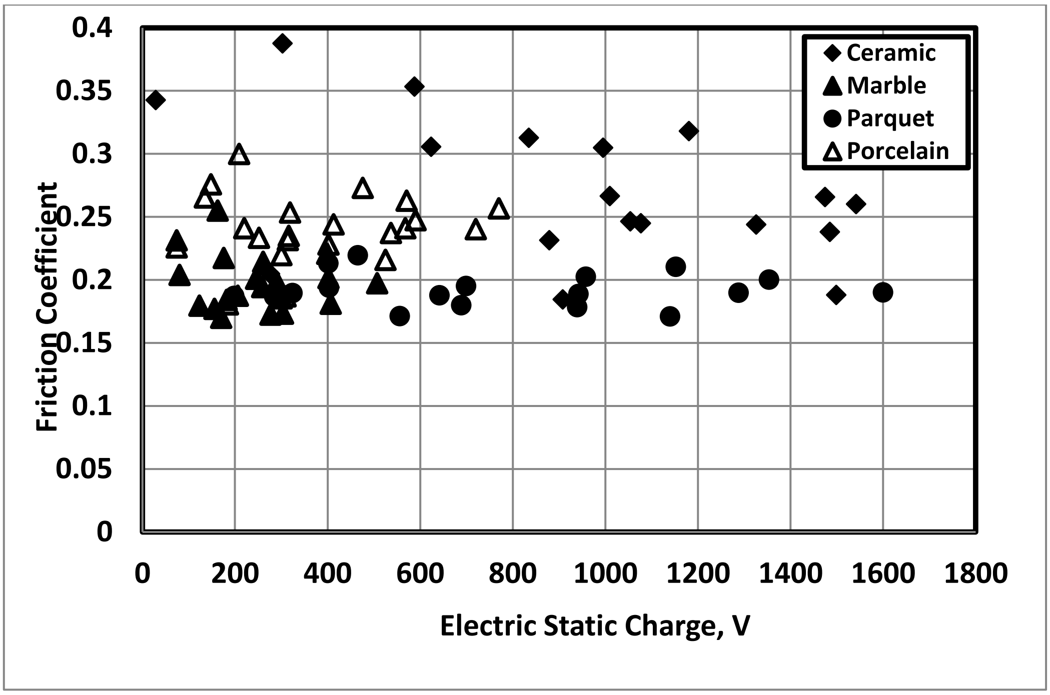

Fig. 5 Friction coefficient displayed by sliding of foot wearing sock (A) against the tested floor materials.

The relationship between friction coefficient and electric static charge generated by the sliding of sock (A) against the tested floors is shown in Figs. 4, 5. Rubber displayed the highest friction values followed by ceramic, parquet ceramic, parquet, porcelain, flagstone, marble and parquet. The values of the generated electric static charge for rubber were the lowest. Although ceramic was considered as very slip resistant it generated relatively higher values of electric static charge. Based on the results, it can be recommended to use sock (A) for rubber floor.

Friction coefficient, displayed by the dry sliding of socks (B) which contain 80 wt. % cotton and 20 wt. % polyester polyurethane copolymer against the tested floor, is shown in Figs. 6, 7. Rubber floor showed the highest friction values which guarantee safe walking. Parquet ceramic tiles gave the lowest electric static charge with reasonable friction values. Porcelain displayed the highest charge with low friction coefficient.

Polyester socks (C) slid against the tested floors, Figs. 8, 9, showed the highest friction values ranging between 0.84 and 0.41. The disadvantage of using polyester socks against rubber is the generation of high electric static charge up to 2000 volts, while flagstone showed slip resistant sliding with 1500 volts electric static charge. Among the tested tiles, porcelain showed the lowest charge accompanied by slip resistant sliding.

