EGTRIB Journal

JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 15, No. 3, July 2018, pp. 1 – 10, **ISSN 2090 - 5882**
(Received February 11. 2018, Accepted in final form June 28. 2018)

FRICTION BEHAVIOR OF EPOXY FLOOR TILES FILLED BY CARBON NANOPARTICLES

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ABSTRACT
The friction behaviour of epoxy floor tiles filled by carbon nanoparticles as well as electrostatic charge (ESC) generated from friction when rubber footwear is sliding against them are investigated.

It was found that filling epoxy by carbon nanoparticles caused significant decrease in friction coefficient at dry sliding. This behavior can be attributed to the fact that carbon nanoparticles transferred into the rubber surface forms low friction layer, where carbon worked as solid lubricant. Besides, carbon transfer into rubber surface could carry negative ESC from epoxy to neutralize the positive ESC on the rubber surface in a manner that adhesion between the two contacting surfaces could decrease. At water wet sliding, friction coefficient showed relatively higher values than that recorded for dry one. Besides, sliding at detergent wet epoxy composites displayed higher values of friction coefficient than that observed for water wet surface. The intensity of ESC increases due to the good electrical conductivity of carbon nanoparticles. The ESC increase is responsible for the increase of friction due to the increase of adhesion of the two contact surfaces. This observation recommends the application of the proposed composites in the floor of bathrooms. Friction coefficient displayed by rubber shoe sliding on oil/water dilution wet epoxy composites showed relatively higher friction than that observed for oil lubricated sliding. This observation recommends the use of the proposed composites in kitchens floor.

KEYWORDS
Epoxy composites, carbon nanoparticles, friction coefficient, electrostatic charge.

INTRODUCTION
Slip accidents indoor can be reduced by developing floor materials. Triboelectrification of polymeric composites can be controlled by filling them by carbon black, [1], where the electrostatic charge (ESC) generated from friction can be reduced. Recently, the effect of reinforcing epoxy by carbon fibres (CF), and coating by polyurethane on the friction coefficient displayed by contact and separation as well as sliding of bare foot and foot wearing rubber contacting epoxy was discussed, [2, 3]. It was observed that ESC increased with increasing CF content. Besides, as the CF were close to the sliding surface ESC increased. It is known that the strength of the electric field inside the epoxy matrix

is proportional to how much charge is generated on the friction surface. The significant ESC increase when the CF were close to the surface confirmed the presence of a magnetic field around the CF that is directly proportional to the current value and inversely proportional to the distance from the conductor. ESC generated during contact and separation as well as sliding of insulating materials can play a major role in adhesion energy and alter friction. Reinforcing epoxy by carbon fibres (CF) and coating by polyurethane gave higher ESC and friction coefficient than that generated by epoxy. Besides, epoxy floor reinforced by CF and coated by polyurethane (PU) contaminated by sand particles was investigated, [4]. It was found ESC generated from sliding of PU coated by sand against bare foot displayed relatively higher values than that measured for epoxy and PU surfaces. Presence of sand increases friction coefficient due to the abrasive action of particles in bare foot surfaces which increases ESC. The penetration of sand particles into bare foot increases the contact area and hence increases ESC. Friction coefficient values recorded relatively higher values than that shown for epoxy and PU coating.

The effect of the cotton content of socks on the frictional behaviour of foot during walking was investigated, [5 – 7]. 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.

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, [8]. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [9, 10]. 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, [11, 12]. 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, [13 - 16], 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 ESC generated from sliding of rubber footwear against epoxy tiles filled by carbon nanoparticles are investigated.

EXPERIMENTA

Experiments were carried out using test rig designed and manufactured to measure friction coefficient through measuring the friction force and applied normal load, Fig. 1. The tested materials were placed in a base supported by two load cells, the first measures the horizontal force (friction force) and the second measures the vertical force (normal load) to measure friction coefficient. A handheld electrostatic meter is used to measure the magnitude and polarity of ESC generated on the sliding surfaces by a back sensor in a disc shape without contact. It is typically held 25 mm from the test specimen surface.

