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Triboelectrification of Flooring Polymeric Materials

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Abstract— The increase of polymeric materials in floors necessitates to study their triboelectrificationbehaviour during friction. Electric static charges built up on human skin and or clothes in direct contact with human body are very harmful and can create serious health problems. Experiments were carried out to measure the electrostatic charge and friction coefficient of bare foot and rubber footwear sliding against epoxy and polyvinyl chloride (PVC) floors were investigated under dry sliding condition. It was found that, voltage generated from the sliding of rubber footwear against epoxy floor slightly increased with increasing load, while that generated from PVC floor displayed higher values. The highest value reached 2400 volts. As the load increased voltage significantly increased. Bare foot sliding against epoxy floor showed relatively lower voltage than that displayed by rubber footwear, where the maximum value reached 280 volts. This behaviour is attributed to the fact that bare foot conducted the electric static charge generated in the contact surface. Voltage generated from sliding of bare foot against PVC floor significantly increased with increasing load. It is clearly noted that PVC floor generated lowest voltage than that displayed by epoxy floor, where the maximum voltage did not exceed 520 volts. This observation can confirm the suitability of PVC floor to be applied as indoor floor where bare foot walking is dominating. 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. Sliding of bare foot against epoxy floor showed relatively lower friction values that did not fulfil the standards. Friction coefficient displayed by sliding against PVC floor showed relatively higher values than that displayed by epoxy floor. The highest friction value was 0.32, while the lowest one was 0.14.

Index Terms— Electrostatic charge, friction coefficient, bare foot, rubber footwear, polymeric floors.

1 Introduction

Triboelectric static charges building up on human skin and or clothes in direct contact with human body are very harmful and can create serious health problems. It is of considerable concern particularly for elderly people and infant. Walking and creeping on flooring can generate electric static charge of intensity depends on the material of flooring. 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, where the maximum voltage did not exceed 520 volts at 800 N load. Friction coefficient displayed by sliding against rubber flooring represented the highest values of friction coefficient compared to the other tested floorings. Bare foot showed the highest values followed by cotton and polyester socks. The lowest values were 0.6 for polyester socks at 800 N.

Voltage generated from sliding against all the tested floorings significantly increased with increasing load. Bare foot conducts the electric static charge, while cotton and polyester socks as insulating materials could store the charge. It is expected that electrical field will be formed due the electric charge formed on the sock and floor surfaces.

Bare foot and the materials of socks can affect the generated charge. 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.

The wide use of polymer fibers in textiles necessitates studying its electrification when rubbing other surfaces. The electric static charge generated from the friction of different polymeric textiles sliding against cotton textiles, which used as a reference material, was discussed, [6]. Experiments were carried out to measure the electric static charge generated from the friction of different polymeric textiles sliding against cotton under varying sliding distance, velocity and load. It was found that increase of cotton content decreased the generated voltage. Besides, as the load increased voltage generated from rubbing of 100 % spun polyester specimens increased. Besides, mixing polyester with rayon (viscose) showed the same behaviour of mixing with cotton. Generally, increasing velocity increased the voltage. The voltage increase when increasing velocity may be attributed to the increase of the mobility of the free electrons to one of the rubbed surfaces. The fineness of the fibers greatly influences the movement of the free electrons.

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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, [7]. 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 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 Ra 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, [8]. 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, [9]. 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, [10]. Surface changes through mechanical wear range from smoothing to roughening, [11, 12], 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 slid against rubber and leather on the friction coefficient was investigated, [13]. 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 behaviours. Floor slipperiness may be quantified using the static and dynamic friction coefficient, [14]. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [15, 16]. 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, [17 - 20]. 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.

The influence of triboelectrification of the contact surfaces on friction coefficient displayed by polymethyl methacrylate (PMMA), and high density polyethylene (HDPE) spheres sliding against polytetrafluoroethylene (PTFE) and steel sheets was presented, [21]. The effect of insulating the sliding surfaces on the friction coefficient was discussed at dry and water as well as salt water wetted sliding conditions, [22]. The increase of polymeric materials use in engineering application necessitates study their triboelectrification behaviour during friction. Experiments were carried out to measure the electric static charge generated from the friction of different polymeric materials {polyamide (PA 6), graphite filled polyamide (GPA 6), polyethylene terephthalate, (PET), polytetrafluoroethylene, (PTFE) and polymethyl methacrylate, (PMMA)} sliding against stainless steel at 60 and 180 N load. The test was carried out at water, salt water and oil lubricated sliding surfaces.