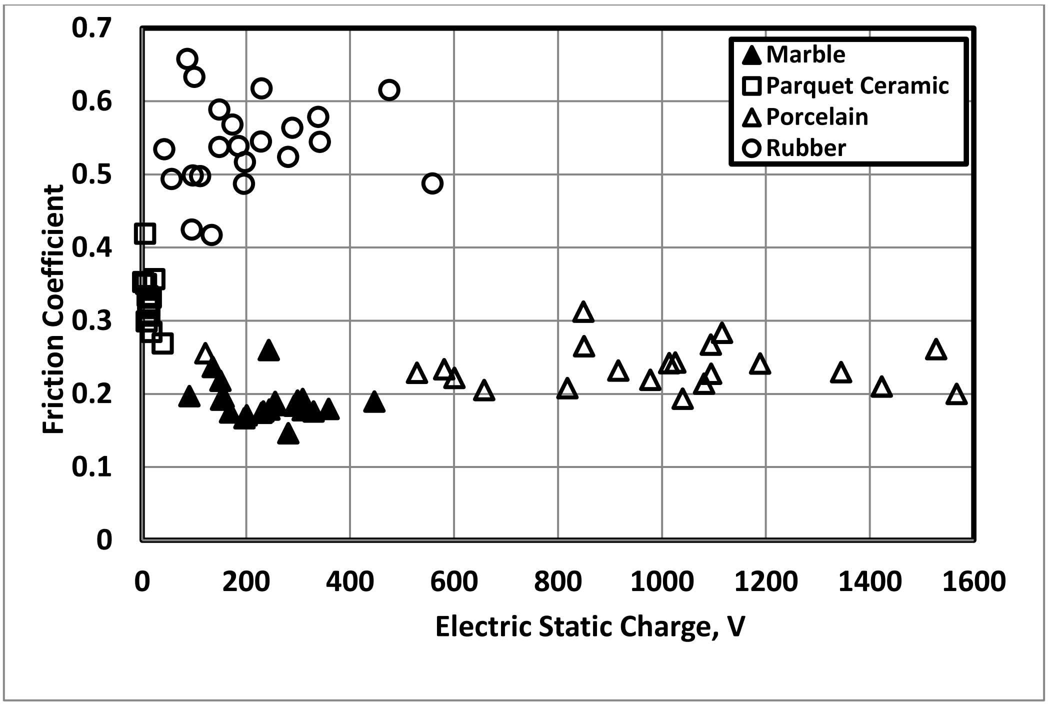

Fig. 6 Friction coefficient displayed by sliding of foot wearing sock (B) against the tested floor materials.

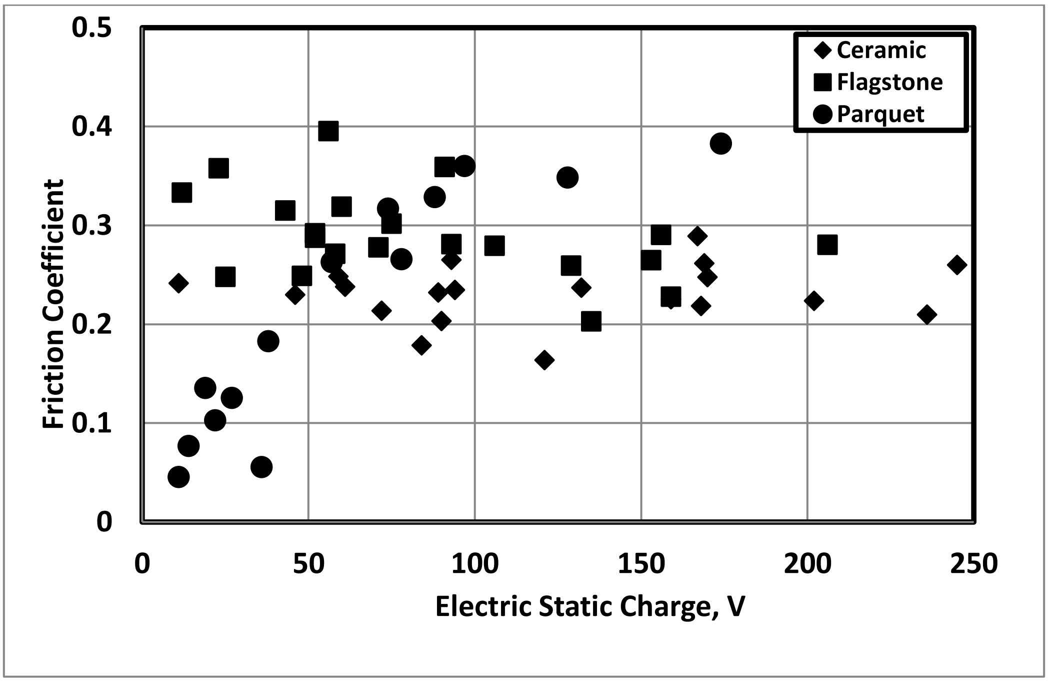

Fig. 7 Friction coefficient displayed by sliding of foot wearing sock (B) against the tested floor materials.

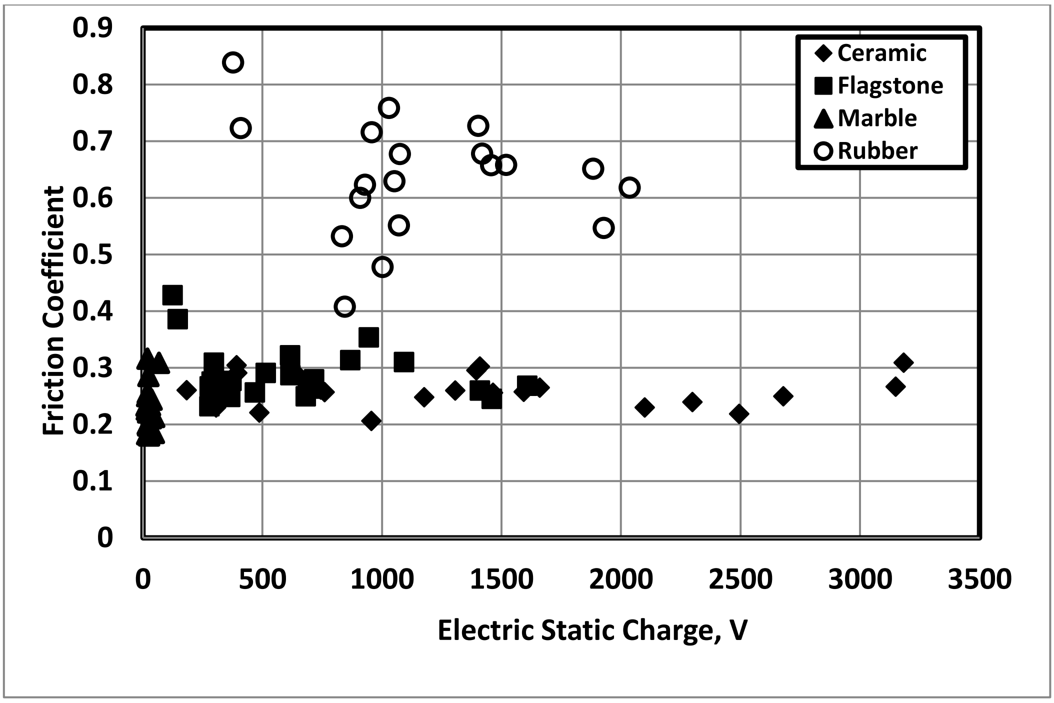

Fig. 8 Friction coefficient displayed by sliding of foot wearing sock (C) against the tested floor materials.

