EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 15, No. 3, July 2018, pp. 24 - 36 ISSN 2090 - 5882
(Received February 27. 2018, Accepted in final form June 08. 2018)

FRICTION BEHAVIOR OF EPOXY FLOOR TILES FILLED BY CARBON AND SAND NANOPARTICLES

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ABSTRACT
The friction behaviour of epoxy floor tiles filled by carbon and sand nanoparticles when rubber footwear is sliding against them is investigated. Electrostatic charge (ESC) generated from friction is measured.

Based on the experiments, it was found that friction coefficient displayed by composites filled by both sand and carbon nanoparticles at dry and water wet sliding represented relatively higher values than that observed for composites filled by either carbon or sand nanoparticles. ESC generated on dry rubber sole after sliding had lower values than that measured for epoxy composites. ESC generated on water wet epoxy composites represented very low values relative to dry sliding. ESC decreased with increasing carbon content. In the presence of nanoparticles of carbon in the matrix of epoxy, ESC transfer would be easier, where sand gained higher positive ESC due to its rank in the triboelectric series. The role of carbon was to distribute the ESC uniformly on the two contact surfaces. Material transfer such as sand and carbon nanoparticles from epoxy into rubber surface as well as water film would control the intensity of ESC and consequently the adhesion between the two contact surfaces.

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

INTRODUCTION
Indoor floor materials are developed to reduce both slip accidents and ESC generated from friction. It was found that filling epoxy by carbon nanoparticles caused significant decrease in friction coefficient at dry sliding, [1]. 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. It was observed that filling epoxy by sand nanoparticles increased friction coefficient at dry sliding, [2]. While at water, detergent and oil wet sliding, friction coefficient showed relatively higher values than that recorded for unfilled epoxy. Besides, sliding of bare foot on dry epoxy composites displayed lower friction coefficient than that recorded for rubber footwear. Cotton socks showed the highest friction values followed by polyester and wool. Besides, ESC generated on rubber surface sliding on dry epoxy composites showed the highest values at 1.0 wt. % sand content. Wool socks slid against epoxy showed significant increase in ESC, compared to that observed for cotton and polyester socks. ESC generated on bare foot sliding on dry epoxy composites represented very low values relative to rubber footweardue to the good electrical conductivity of the human body.

Triboelectrification of polymeric composites can be controlled by filling them by carbon black, [3], 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, [4, 5]. 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, [6]. 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, [7 – 9]. 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, [10]. Certain values of friction coefficient were recommended as the slip-resistant standard for unloaded, normal walking conditions, [11, 12]. 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, [13, 14]. 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, [15 - 18], 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 and sand nanoparticles are investigated.

EXPERIMENTAL

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 calculate 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. They are prepared in square shape with area of 300 × 300 mm^2 and 5 mm thickness. The counterface is rubber footwear of 70 Shore A hardness. Friction test was carried out under different applied normal loads ranging from 200 to 1000 N at dry, water, detergent (1.0 wt. % detergent), Paraffin oil and oil/water dilution (5.0 wt. % oil) wet sliding conditions. The tested epoxy tiles were filled by sand nanoparticles (30 – 50 nm) of 1.0 wt. % and 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 1000 N load.

