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FRICTION DISPLAYED BY THE SLIDING OF RUBBER ON EPOXY FILLED BY RECYCLED RUBBER PARTICLES

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ABSTRACT
The brittleness of floor materials made of epoxy resins limits their applications. To decrease that effect, recycled rubber particles and paraffin oil are proposed to blend epoxy. The role of oil is to increase the viscoelastic property of the proposed composites. Different sizes of recycled rubber particles were used as filling material, while oil content was 5.0 and 10.0 wt. %. The tested composites slid against rubber surface, where coefficient of friction was determined.

The experiments revealed that composites filled by oil showed slight decrease in friction values compared to composites free of oil. As the oil content increased, friction decreased. When the rubber content increased, friction significantly increased. The recommended rubber particle size was ranging between 1.0 to 2.0 mm that caused the highest friction values. As for composites filled by oil, further increase in rubber particle size was accompanied by friction increase. It was observed that values of friction coefficient were much higher than the recommended values for safe floor materials. The difference in the friction values observed for unfilled and filled composites oil was slight. Based on that, the proposed composites can be used in different applications, where addition of oil into epoxy matrix is intended to decrease the abrasion of the proposed composites.

KEYWORDS
Friction coefficient, epoxy, recycled rubber particles.

INTRODUCTION
Epoxy has wide industrial applications due to the relatively high elastic modulus and good adhesion properties, [1]. In the other side, epoxy suffers from brittleness that limits its use, [2]. Butadiene-acrylonitrile rubber was used to fill epoxy matrix, [3 – 5]. The ductility of epoxy can be enhanced by the rubber particles that work as initiator for plastic deformation due to the shear banding of the matrix facilitated by the rubber as well as the plastic void growth of the matrix. It is known that rubber particles are responsible for concentrating the stress and plastic deformation in the neighboring matrix.

Fracture toughness of epoxy resins was enhanced by blending by block copolymer, [6]. Significant improvements in fracture toughness were addressed by incorporation of block copolymers. In addition to that, the effect of voids and shear yielding of the

matrix can be reduced, [7, 8]. The blending process was responsible for cavitation of the rubber leading to the shear deformation of the epoxy matrix and consequently fracture toughness was significantly improved. It was proved that rubber addition into epoxy matrix was able to overcome the brittleness of epoxy resins, [9].

Used rubber is often burned or end up in landfills. Those processes represent environment pollution. It is safe to recycle used rubber to fill epoxy resin. The mechanical and tribological properties of used polymeric materials were investigated, [10, 11]. It was proved that the recycled polymers can be used in different applications due to their good mechanical and tribological properties. Toughening of epoxy by incorporation of waste ground rubber particles is used, [12 - 17]. The application of the proposed composites find extensive use in automotive components such as spoilers.

Rubber possesses relatively higher contact area and pronounced deformations when mechanically loaded on the surface asperities of a rigid material, where higher friction coefficient can be expected, [18 - 20]. Besides, abrasions of floor surface can be reduced by the presence of rubber.

Filling epoxy by oil leads to the presence of oil inside the polymer matrix in infinite number of pores, where they work as reservoirs. Then the oil leaks up to the sliding surface and forms oil film. In this condition, the contact will be partially polymer composites/steel and oil/steel result of the mixed lubrication regime provided by the oil film. It is clear that friction decrease was displayed by the oil transfer from the composites to the rubber surface, [21 – 25]. At the mixed friction condition, the decrease of friction coefficient may be attributed to the adhesion of oil molecules into the sliding surfaces. It was observed that the oil is trapped in pores after solidification of the composites. The oil pores are feeding the oil into the sliding surfaces and forming oil transfer film on the friction surfaces. The value of friction depends on the adhesion of the oil molecules into the sliding surfaces experiencing boundary lubricating film that easily be removed by the shear instead of the contacting asperities. It is worthy to mention that due to the polarity of paraffin oil, the adhesion of its molecules into the sliding surfaces will be relatively stronger, where polar molecules will form multilayers, which strengthen the adhesion of oil into the sliding surfaces.