The tested floor materials are in form of epoxy tiles filled by carbon nanoparticles of 30 – 50 ηm particle size. The counterface is rubber footwear. The tested floor tiles are prepared in square shape with area of 300 × 300 mm^2 and 5 mm thickness. The hardness

of the rubber foot wear was 70 Shore A. Friction test was carried out under different applied normal loads ranging from 200 to 1000 N at dry, water, detergent (1.0 wt. %), Paraffin oil and oil/water dilution (5.0 wt. % oil) wet sliding conditions. The tested epoxy tiles were filled by carbon nanoparticles of 0, 0.2, 0.4, 0.6, 0.8 and 1.0 wt. %. Tests were carried out by pressing and sliding the foot against tested tiles at different applied load and sliding distance of 0, 50, 100, 150 and 200 mm.

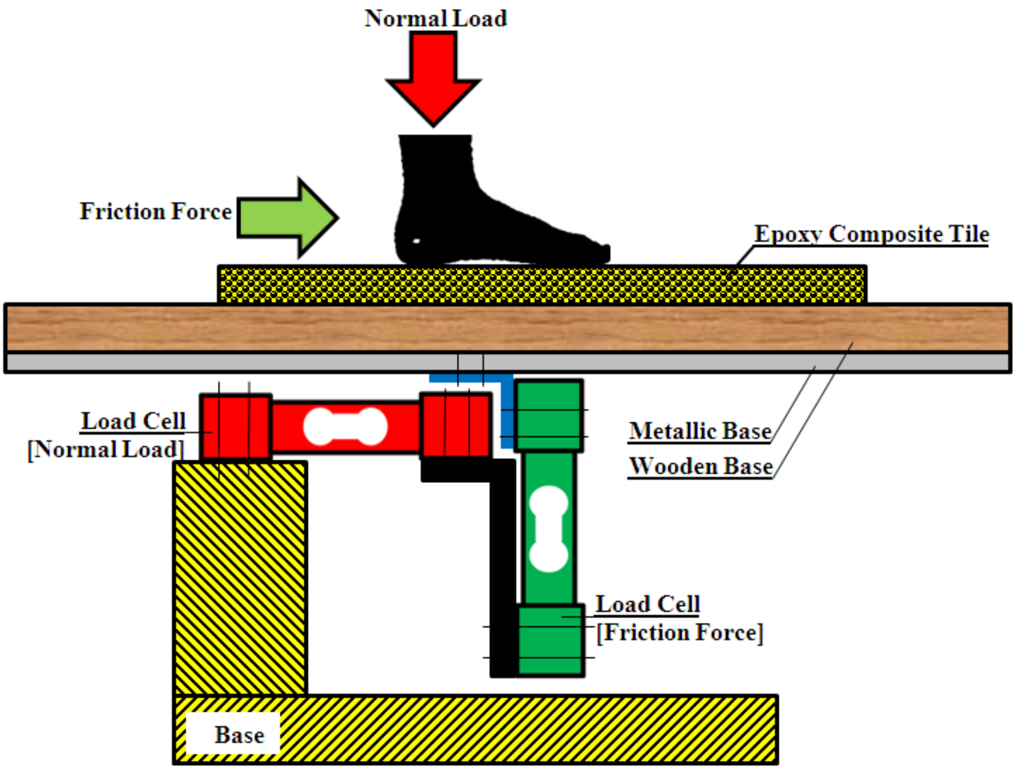

Fig. 1 Arrangement of the test rig.

RESULTS AND DISCUSSION

Friction coefficient displayed by rubber shoe sliding on dry epoxy composites, Fig. 2, drastically decreased down to minimum then slightly increased with increasing carbon nanoparticles content. The minimum friction values were observed at 0.6 – 0.8 wt. % carbon. It is clearly shown that filling epoxy by carbon nanoparticles caused significant decrease in friction coefficient. This behavior can be attributed to the fact that carbon nanoparticles transferred into the rubber surface forming low friction layer, where carbon worked as solid lubricant. Besides, carbon transfer into rubber surface carried negative ESC from epoxy to neutralize the positive ESC on the rubber surface in a manner that adhesion between the two contacting surfaces decreased.

At water wet sliding, friction coefficient showed relatively higher values than that recorded for dry sliding, Fig. 3. The highest friction values were observed at 0.6 wt. % carbon content. The presence of carbon nanoparticles is responsible for the friction increase. This behavior can be illustrated in Figs. 4 and 5. When unfilled epoxy contacted rubber, ESC was generated as result of friction. Rubber surface gained positive ESC, while epoxy gained negative ESC. In the presence of carbon nanoparticles the intensity of ESC increased due to the good electrical conductivity of carbon nanoparticles. ESC generated will uniformly distributed on the friction surface. The ESC increase was

responsible for the increase of friction due to the increase of adhesion of the two contact surfaces. The minimum friction coefficient value reached 0.115 at 1000 N load. This friction value recommends the application of the proposed composites in the internal surfaces of ducts and tubes. In the presence of water film, friction increased due to good distribution of ESC on the contacting two surfaces so that the adhesive force between the two charges increased.