In the present work, electrostatic charge and friction coefficient of bare foot and rubber footwear sliding against epoxy and PVC flooring materials were investigated under dry sliding condition.

2.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 floor materials were epoxy and PVC in form of a quadratic sheet of 0.4 m × 0.4 m. The sliding surfaces were thoroughly cleaned with soap water to eliminate dirt as well as dust and carefully dried before the tests. Bare foot and rubber footwear were loaded against the tested floor materials. 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 specimens 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

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mm apart from the surface being tested.

3 RESULTS AND DISCUSSIONAS

The electric static charge generated from the sliding of rubber footwear and bare foot against epoxy floor as well as friction coefficient are illustrated in Figs. 1 – 8. Voltage generated from the sliding of rubber footwear against epoxy floor slightly increased with increasing load, Fig. 1. This behaviour might be attributed to increase of the contact area with increasing load. Due to the nature of the electric static charge the scatter in the values measured during experiments was relatively high, where the maximum value was 1000 volts while the minimum was 200 volts.

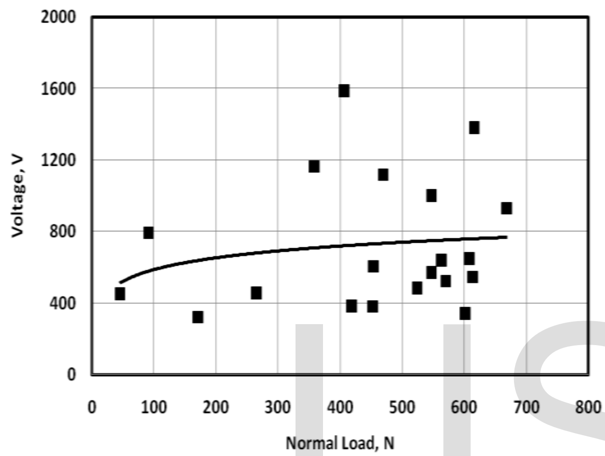

Fig. 1 Voltage generated from sliding of rubber footwear against epoxy floor.

The values of friction coefficient displayed by sliding against epoxy floor are shown in Fig. 2, where rubber footwear displayed consistent trend of friction coefficient with increasing load. The highest friction coefficient value was 0.86, while the lowest was 0.58.

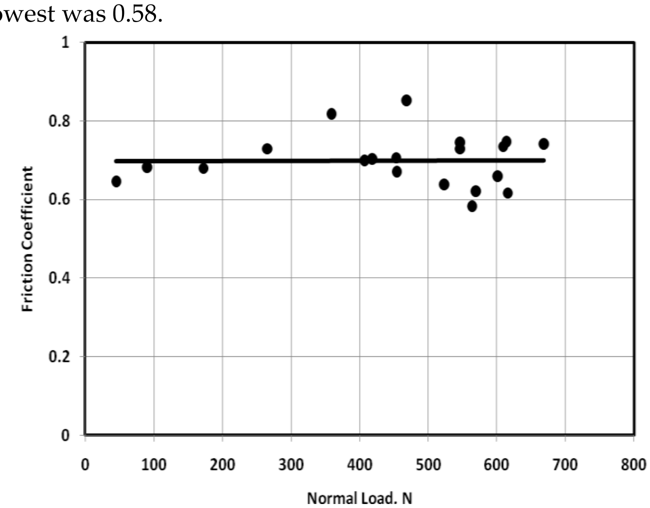

Fig. 2 Friction coefficient displayed for sliding of rubber footwear against epoxy floor.

Voltage generated from sliding rubber footwear against PVC floor displayed higher values than that observed for epoxy floor, Fig. 3. The highest value reached 2400 volts. As the load increased voltage significantly increased. Based on this observation it can be concluded that PVC floor is much dangerous than epoxy floor in generating electric static charge.

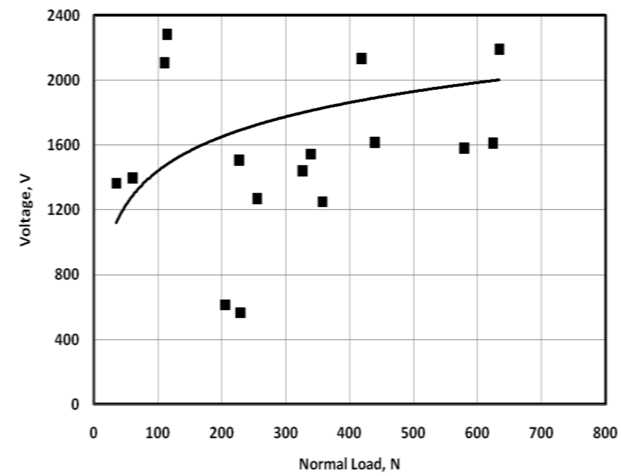

Fig. 3 Voltage generated for sliding of rubber footwear against PVC floor.