The present work investigates the friction of epoxy test specimens filled by recycled rubber particles and paraffin oil. The proposed composites are tested as floor materials.

EXPERIMENTAL

The friction coefficient caused by the sliding of epoxy composites on the rubber surface was determined by the means of the designed and manufactured test rig, Fig. 1. The epoxy composites in 5.0 mm thickness were adhered to one surface of wooden cube of 35 × 35 × 35 mm^3 and loaded into rubber sheet of 10 mm thickness of 50 Shore D hardness. The rubber sheet was placed in a base supported by two load cells, where the first measures the horizontal force (friction force) and the other the vertical force (applied load). Digital screen was used to the friction and vertical forces. The arrangement of the test rig as well as the details of the used materials are illustrated in Figs. 1 and 2 respectively.

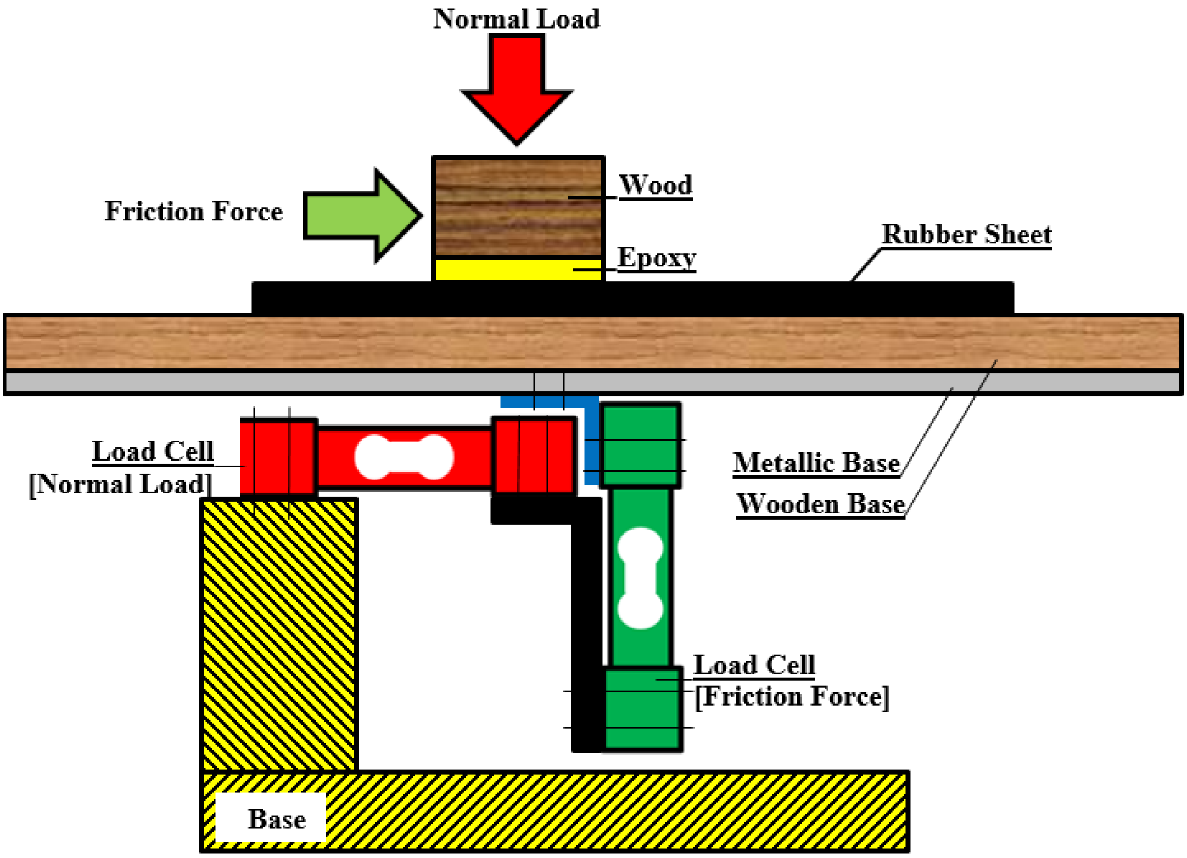


Fig. 1 Arrangement of the test rig.