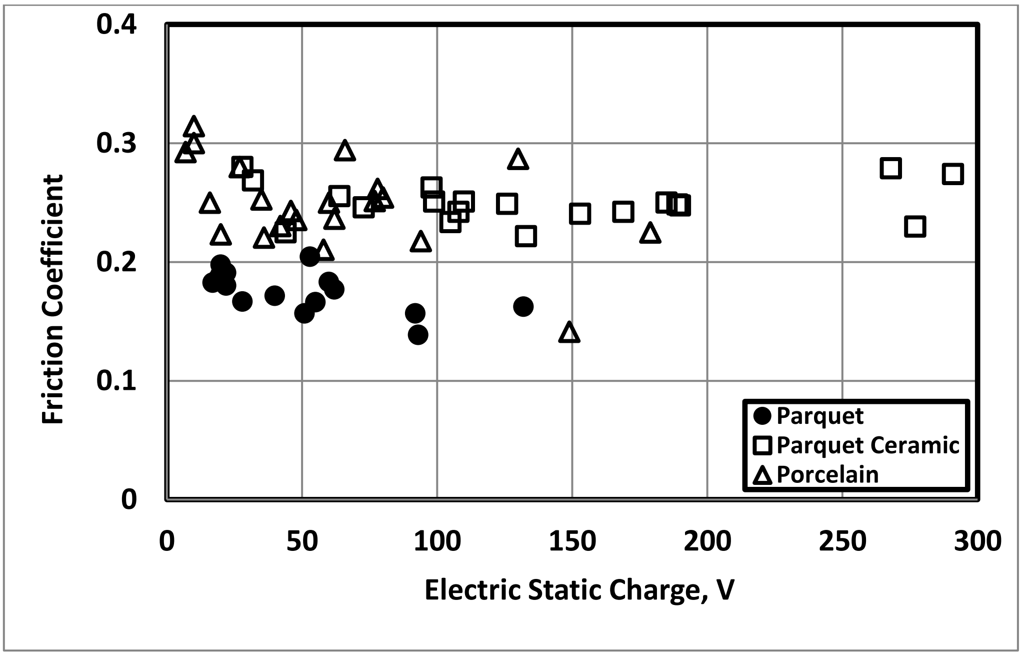

Fig. 9 Friction coefficient displayed by sliding of foot wearing sock (C) against the tested floor materials.

When socks (D) of 50 wt. % polyester and 50 wt. % polyacrylonitrile slid against the tested tiles, rubber showed very high values of electric static charge up to 4000 volts, Figs. 10, 11. The highest values of friction coefficient were not enough for safe use. This behaviour recommends the proper selection of sock materials. On the other side, porcelain generated very low electric static charge with considerable values of friction coefficient.

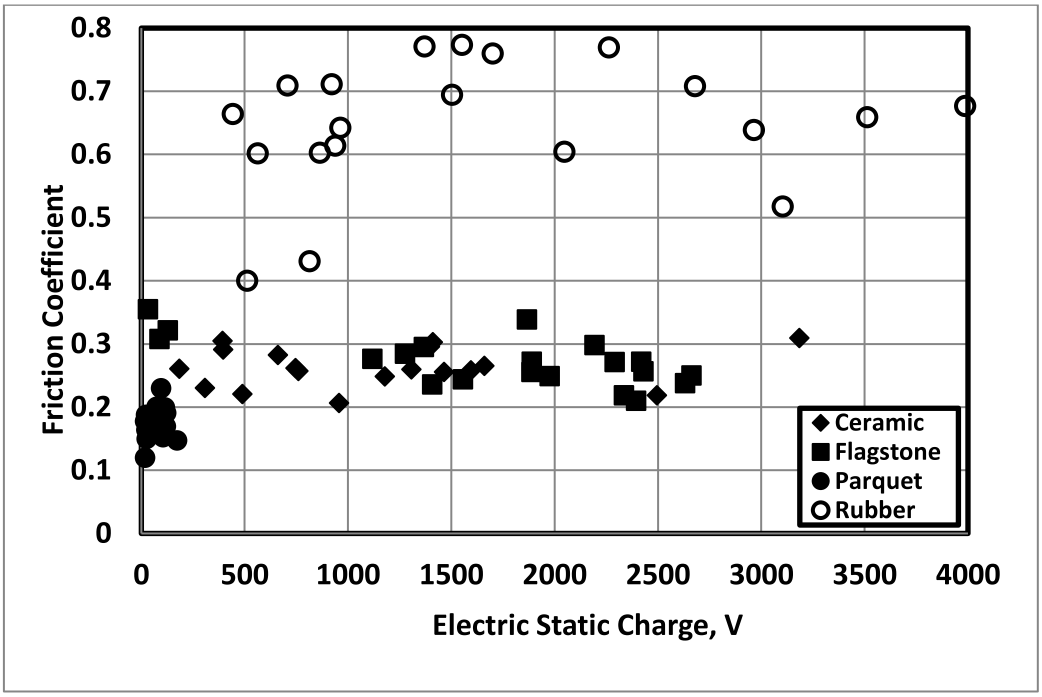

Fig. 10 Friction coefficient displayed by sliding of foot wearing sock (D) against the tested floor materials.