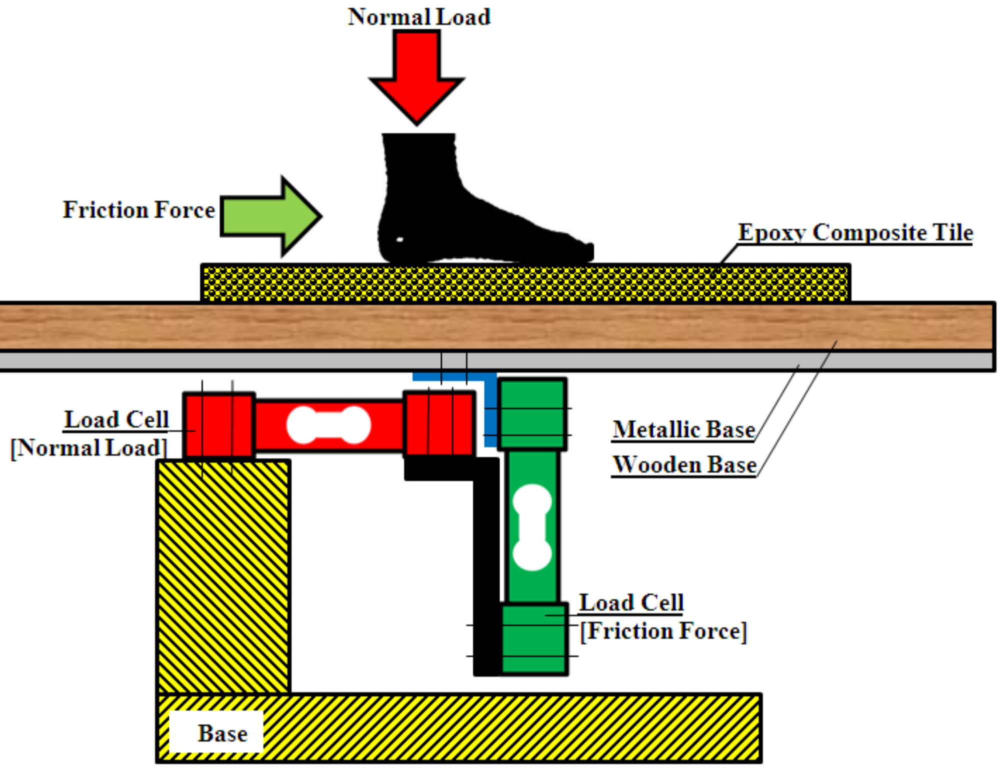

Fig. 1 Arrangement of the test rig.

RESULTS AND DISCUSSION

The comparative performance of frictional behaviour of epoxy composites filled by nanoparticles of sand and carbon are shown in Figs. 2 – 6. Friction coefficient displayed by rubber footwear sliding on dry epoxy composites filled by sand nanoparticles, Fig. 2, slightly increased up to maximum then slightly decreased with increasing sand content. The maximum friction values were observed at 0.6 wt. % sand content. It is clearly shown that filling epoxy by sand nanoparticles caused an increase in friction coefficient. Sliding on dry epoxy composites filled by carbon nanoparticles showed drastic decrease in friction coefficient with increasing carbon nanoparticles content. The minimum friction values were observed at 0.8 wt. % carbon. This behavior can be attributed to the fact that carbon nanoparticles transferred into the rubber surface has formed low friction layer, where carbon worked as solid lubricant. Besides, carbon transfer into rubber surface conducted negative ESC from epoxy to neutralize the positive ESC on the rubber surface in a manner that adhesion between the two contacting surfaces decreased.

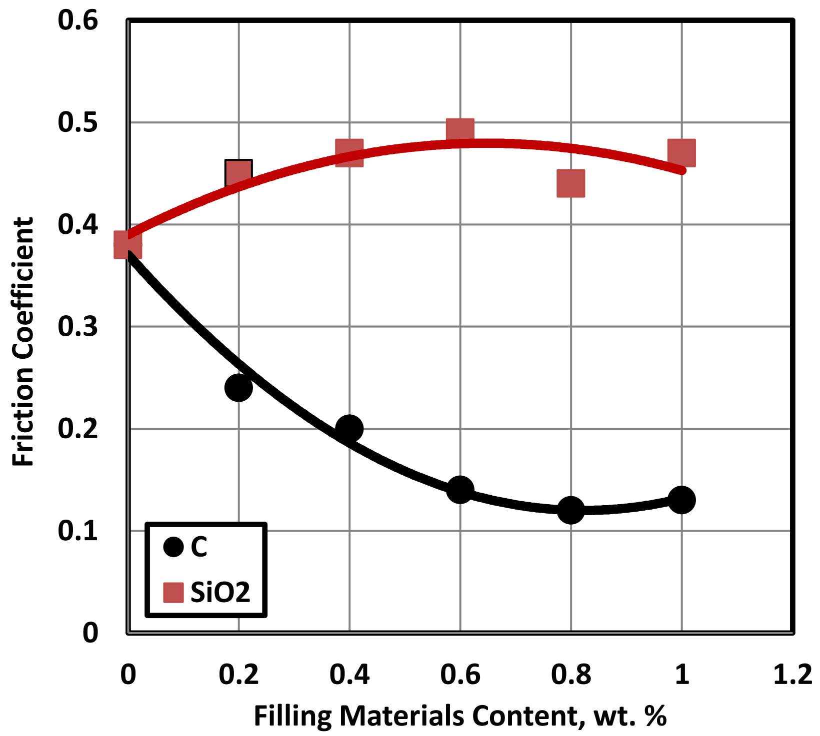

Fig. 2 Friction coefficient displayed by rubber footwear sliding on dry epoxy composites.

At water wet sliding, friction coefficient showed relatively lower values than that recorded for dry sliding, Fig. 3. The highest friction values were observed at 0.6 wt. % sand content, while composites filled by carbon nanoparticles showed relatively higher values than that recorded for composites filled by sand. The presence of carbon nanoparticles was responsible for the friction increase. In the presence of carbon nanoparticles the intensity of ESC increased due to their good electrical conductivity. ESC was 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. 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.