Rubber footwear sliding against PVC floor, Fig. 4, experienced lower friction coefficient than that observed on epoxy one. The highest friction value reached 0.82, while the lowest was 0.4. Friction coefficient slightly decreased with increasing applied load. Based on the American and European standards those values are enough for safe walking at dry sliding condition.

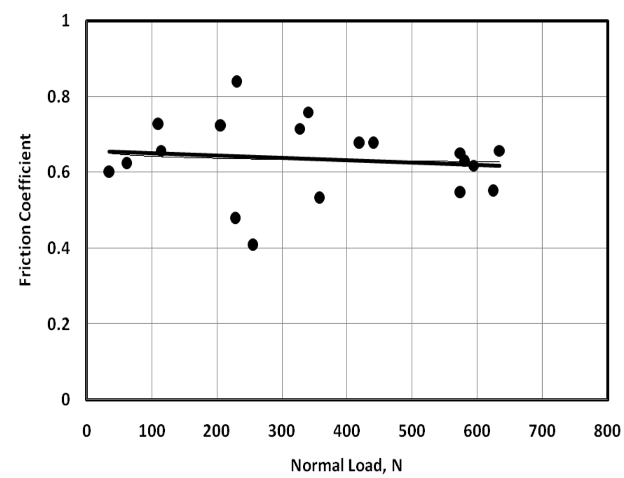

Fig. 4 Friction coefficient displayed for sliding of rubber footwear against PVC floor.

Voltage generated from sliding of bare foot against epoxy floor is illustrated in Fig. 5. Compared to rubber footwear,

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bare foot showed relatively lower voltage, where the maximum value reached 280 volts. This behaviour is attributed to the fact that bare foot conducted the electric static charge generated in the contact surface. When two materials contact each other, the upper one in the triboelectric series will get positively charged and the other one will be negatively charged. As the difference in the rank of the two materials increases the generated voltage increases, [4]. It is known that epoxy is ranked as negative charged material, while skin of the bare foot is positive charged one and the gap is relatively short in the triboelectric series which decreases the voltage difference. It is therefore necessary to select the materials based on their triboelectric charging.

Sliding against epoxy floor showed relatively lower friction values for bare foot, Fig. 6, where drastic decrease was observed in friction coefficient with increasing normal load. Bare foot displayed friction value of 0.25 and 0.20 at 100 and 800 N respectively. The friction values did not fulfill the American standards, where the static coefficient of friction of 0.5 has 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.

Voltage generated from sliding of bare foot against PVC floor significantly increased with increasing load, Fig. 7. It is clearly noted that PVC floor resulted lowest voltage than that display the all tested flooring, where the maximum voltage did not exceed 520 volts at d by epoxy floor. The highest value was 142 volts. This observation can confirm the suitability of PVC floor to be applied as indoor floor where bare foot walking is dominating.

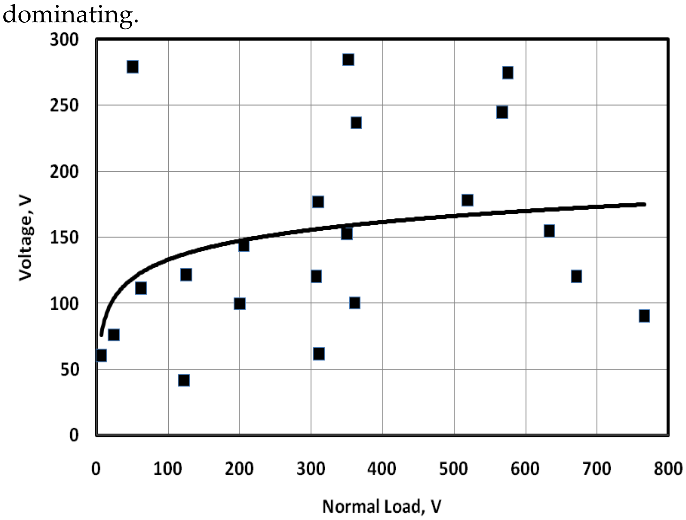

Fig. 5 Voltage generated for sliding of bare foot against epoxy floor.