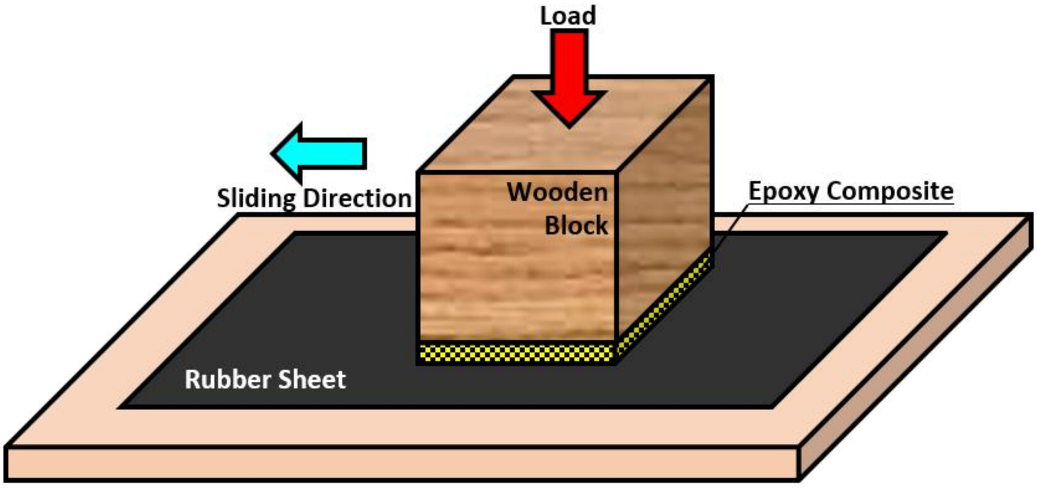
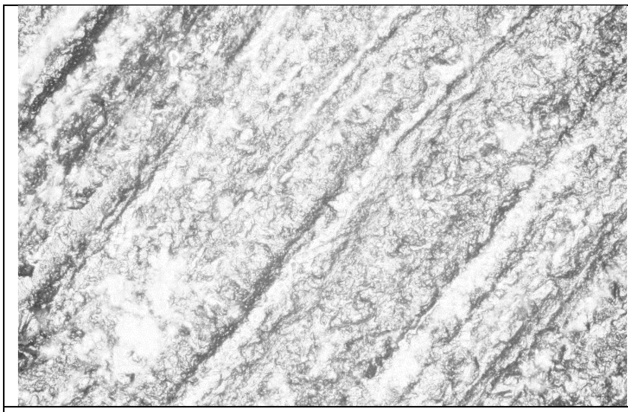
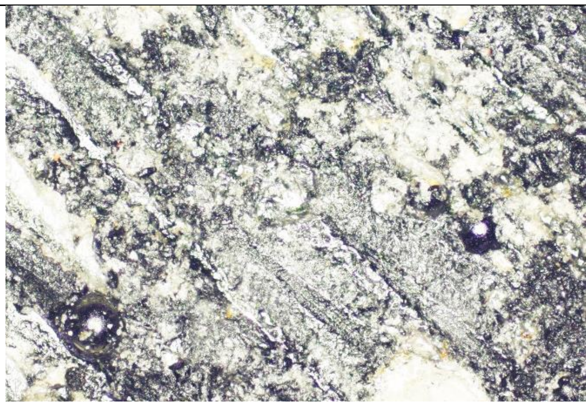


Fig. 2 Details of the used materials.