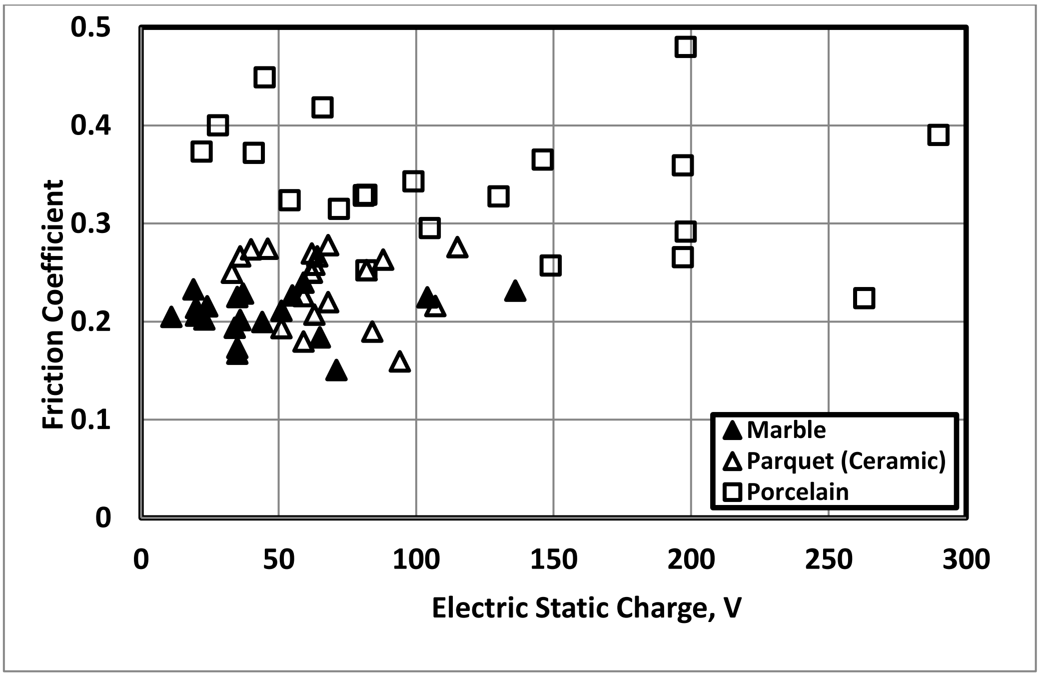

Fig. 11 Friction coefficient displayed by sliding of foot wearing sock (D) against the tested floor materials.

Friction and electric static charge values generated by cotton socks (D) showed the highest values when slid against rubber tiles, Figs. 12, 13. Parquet ceramic tiles gave the lowest electric static charge with friction coefficient ranged between 0.27 and 0.44.

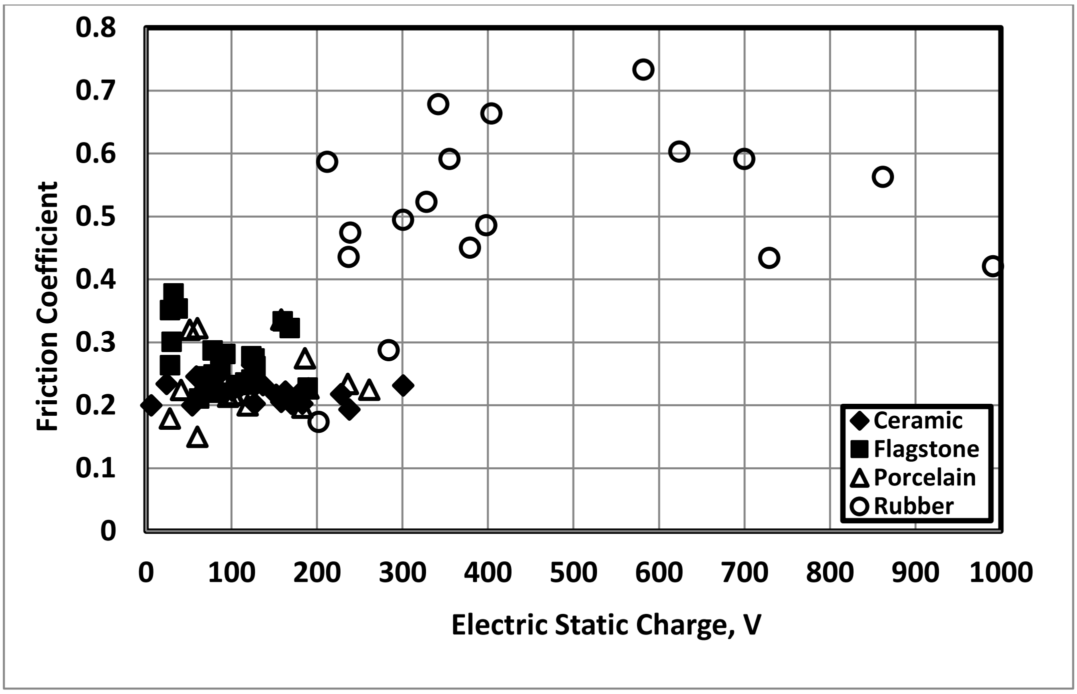

Fig. 12 Friction coefficient displayed by sliding of foot wearing sock (E) against the tested floor materials.