Sliding at detergent wet epoxy composites filled by sand displayed relatively higher values of friction coefficient than that observed for composites filled by carbon nanoparticles, Fig. 4. It seems that adhesion of the detergent molecules into the sliding surfaces was facilitated by the carbon film transferred from epoxy composites into the contact area, while sand particles were responsible for friction increase due to their interaction into the rubber surface.

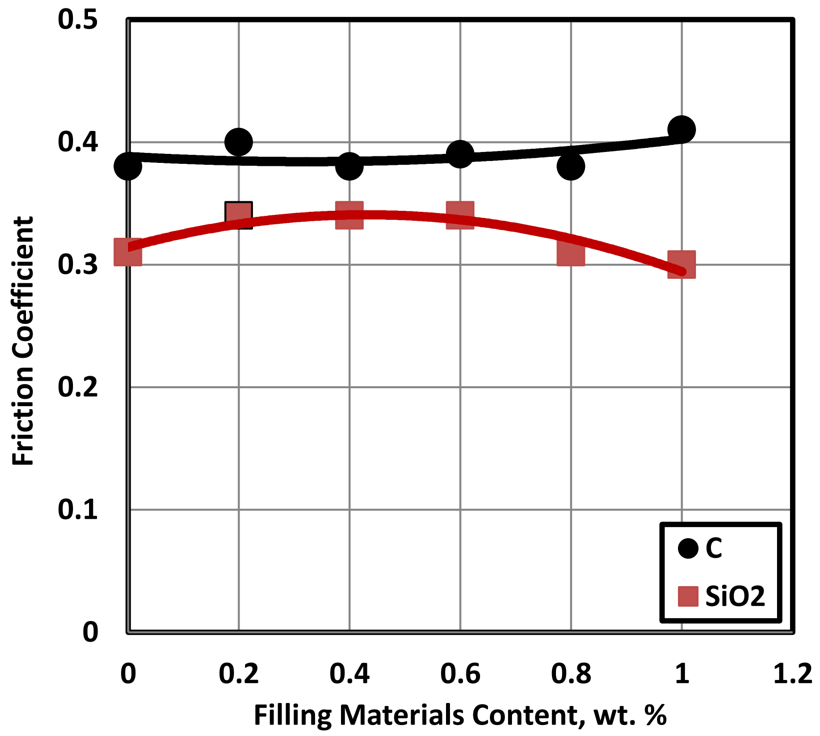

Fig. 3 Friction coefficient displayed by rubber footwear sliding on water wet epoxy composites.

Drastic friction decrease was observed for sliding of rubber footwear at oil lubricated epoxy composites, Fig. 5. Filling epoxy by sand nanoparticles significantly increased friction coefficient. It seems that sand particles could break the oil film adhered on both rubber and epoxy surfaces leading to the increase in friction. Besides, the interaction of sand particles in rubber surface might contribute friction increase. Filling epoxy by carbon nanoparticles slightly increased friction coefficient of relatively lower values. It seems that the interaction of the carbon particles in rubber surface might decrease the adhesion of oil into the rubber surface.

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, Fig. 6. 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 contaminated by oil and water.