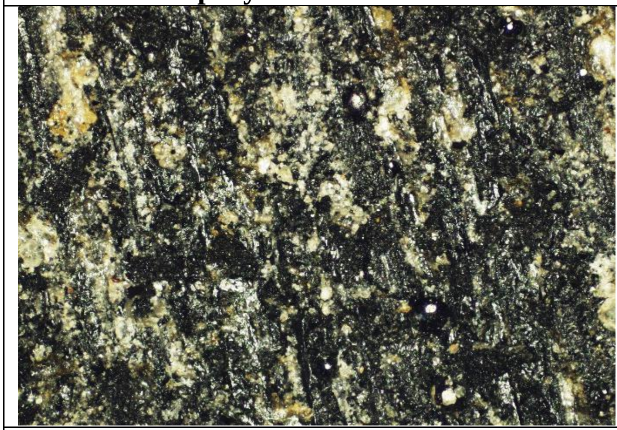
Epoxy was filled by recycled rubbers of different double cut particle size of (0 – 0.5), (0.5 – 1.0), (1.0 – 2.0) and (2.0 – 3.0) mm. Three sets of test composites were prepared, the first was free of oil, while the second and the third were filled by 5.0, 10.0 wt. % paraffin oil. The photomicrographs of the tested composites are shown in Fig. 3. Friction tests were carried out at different values of normal load exerted by hand, where the load value was ranging from 0 to 70 N. Friction coefficient was calculated and plotted against load. Then the values of friction coefficient were extracted at loads of 60 N.



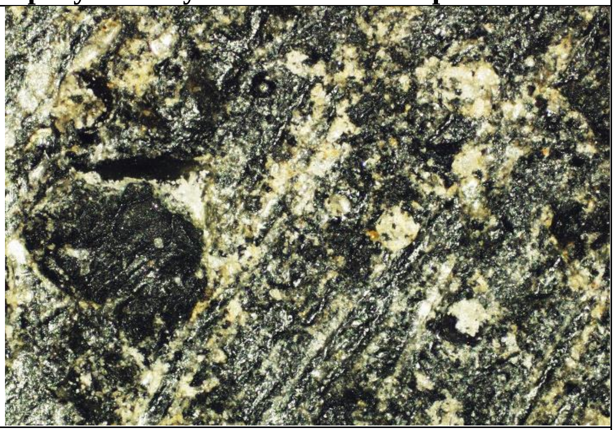
Epoxy free of rubber.



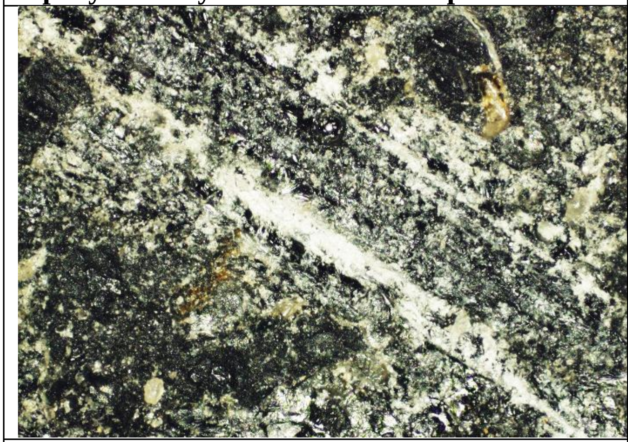
Epoxy filled by rubber of 0.5 mm particle size.



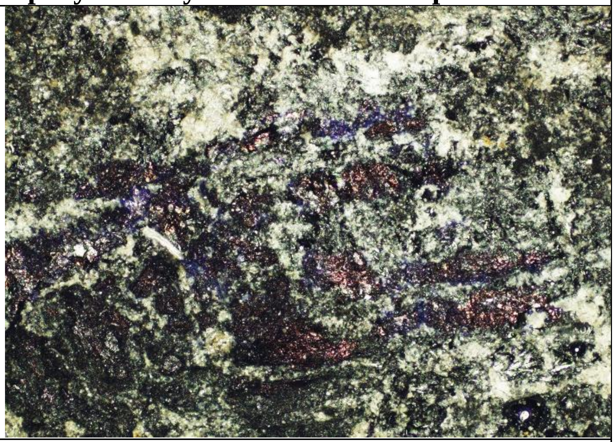
Epoxy filled by rubber of 1.0 mm particle size.



Epoxy filled by rubber of 2.0 mm particle size.



Epoxy filled by rubber and 5.0 wt. % oil content.