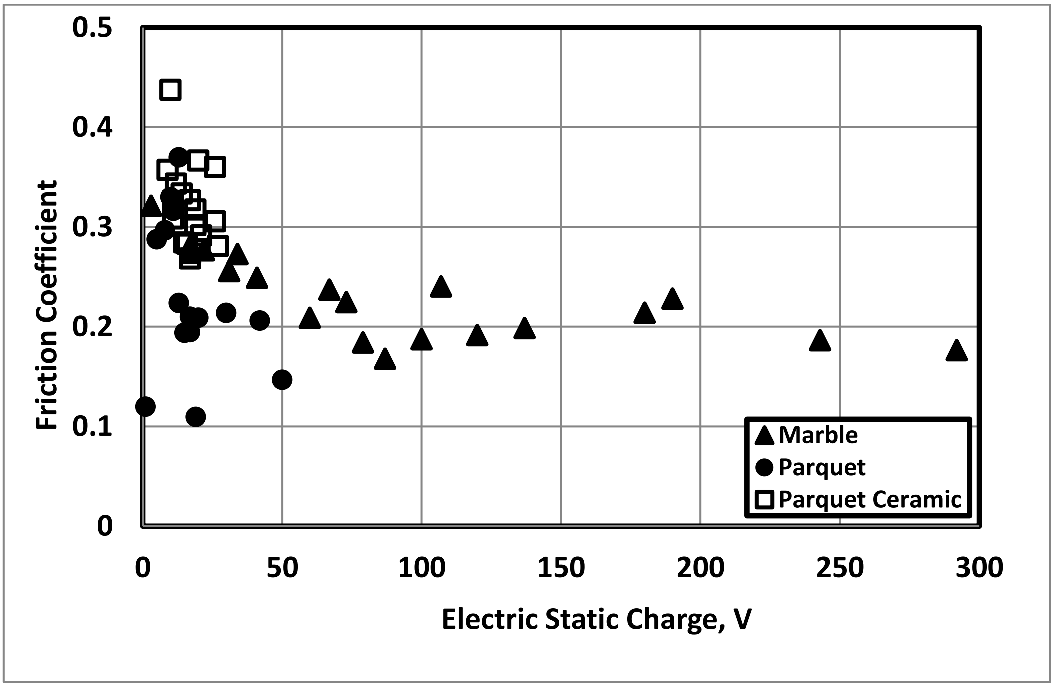

Fig. 13 Friction coefficient displayed by sliding of foot wearing sock (E) against the tested floor materials.

Friction coefficient displayed by sliding of foot wearing socks (F) of polyester-polyurethane copolymer (lycra) slid against the tested floor materials is shown in Figs. 14, 15. Rubber showed the highest values of both friction coefficient and electric static charge, Fig. 14. Ceramic and marble displayed the lowest electric static charge.

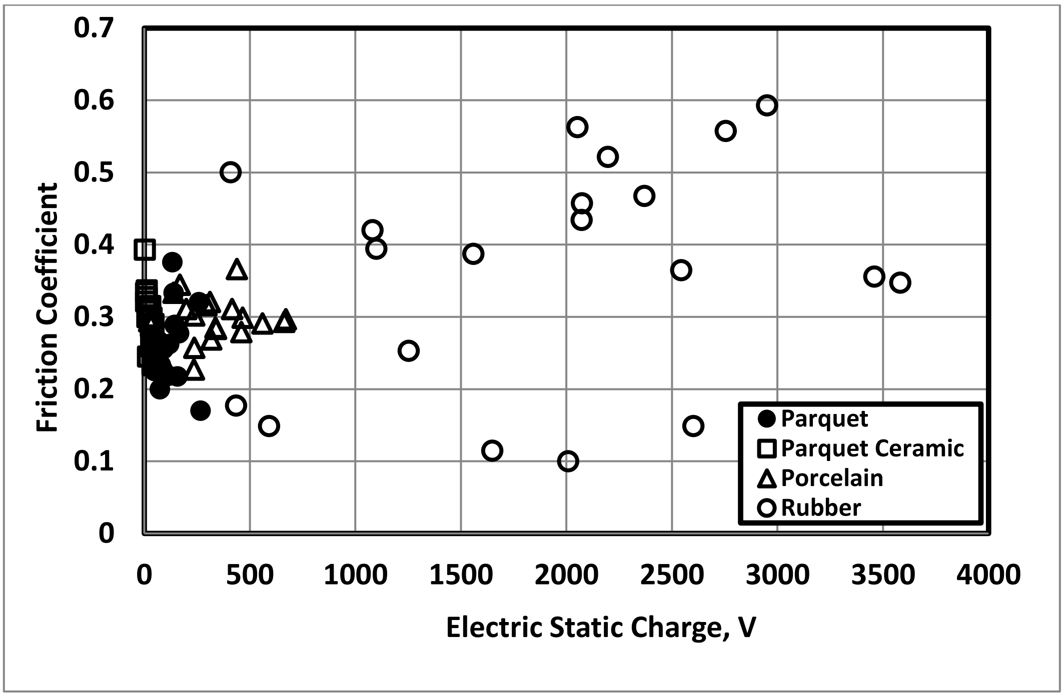

Fig. 14 Friction coefficient displayed by sliding of foot wearing sock (F) against the tested floor materials.