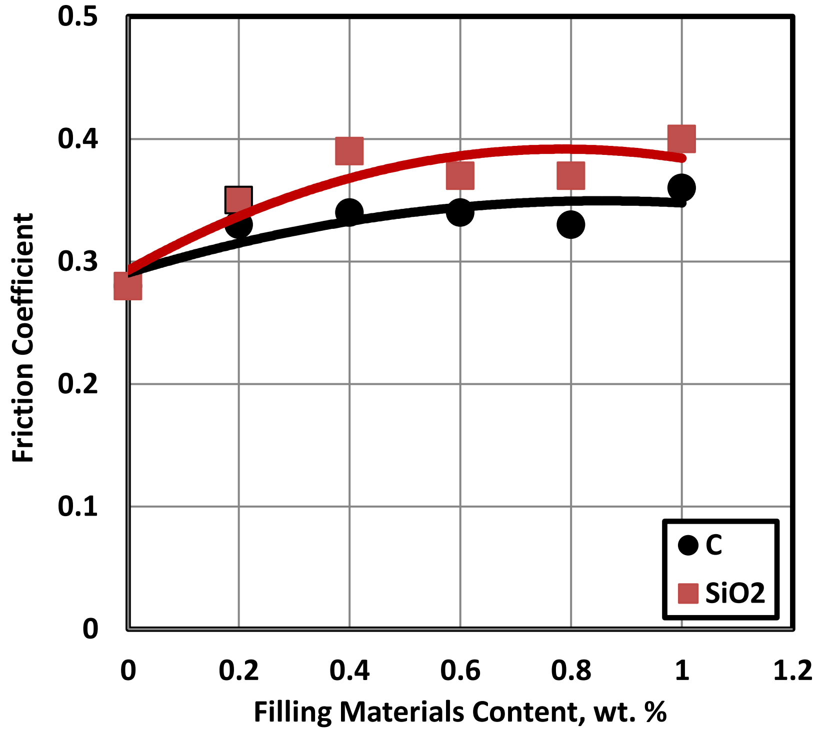

Fig. 4 Friction coefficient displayed by rubber footwear sliding on detergent wet epoxy composites.

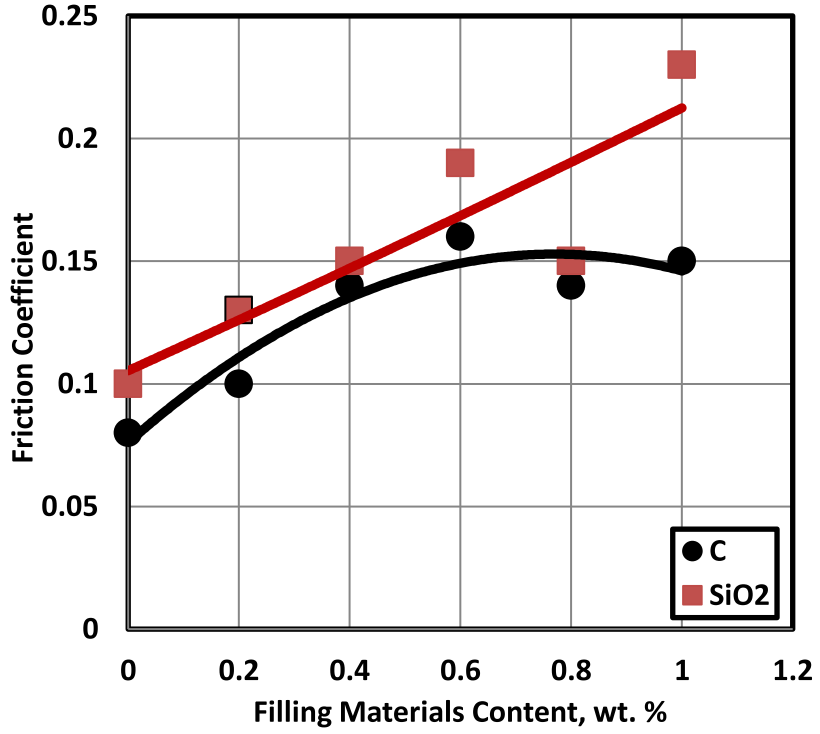

Fig. 5 Friction coefficient displayed by rubber footwear sliding on oil lubricated epoxy composites.

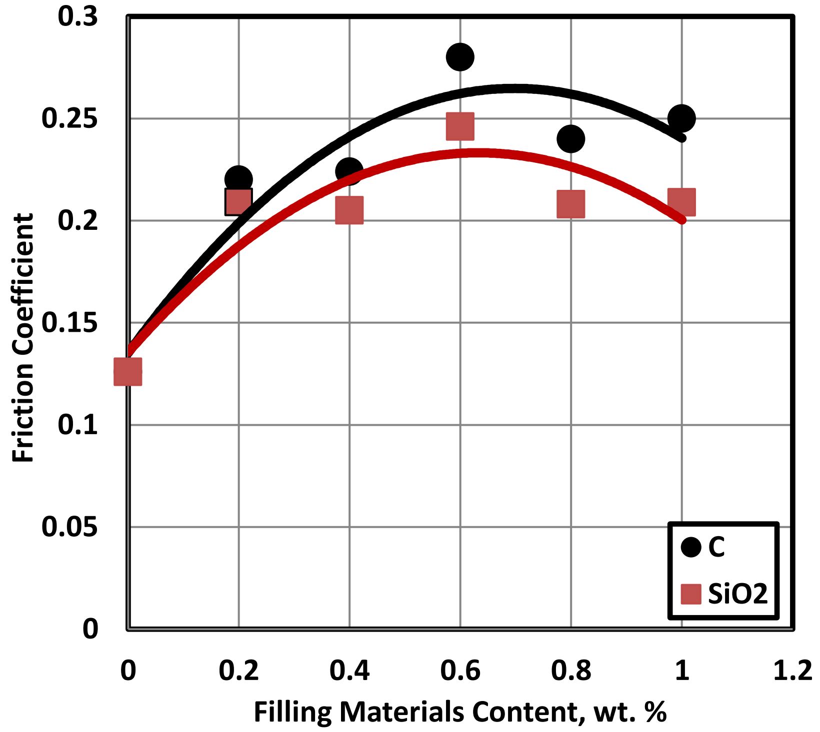

Fig. 6 Friction coefficient displayed by rubber footwear sliding on oil/water dilution epoxy composites.