Epoxy filled by rubber and 10.0 wt. % oil content.

Fig. 3 Photomicrographs of the tested composites

RESULTS AND DISCUSSION

The results of friction coefficient displayed by the sliding of epoxy filled by recycled rubber particles of size up to 0.5 mm and filled by 5.0 and 10.0 wt. % paraffin oil is shown in Fig. 4. Composites free of oil showed the highest friction values. As the oil content increased, friction decreased. On the other side, friction significantly increased with increasing rubber content. Friction coefficient values displayed by composites free of oil and that filled by 80 wt. % rubber were 1.4 and 1.85 respectively. When the

rubber particle size increased up to 1.0 mm, Fig. 5, composites free of oil and that filled by 5.0 wt. % oil represented relatively higher friction values than that observed for composites filled by 0.5 mm rubber particles. The same trend was observed for rubber particle size up to 2.0 mm, Fig. 6. Further increase in rubber particle size caused an increase in friction values displayed by composites filled by oil, Fig. 7. Although the difference in the friction values was slight, that observation can be applicable to compensate the decrease of friction due to the presence of oil in the matrix of epoxy. Figure 8 illustrates the friction coefficient as a function of rubber content for the tested composites filled by rubber of different size and 5.0 wt. % oil. It is clearly shown that rubber particle size up to 2.0 mm represented the highest friction values.

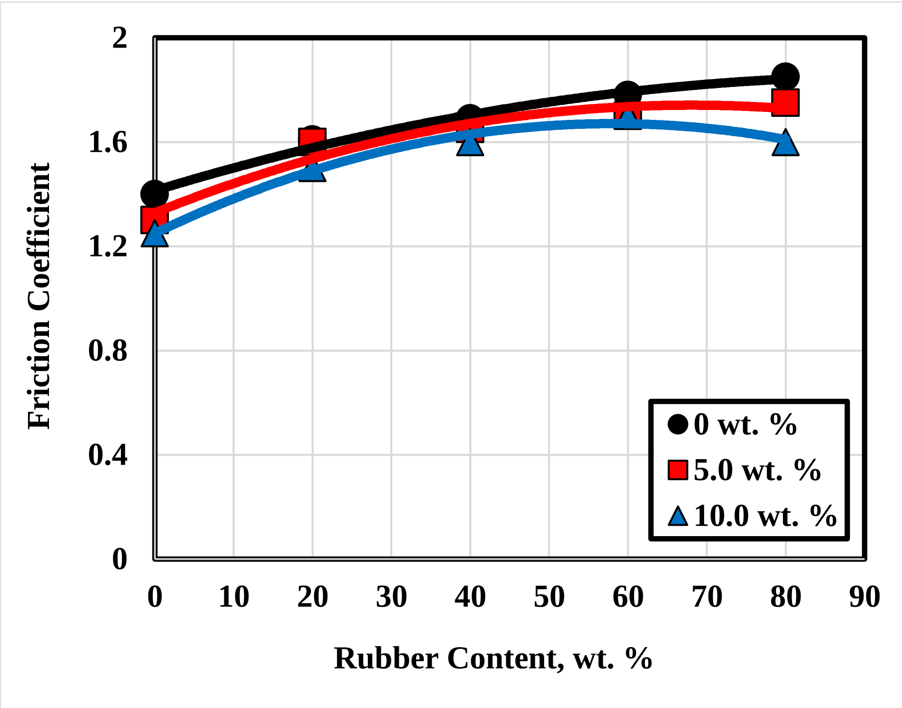


Fig. 4 Friction coefficient as a function of rubber content for (0 - 0.5) mm particle size.

Based on the observations shown in Figs. 4 – 8, it is observed that particle size of rubber had significant effect on the friction values. It seems that as the particle size increased, the deformation of rubber particles allowed the increase of the friction coefficient. Relatively smaller particles facilitated the deformation of the rubber particles

The schematic illustrations, Figs. 9 and 10, show that the contact area between rubber particles and rubber surface differs according to the rubber particle size. As the particle size increased the contact area decreased, that interprets the decrease of friction coefficient with increasing particle size. The optimum particle size of rubber was 2.0 mm that produced the highest friction coefficient.