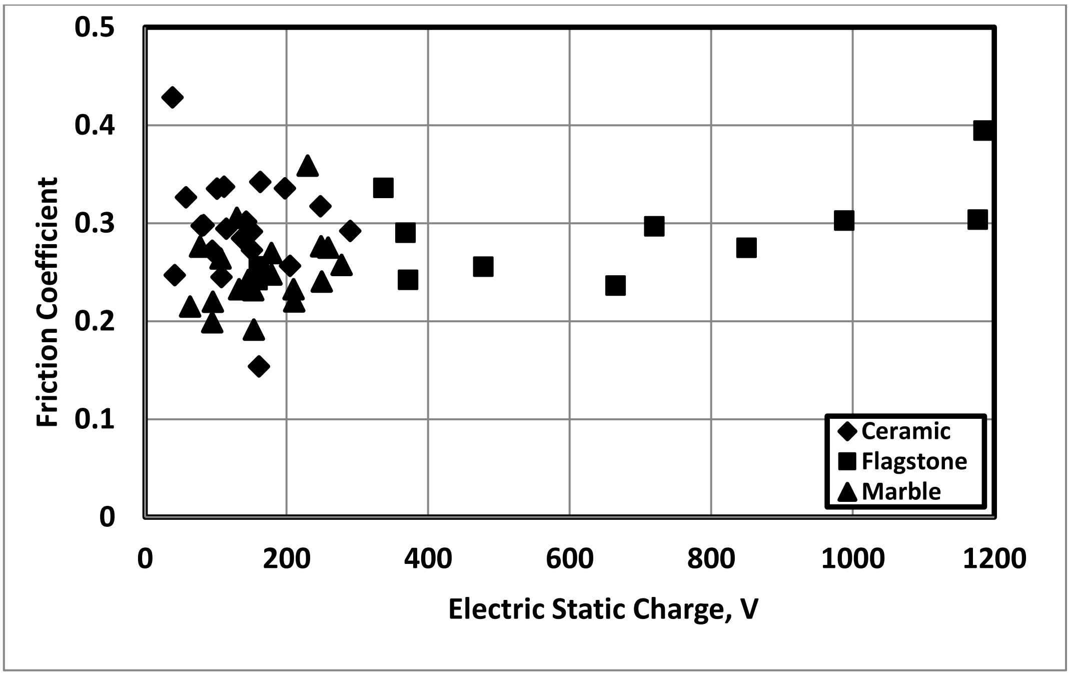

Fig. 15 Friction coefficient displayed by sliding of foot wearing sock (F) against the tested floor materials.

Friction coefficient and electric static charge generated by sliding of foot wearing socks (G) of 80 wt. % nylon and 20 wt. % lycra against the tested floor materials is illustrated in Figs. 16, 17. Rubber tiles still displayed the highest friction values with relatively low electric static charge.

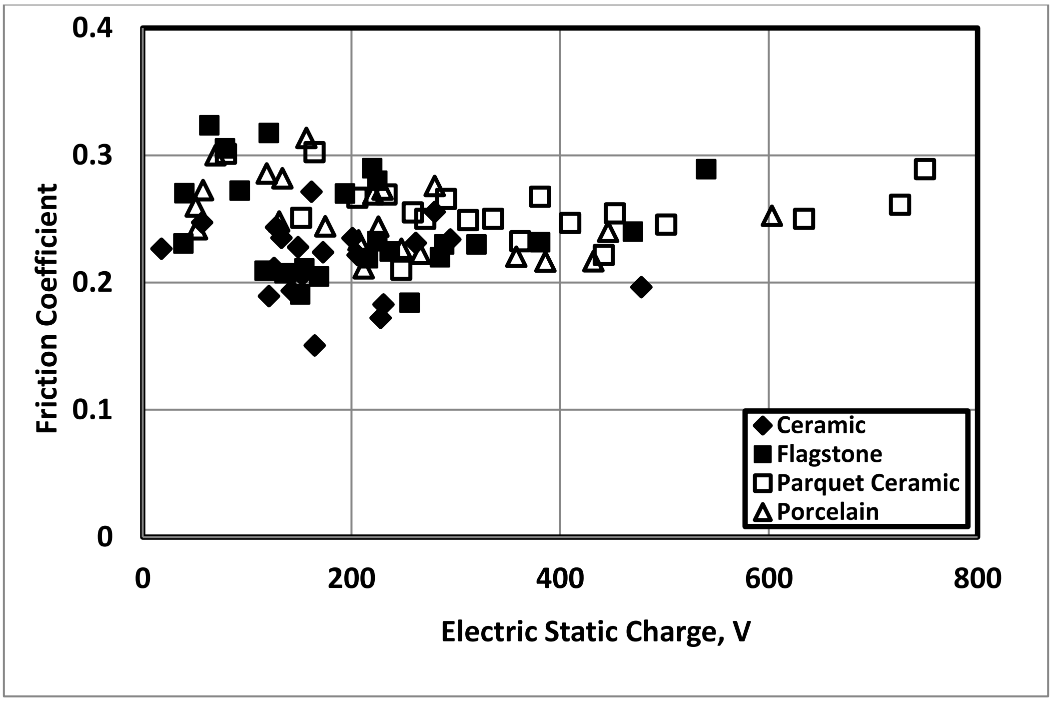

Fig. 16 Friction coefficient displayed by sliding of foot wearing sock (G) against the tested floor materials.