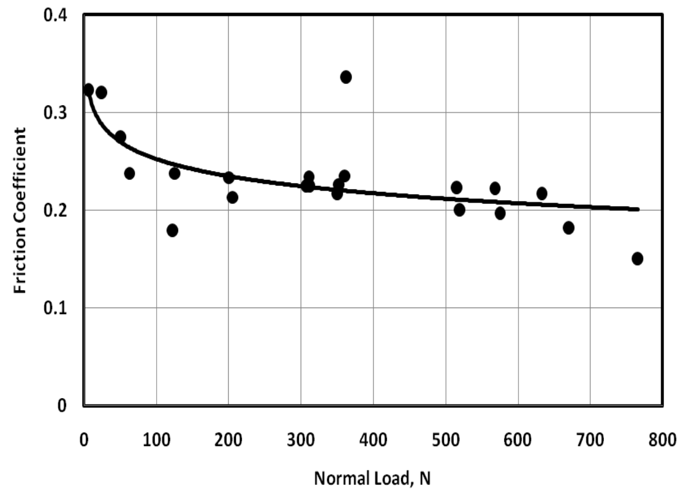

Fig. 6 Friction coefficient displayed for sliding of bare foot against epoxy floor.

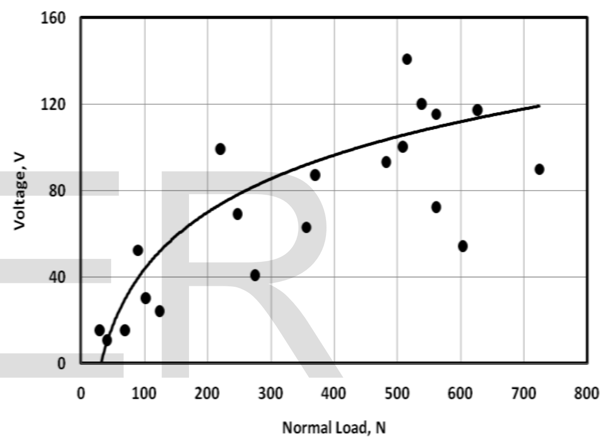

Fig. 7 Voltage generated for sliding of bare foot against PVC floor.

Friction coefficient displayed by sliding against parquet PVC floor showed relatively higher values than that displayed by epoxy floor, Fig. 8. The highest friction value was 0.32, while the lowest one was 0.14. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [16, 17]. Relatively higher static and dynamic friction coefficient values may be required for safe walking when handling loads. The observed friction values for epoxy and PVC floors were lower than the recommended ones.

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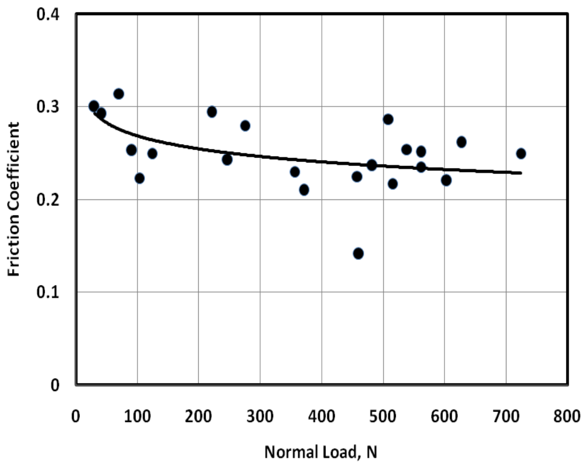

Fig. 8 Friction coefficient displayed for sliding of bare foot against PVC floor.

4 Conclusion

1. Voltage generated from the sliding of rubber footwear against epoxy floor slightly increased with increasing load.
2. Voltage generated from sliding rubber footwear against PVC floor displayed higher values than that observed for epoxy floor. The highest value reached 2400 volts. As the load increased voltage significantly increased.
3. 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.
4. Rubber footwear 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.

5. Bare foot sliding against epoxy floor showed relatively lower voltage than that displayed by rubber footwear, where the maximum value reached 280 volts. This behaviour is attributed to the fact that bare foot conducted the electric static charge generated in the contact surface.
6. Voltage generated from sliding of bare foot against PVC floor significantly increased with increasing load. It is clearly noted that PVC floor generated lowest voltage than that displayed by epoxy floor, where the maximum voltage did not exceed 520 volts. This observation can confirm the suitability of PVC floor to be applied as indoor floor where bare foot walking is dominating.
7. Sliding of bare foot against epoxy floor showed relatively lower friction values, where friction values did not fulfil the standards.
8. Friction coefficient displayed by sliding against parquet PVC floor showed relatively higher values than that displayed by epoxy floor. The highest friction value was 0.32, while the lowest one was 0.14. charge homogeneously on the PMMA and PTFE surfaces.

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