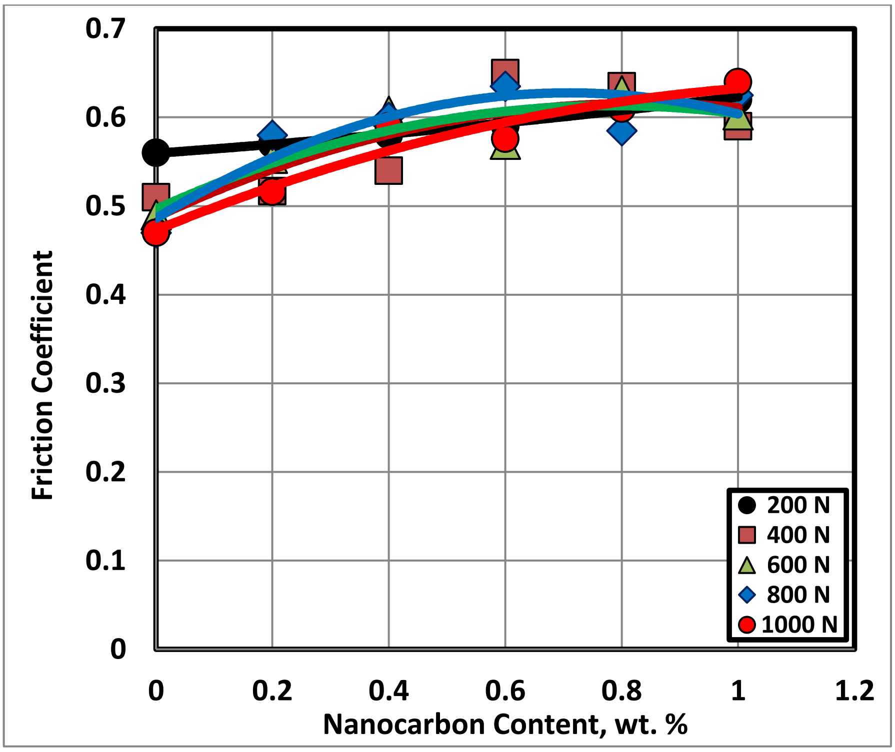

Fig. 7 Friction coefficient displayed by rubber footwear sliding on dry epoxy composites.

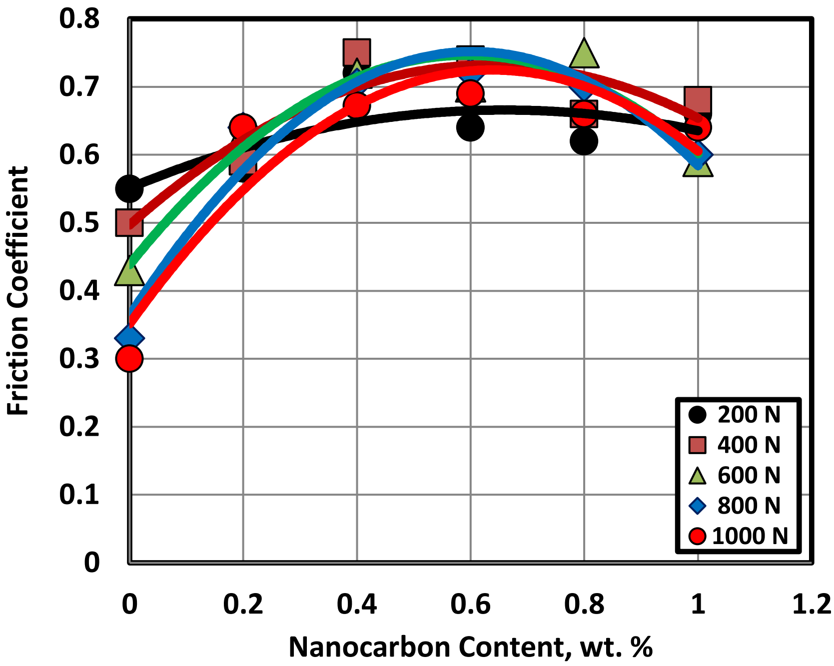

Fig. 8 Friction coefficient displayed by rubber footwear sliding on water wet epoxy composites.