The minimum safe value for the static friction coefficient is 0.5 recommended for floor surfaces. This value may increase for disables, walkways and elevators to 0.6 – 0.8. Rubber can provide relatively higher contact area and deformation during friction, where higher friction coefficient values can be obtained than epoxy. The above characteristic frictional behaviour of rubber was slightly disturbed when epoxy was

filled by oil. Generally, the values of friction coefficient observed for the proposed composites were much higher than the recommended values mentioned above.

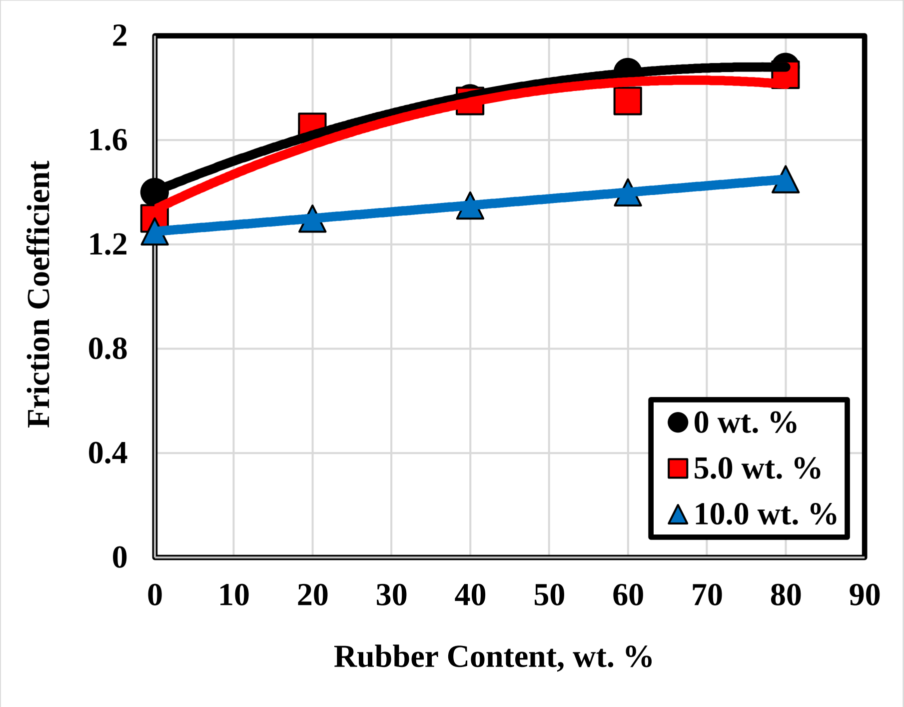


Fig. 5 Friction coefficient as a function of rubber content for (0.5 - 1.0) mm particle size.