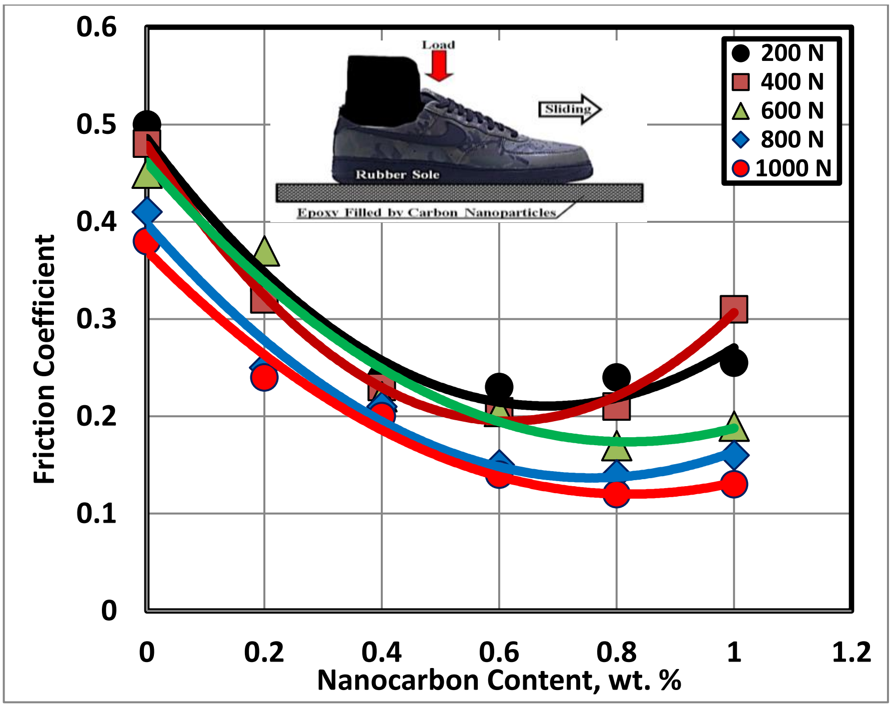

Fig. 2 Friction coefficient displayed by rubber shoe sliding on dry epoxy composites.

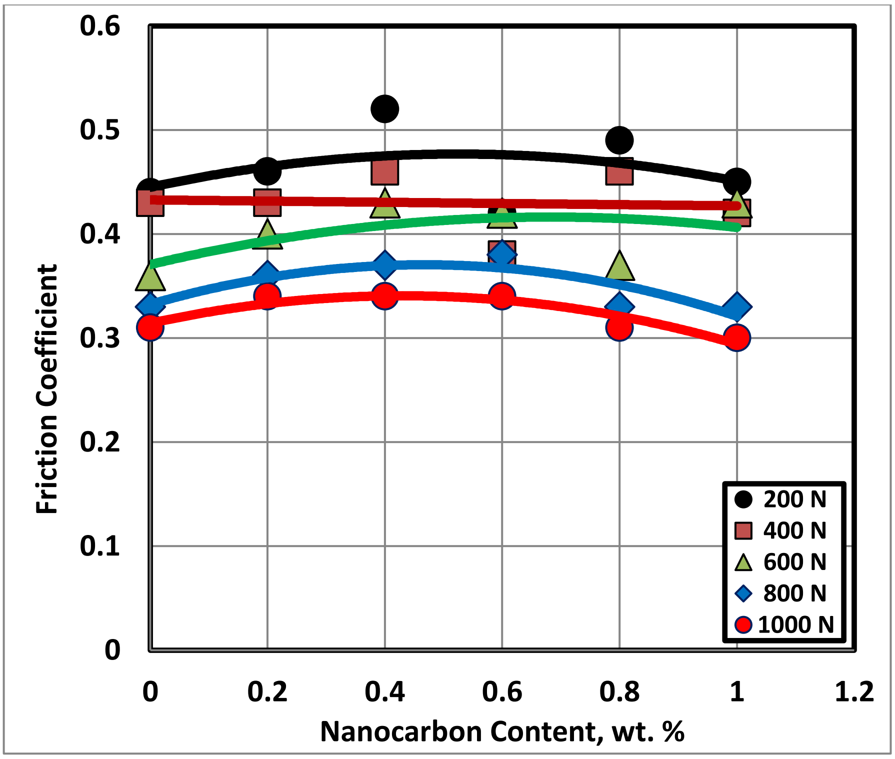

Fig. 3 Friction coefficient displayed by rubber shoe sliding on water wet epoxy composites.