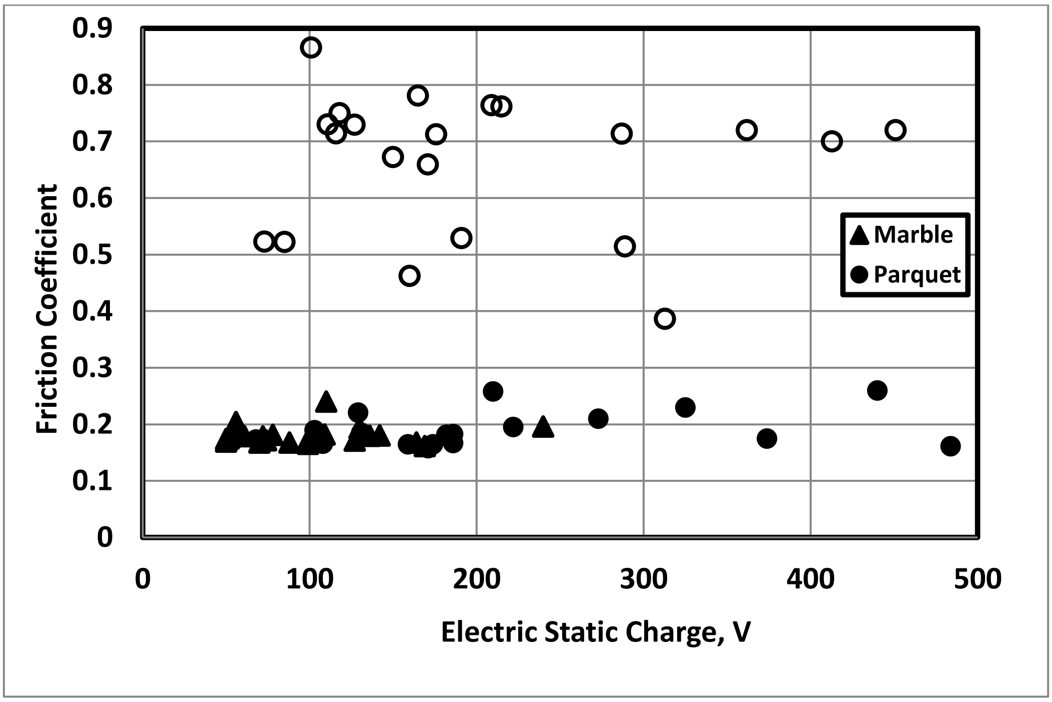

Fig. 17 Friction coefficient displayed by sliding of foot wearing sock (G) against the tested floor materials.

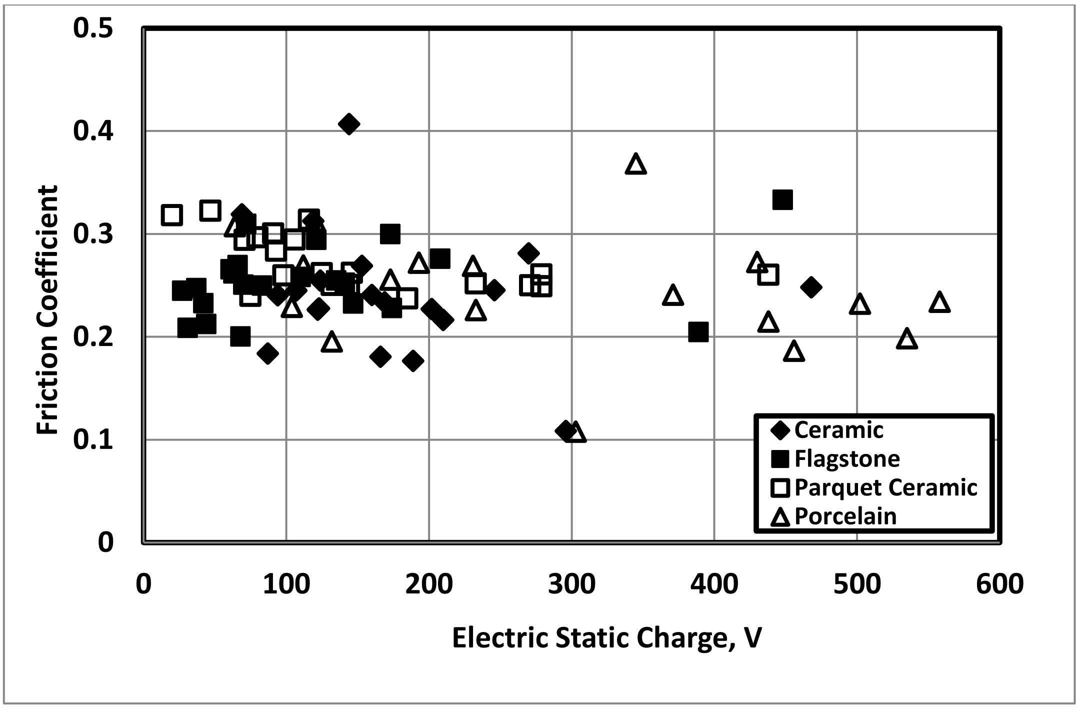

Fig. 18 Friction coefficient displayed by sliding of foot wearing sock (H) against the tested floor materials.