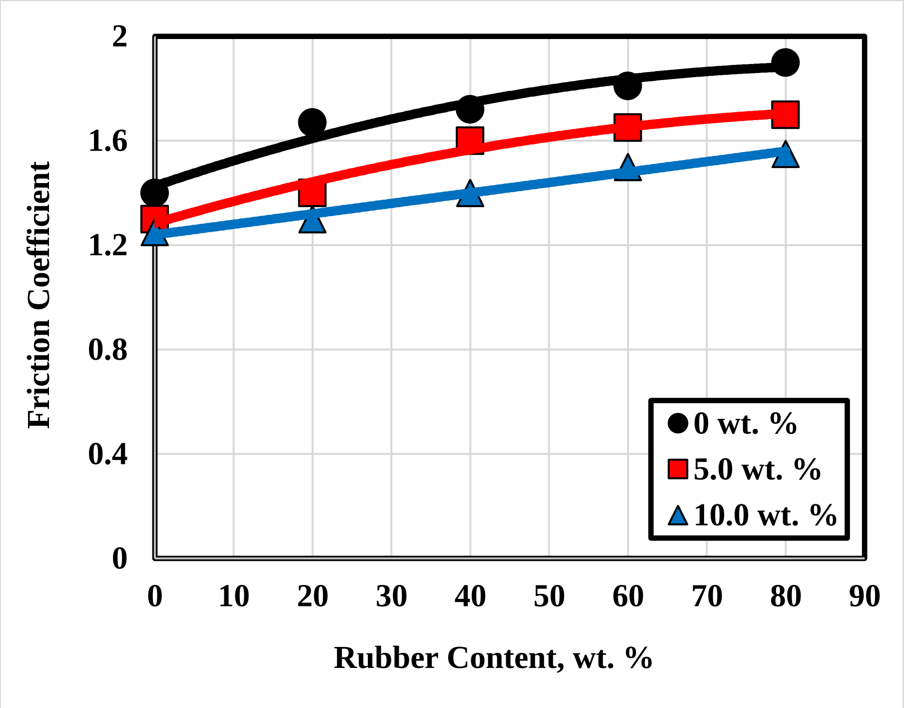


Fig. 6 Friction coefficient as a function of rubber content for (1.0 - 2.0) mm particle size.

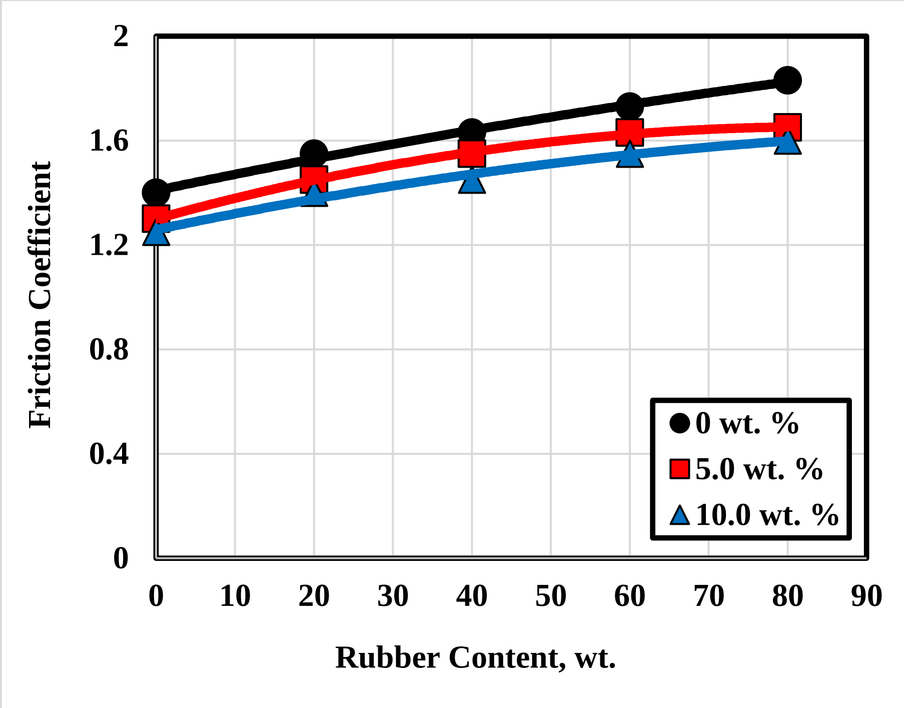


Fig. 7 Friction coefficient as a function of rubber content for (2.0 – 3.0) mm particle size.