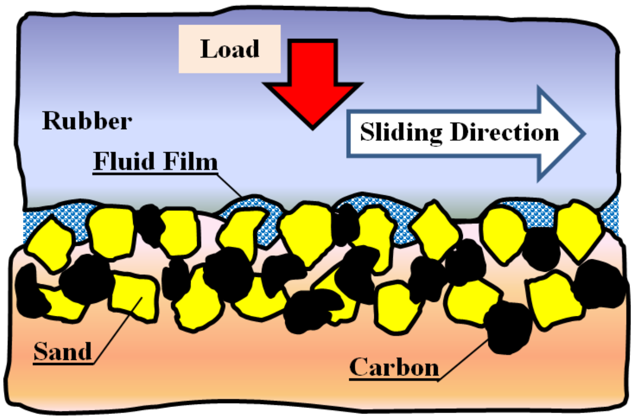

Fig. 9 Contact between rubber and epoxy filled by sand and carbon nanoparticles during sliding.

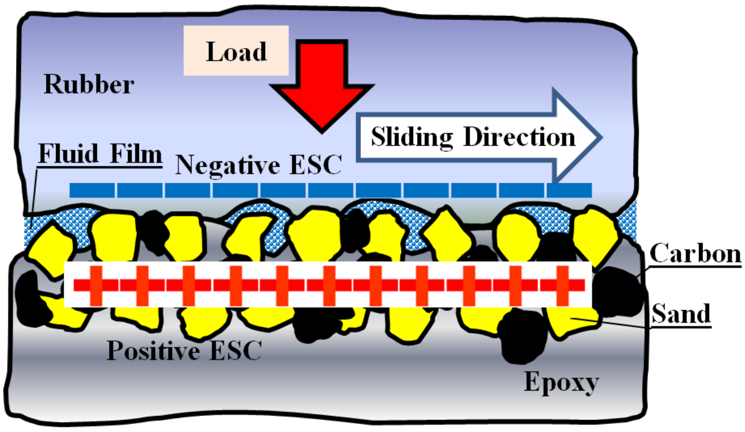

Fig. 10 ESC generated on the sliding surfaces.

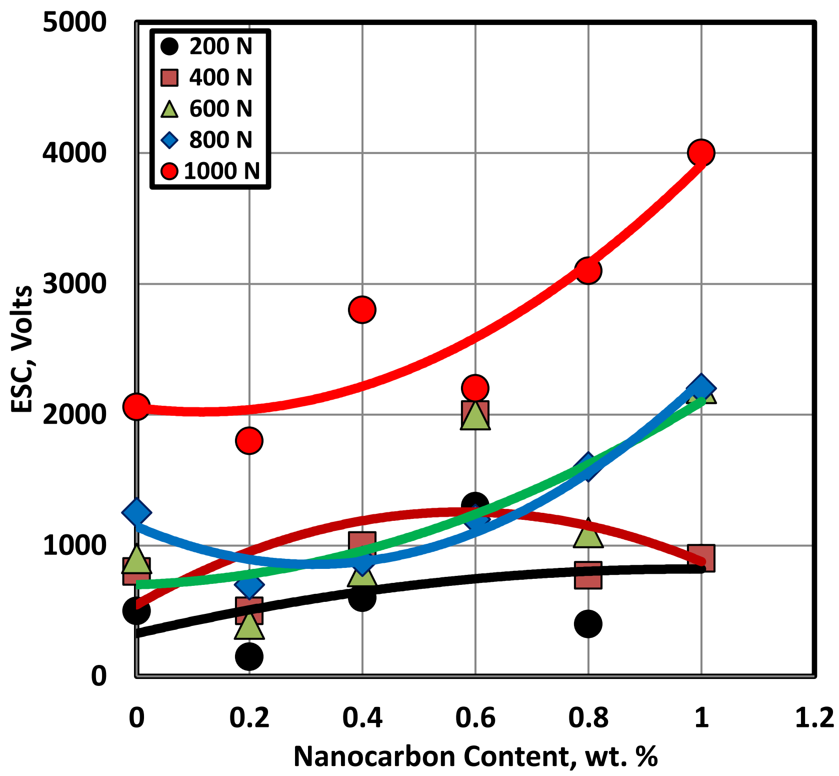

Fig. 11 ESC generated on epoxy composites at dry sliding.