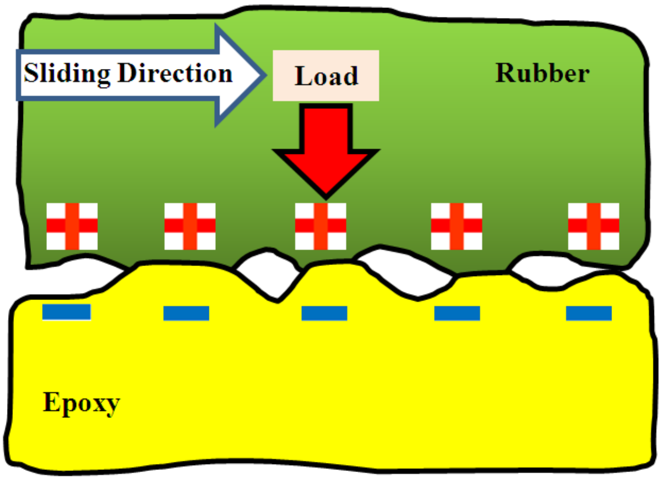

Fig. 4 Contact between rubber and unfilled epoxy surfaces during sliding.

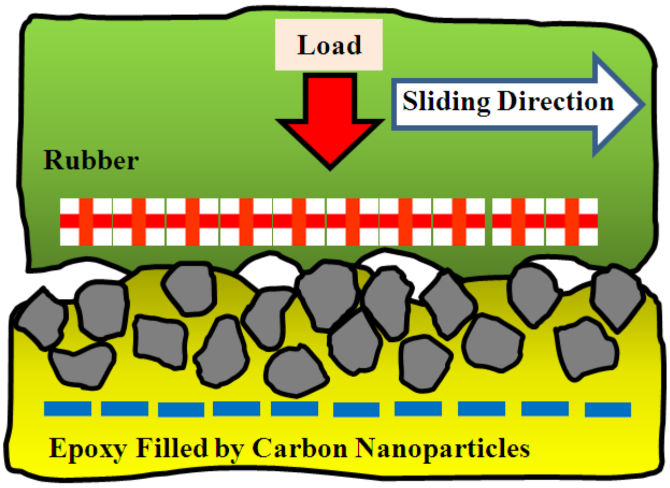

Fig. 5 Contact between rubber and carbon nanoparticles filled epoxy surfaces during sliding.

Sliding at detergent wet epoxy composites displayed higher values of friction coefficient than that observed for water wet surface, Fig. 6. This behaviour can be explained on the fact that adhesion of the two contact surfaces was stronger than that occurred in the presence of water. It seems that electric properties of polar detergent molecules are responsible for adhesion increase. That observation can be useful in the floor of bathrooms. While sliding of rubber shoe at oil lubricated epoxy composites, Fig. 7, showed drastic friction decrease. Filling epoxy by carbon nanoparticles slightly increased friction coefficient. It seems that carbon particles could break the oil film adhered on both rubber and epoxy surfaces leading to the increase in friction values. Besides, the interaction of the carbon particles in rubber surface might decrease the adhesion of oil into the rubber surface. At relatively lower loads (200, 400 N) friction increase was slight, while at higher loads (600, 800 and 1000 N) friction increase was pronounced. Friction coefficient displayed by rubber shoe sliding on oil/water dilution wet epoxy composites showed relatively higher friction than that observed for oil lubricated sliding,

Fig. 8. It seems that presence of water enhanced the conductivity of the fluid film and ESC generated on the two contacting surfaces was quite strong to increase adhesion of the sliding surfaces. This observation recommends the use of the proposed composites in kitchens floor where the floor is spotty by oil and water.