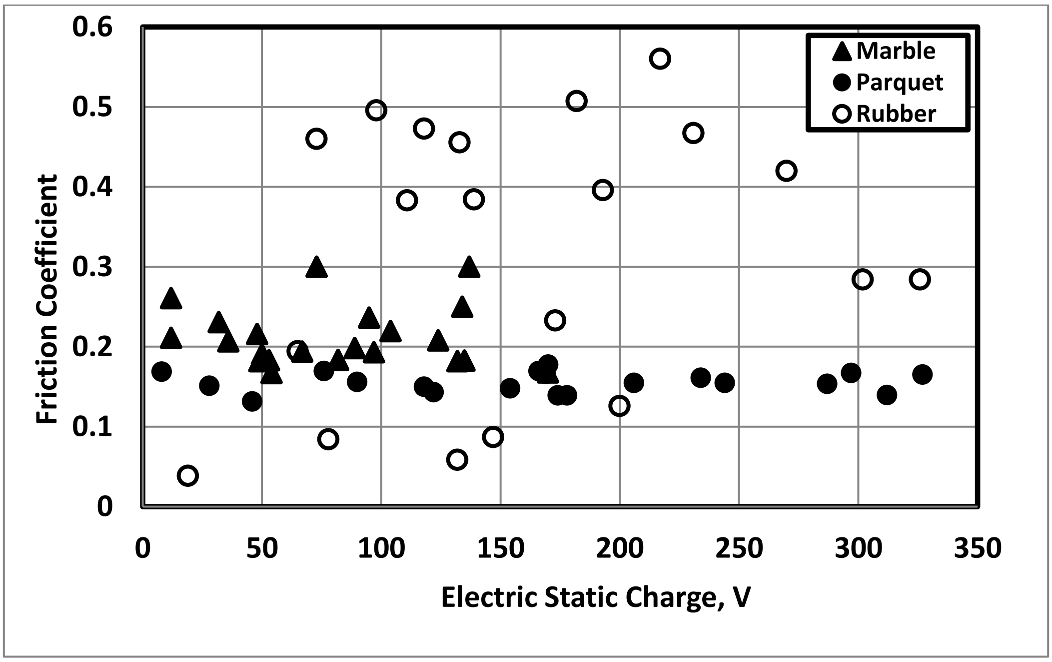

Fig. 19 Friction coefficient displayed by sliding of foot wearing sock (H) against the tested floor materials.

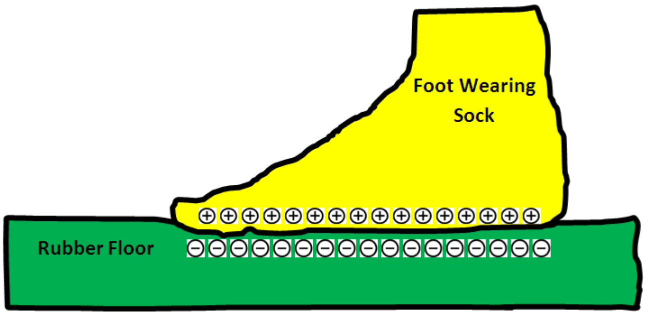

Fig. 20 Illustration of the generation of electric static charge on the sliding surfaces.

Polyamide socks slid against rubber floor showed significant decrease in friction coefficient and electric static charge, Figs. 18, 19, compared to that observed for socks made of 80 wt. % polyamide and 20 wt. % polyester-polyurethane copolymer (lycra), Figs. 6, 17. It seems that mixing polyamide of positive charge with lycra of relatively negative charge decreased the intensity of the electric static charge generated from friction. This behavior may be attributed to decrease of the gap between sock and floor materials in the triboelectric series. Extra work should be done to determine the position of the floor materials in the triboelectric series in order to properly select the material of the socks to avoid generation of excessive electric static charge.

Illustration of the generation of electric static charge on the sliding surfaces is shown in Fig. 20, where the equal electric static charges generated 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. When two materials contact each other, the upper one in the triboelectric series will be 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. Therefore, it is necessary to select the materials based on their triboelectric ranking. Besides, rubber floor showed the highest elastic deformation among the tested floors. Consequently, the contact area increased causing significant increase in the friction force.

CONCLUSIONS

1. It is recommended to establish codes for the intensity of electric static charge generated from the friction of floors.
2. Rubber displayed the highest friction values, while marble showed the lowest ones.
3. Porcelain generated the highest electric static charge followed by ceramic, rubber, flagstone, parquet, parquet ceramic and marble.
4. Mixing polyamide of positive charge with lycra of relatively negative charge decreased the intensity of the electric static charge generated from friction.
5. Further experiments should be carried out to determine the position of the floor materials in the triboelectric series in order to properly select the material of the socks to avoid generation of excessive electric static charge.

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