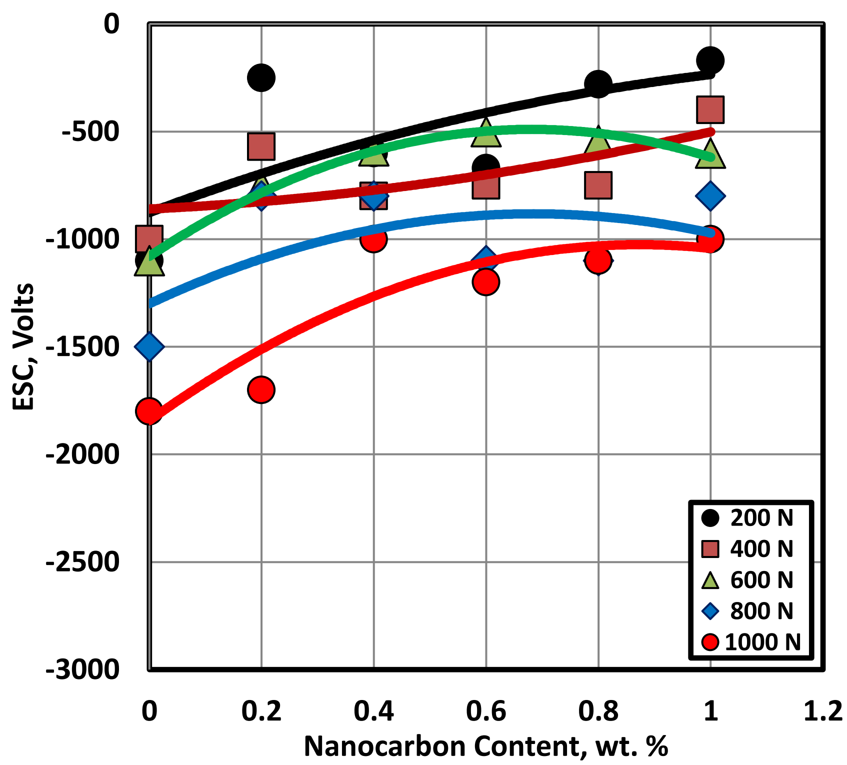

Fig. 12 ESC generated on rubber sole at dry sliding.

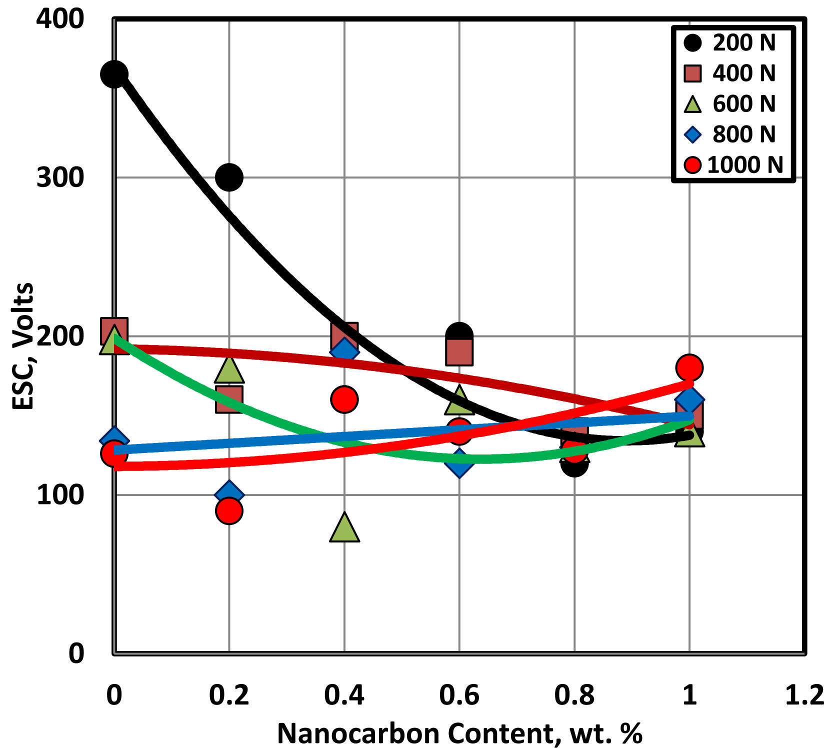

Fig. 13 ESC generated on epoxy composites at water wet sliding.