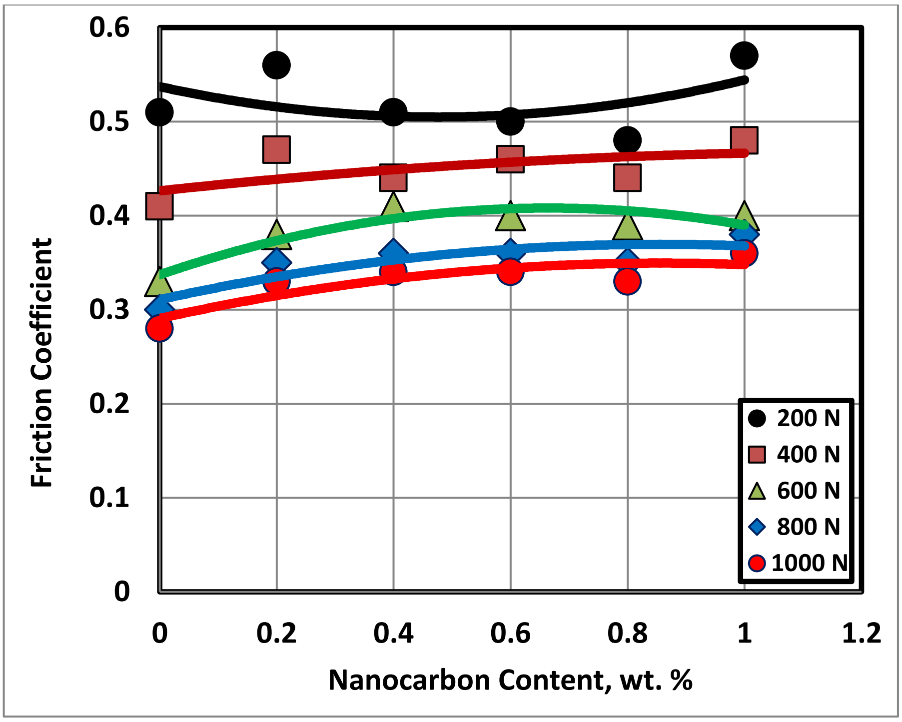

Fig. 6 Friction coefficient displayed by rubber shoe sliding on detergent wet epoxy composites.

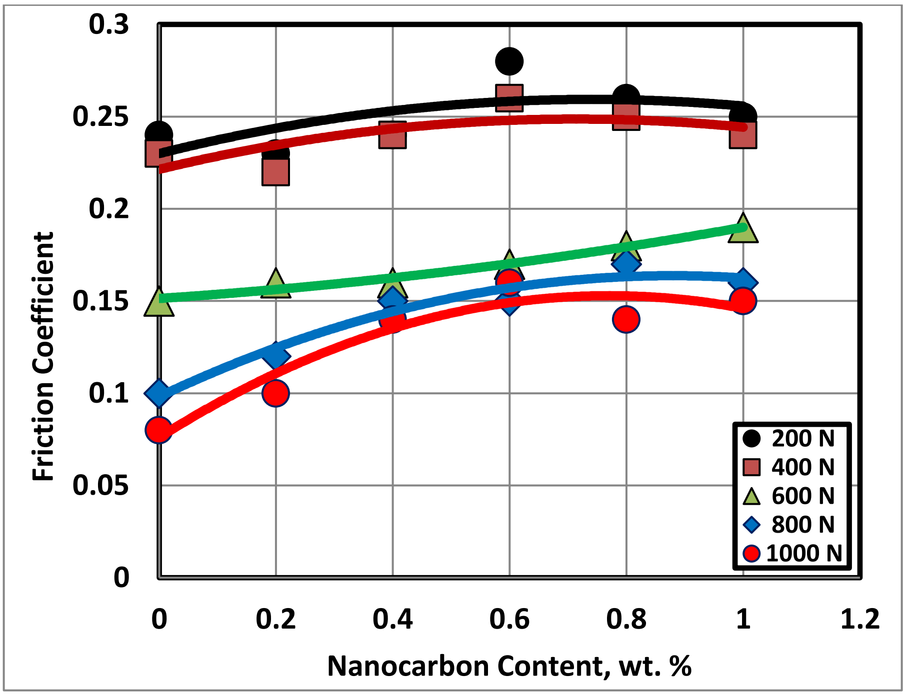

Fig. 7 Friction coefficient displayed by rubber shoe sliding on oil lubricated epoxy composites.