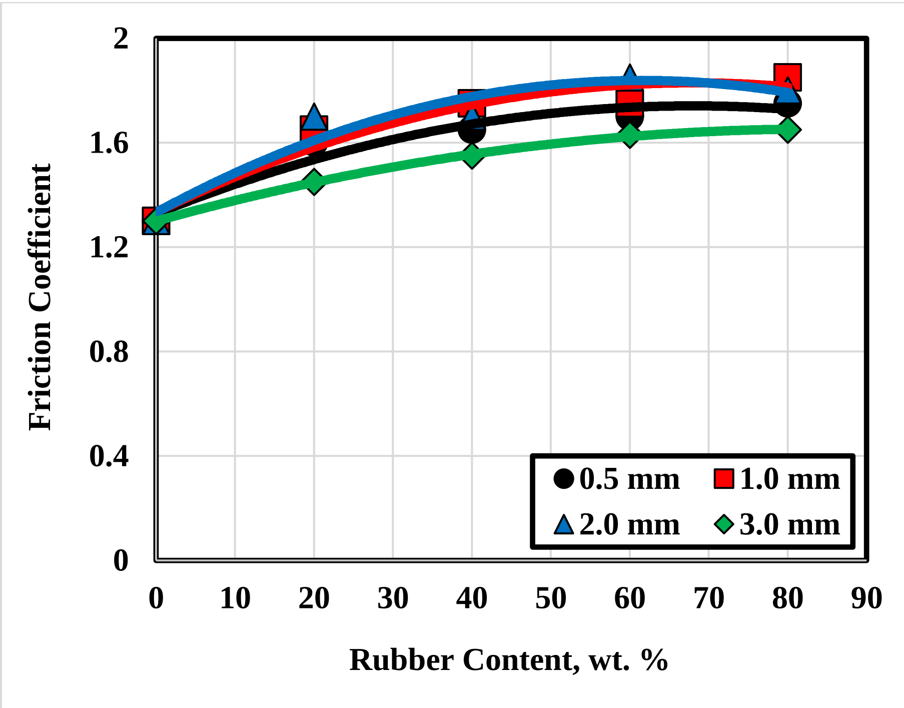


Fig. 8 Friction coefficient as a function of rubber content for the tested composites filled by rubber of different size.

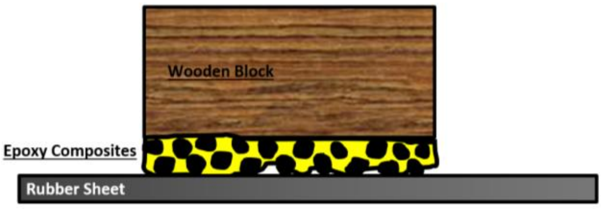


Fig. 9 Contact between relatively small rubber particles and rubber surface.

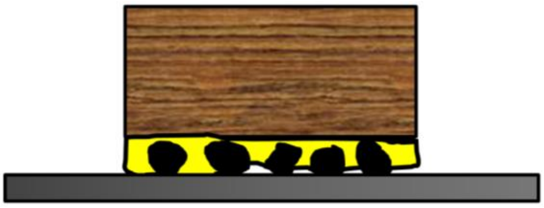


Fig. 10 Contact between relatively big rubber particles and ceramic surface.

The slight friction decrease is attributed to the oil stored in the pores inside epoxy matrix. The mechanism of action of oil depends on the presence of the oil film formed on the sliding surfaces and separates the contacting asperities of the two sliding surfaces. It is expected that the pores were working as oil reservoirs and feeding oil into the sliding surface. When the trapped oil in the epoxy matrix leaks to the surface, it forms oil film on the sliding surface and decreases the friction. In addition to that, oil film reduces epoxy transfer into the rubber surface and homogeneously distributed rubber particles inside epoxy matrix. The advantage of adding oil into epoxy is to decrease the abrasion of the proposed composites. The results of the abrasion resistance of the tested composites will be discussed in the future work.

It was observed that presence of rubber particles in the matrix of epoxy caused relatively high friction due to the very low elastic modulus of rubber and its high internal friction. Rubber friction force has two components, adhesion and deformation. Adhesion deforms the rubber at the friction surface, while deformation results from the internal rubber friction then rubber follows the short-wavelength surface roughness profile. The two components are responsible for the high friction force.

CONCLUSIONS

1. Composites free of oil showed relatively higher friction values than that filled by oil. As the oil content increased, friction decreased.
2. Friction significantly increased with increasing rubber content.
3. The highest friction values were displayed by composites filled by rubber particle size ranged between 1.0 to 2.0 mm.
4. Further increase in rubber particle size increased friction values displayed by composites filled by oil.
5. Values of friction coefficient observed for the proposed composites were much higher than the recommended values for safe floor materials.

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