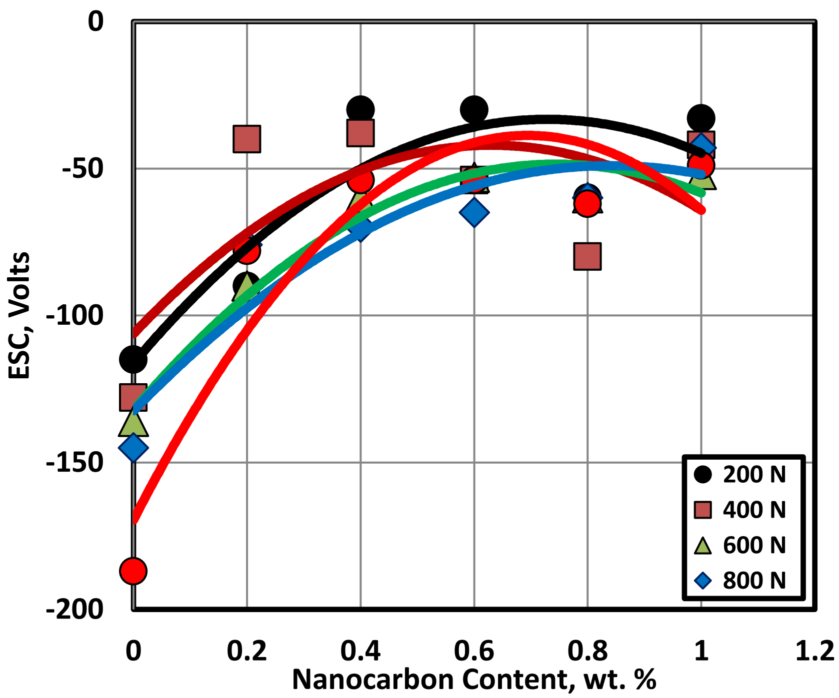

Fig. 14 ESC generated on rubber sole at water wet sliding.

The results of the friction coefficient displayed by composites filled by both sand and carbon nanoparticles at dry and water wet sliding are illustrated in Figs. 7 and 8 respectively, where they represented relatively higher values than that observed for composites filled by either carbon or sand nanoparticles. Friction coefficient increased

with increasing carbon content. This observation can recommend those composites to be used as floor materials at dry sliding.

Friction coefficient displayed by rubber footwear sliding on water wet epoxy composites significantly increased up to maximum at 0.6 wt. % carbon then slightly decreased. The highest friction value was 0.75, while that determined for dry sliding did not exceed 0.65. This behavior can be illustrated in Figs. 9 and 10. When epoxy filled by sand contacted rubber, the contact could be classified as partially rubber/epoxy, fluid/epoxy, sand/rubber and fluid/rubber. When rubber slid on epoxy composites, it gained positive ESC, while epoxy gained negative ESC. Rubber sliding on sand particles gained negative ESC, while sand gained positive ESC. In the presence of nanoparticles of carbon in the matrix of epoxy, ESC transfer would be easier and homogeneous, where sand gained higher positive ESC due to its rank in the triboelectric series. The role of carbon was to distribute the ESC uniformly on the two contact surfaces. Water film would enhance ESC distribution where the generated electric force increased and consequently adhesion increased between rubber and epoxy composites. Material transfer such as sand and carbon nanoparticles from epoxy into rubber surface as well as water film would control the intensity of ESC and adhesion between the two contact surfaces. It was proved that sand nanoparticles filling epoxy strongly influenced the friction values, [2].

ESC generated on epoxy composites at dry sliding is shown in Fig. 11, where the highest intensity (4000 Volts) was observed at 1.0 wt. % carbon content at 1000 N load. Generally, ESC generated on dry rubber sole after sliding, Fig. 12, had negative signs of lower values than that measured for epoxy composites. It seems that this behaviour is attributed to the possibility of carbon transfer from epoxy to rubber surface carrying positive ESC into the rubber surface, where the resultant of ESC decreased as the carbon content increased. ESC generated on water wet epoxy composites represented very low values relative to dry sliding, Fig. 13, due to the good electrical conductivity of the water film that leaked part of ESC out of the sliding surfaces. ESC generated on water wet rubber showed the same trend observed for epoxy composites, Fig. 14. ESC decreased with increasing carbon content.

CONCLUSIONS

1. Friction coefficient displayed by rubber footwear sliding on dry epoxy composites filled by sand nanoparticles slightly increased up to maximum then decreased with increasing sand content.
2. Sliding at detergent wet epoxy composites filled by sand displayed relatively higher values of friction coefficient than that observed for composites filled by carbon nanoparticles.
3. Drastic friction decrease was observed for sliding of rubber footwear at oil lubricated epoxy composites. Filling epoxy by sand nanoparticles significantly increased friction coefficient with increasing sand content.
4. 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.
5. The results of the friction coefficient displayed by composites filled by both sand and carbon nanoparticles at dry and water wet sliding represented relatively higher values than that observed for composites filled by either carbon or sand nanoparticles.
6. ESC generated on water wet epoxy composites represented very low values relative to dry sliding. ESC decreased with increasing carbon content.

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