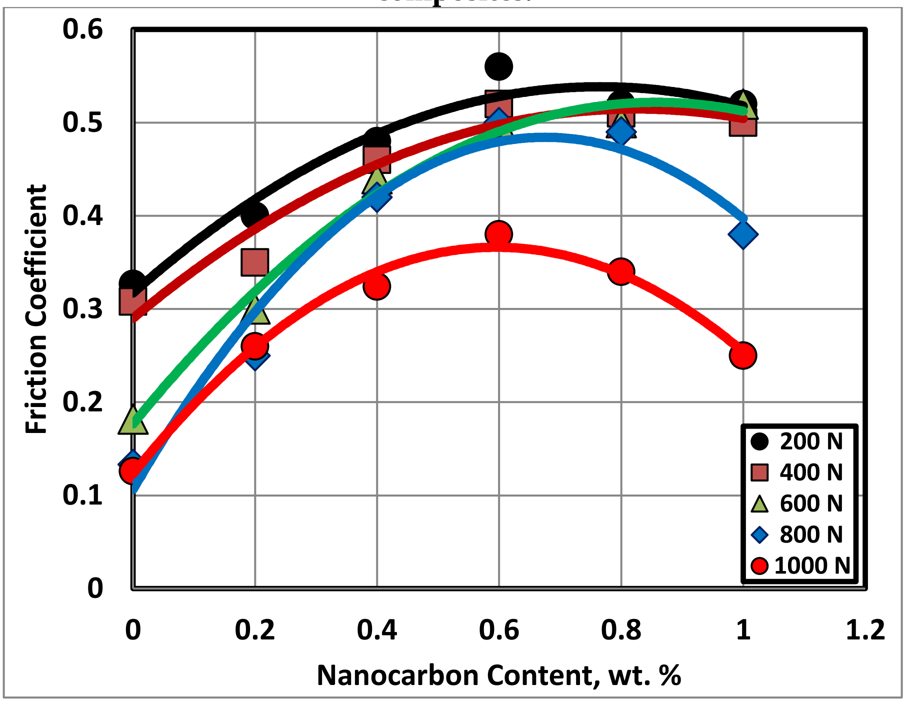

Fig. 8 Friction coefficient displayed by rubber shoe sliding on oil/water dilution wet epoxy composites.

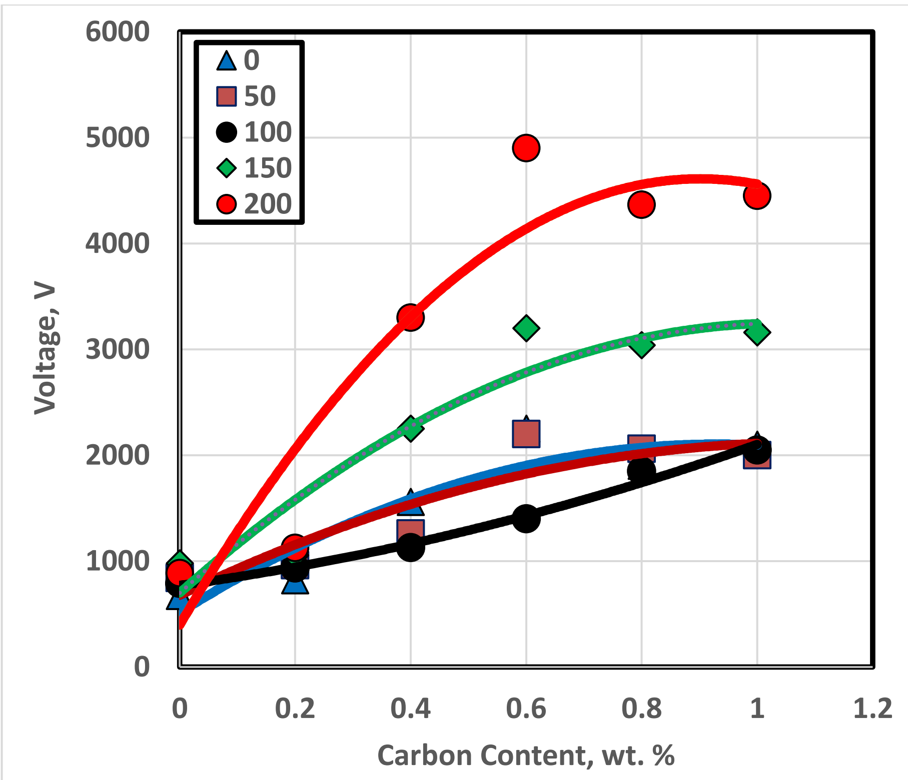

Fig. 9 ESC generated on rubber surface sliding on dry epoxy composites.

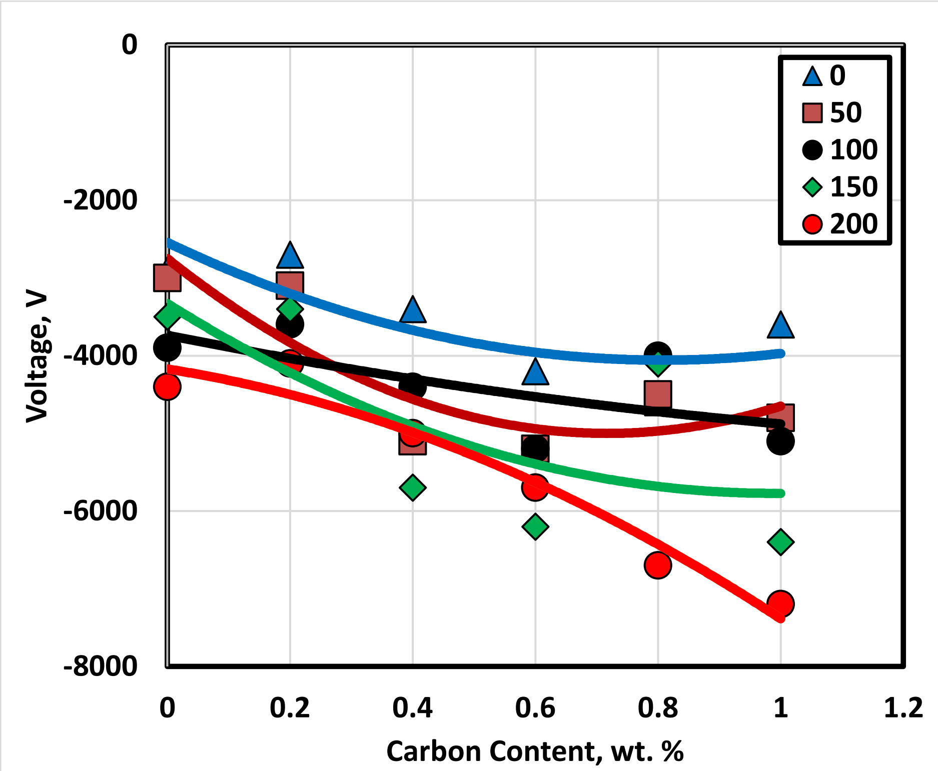

Fig. 10 ESC generated on dry epoxy composites when rubber surface slid on it.

ESC generated on the sliding surfaces is shown in Figs. 9 and 10, where the ESC is generated of different signs on both the rubber shoe and epoxy composites. 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. ESC generated on rubber surface sliding on dry epoxy composites is shown in Fig. 9, where the highest intensity was observed after 200 mm sliding distance. ESC significantly increased with increasing carbon content. ESC generated on dry epoxy composites after sliding is illustrated in Fig. 10. The highest ESC values (5000 and -7200 volts for rubber and epoxy respectively) were recorded at 1.0 wt. % carbon content. ESC generated on rubber represented higher values relative to epoxy filled by carbon nanoparticles due to the good electrical conductivity of epoxy composites.

CONCLUSIONS

1. Friction coefficient displayed by rubber shoe sliding on dry epoxy composites drastically decreased down to minimum then slightly increased with increasing carbon nanoparticles content. The minimum friction values were observed at 0.6 – 0.8 wt. % carbon.

2. At water wet sliding, friction coefficient showed relatively higher values than that recorded for dry sliding, where ESC increases due to the good electrical conductivity of carbon nanoparticles. The ESC increase is responsible for the increase of friction due to the increase of adhesion of the two contact surfaces.

3. Sliding at detergent wet epoxy composites displayed higher values of friction coefficient than that observed for water wet surface.
4. Sliding of rubber footwear at oil lubricated epoxy composites showed drastic friction decrease.
5. Friction coefficient displayed by rubber footwear sliding on oil/water dilution wet epoxy composites showed relatively higher friction than that observed for oil lubricated sliding.
6. ESC significantly increased with increasing carbon content.

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