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FRICTION COEFFICIENT OF RECYCLED RUBBER SOLES

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ABSTRACT

The present work studies the possibility of using recycled rubber in soles. Different sizes of recycled rubber particles were bonded together and adhered to wooden block. Two types of test specimens of smooth and treaded surfaces were investigated. The tested rubber slid against ceramic surface, where coefficient of friction was determined.

At dry sliding; results showed that coefficient of friction of treaded rubber recorded slight decreasing trend with increasing normal load. For smooth test specimens, friction coefficient showed remarkable increase followed by slight decrease with increasing rubber particle size. When the water covered the sliding surface, friction coefficient showed decreasing trend to minimum then significantly increased as the rubber particle size increased. In this condition, the spaces and gaps between the rubber particles and ceramic surface were big enough to allow the water to go out the contact area causing the friction to increase due to the increase of the partial rubber/ceramic contact. Besides, relatively smaller particles facilitated the water to be formed on the surface area, where friction coefficient decreased. It is proposed to use treaded rubber in water wet floor tiles. The same trend was noticed at detergent wet surfaces, where coefficient of friction displayed lower values than that regarded by sliding on water wet ceramic surface. Treaded rubber showed relatively lower friction than smooth one. The lowest friction values were displayed by smooth surface at oil sliding, where friction coefficient increased when rubber particle size increased.

KEYWORDS

Friction coefficient, recycled rubber soles, particle size, dry, water, detergent wet, oily sliding.

INTRODUCTION

It was found that, surface roughness of tiles made of recycled rubber had insignificant effect on the frictional behavior, where the increase of the tile thickness had slightly increased friction coefficient, [1, 3]. When the water covered the sliding surface, rough surface showed higher friction values than smooth one. Besides, friction coefficient reduced with increasing the thickness of the tiles. Friction coefficient displayed by detergent wet surfaces was lower than that observed for water wet surface. When the sliding surface was covered by sand particles, friction coefficient displayed by rough surface increased, while decreased for smooth one with increasing the tile thickness. For tiles wetted by sand particles contaminated in water, rough surface showed relatively

higher friction. In contradiction to the case of existence of dry sand, friction coefficient displayed by rough surface decreased with increasing tiles thickness.

Bare foot sliding against dry porous recycled rubber tiles showed friction increase with increasing normal load, where pores inside the rubber matrix were responsible for the extra deformation displayed by the porous recycled rubber and consequently the contact area between the sliding surfaces increased, [4]. When rubber shoe slid against dry rubber tiles the increased deformation of the rubber tiles increased friction coefficient significantly. Rubber mats made of recycled rubber and filled by polyurethane of different hardness showed that friction coefficient depended on the hardness of the rubber mats increased, [5]. At water wetted and sand contaminated rubber mats, the variation of friction coefficient was significantly affected with the hardness of the tested rubber mats. Compared to ceramic and polymeric tiles, rubber mats showed the highest friction. It can be recommended that it is necessary to avoid the use of relatively higher hardness for flooring tiles in bathrooms where water and detergent exist, [6]. Sand particles decreased friction coefficient, where it drastically decreased as the hardness increased.

Tiles of smooth surface like glazed ceramics are widely applied as floors to facilitate the cleaning process for the consumer. Slips and falls accidents represent great loss because of the cost of occupational injuries, [7]. Relatively higher friction could enhance slip resistance, [8 - 14]. Floor slipperiness specially in hydrodynamic squeeze-film sliding, [15], is much influenced by surface roughness, where treaded groove can develop the contact between the floor tiles and shoe sole on sand contaminated wet surface, [16]. The design of the treaded groove and the shoe sole material affect friction behavior, where enough width of the treaded grooves is essential to provide efficient drainage.

The friction coefficient of rubber flooring, provided by cylindrical treads, was investigated, [17]. Increasing treads diameter significantly increased friction coefficient at dry sliding, where the tread directions displayed significant role in increasing the friction coefficient which reached a value of 0.92 at dry sliding. As for lubricated sliding surfaces, significant decrease in friction values was noticed when water covered the sliding surface, where friction values declined with growing treads diameter. Detergent wet floor caused drastic decrease in friction coefficient to values lower than water. Perpendicular treads recorded higher friction values, while parallel treads showed lower friction coefficient. The squeeze oil film separating footwear and rubber flooring was responsible for decreasing trend of friction coefficient with increasing tread diameter at oil sliding.

The effect of perpendicular and parallel treads of rubber surface, on the friction coefficient, was discussed, [18]. At dry sliding, friction values raised as the treads heightened, where perpendicular treads, because of their higher deformation, showed significant friction increase, in contradiction to parallel treads. When water covered the rubber surface, friction coefficient recorded lower values than that seen with dry sliding. Detergent wet surfaces cased extra drop in friction coefficient. In contradiction to dry sliding, parallel treads caused higher friction coefficient, while perpendicular treads exhibited lower values due to the formation of the hydrodynamic wedge.

Influence of surface roughness of floor materials sliding against rubber was investigated, [19]. The tested floor materials included ceramic, polyvinyl chloride, wood, epoxy resin,

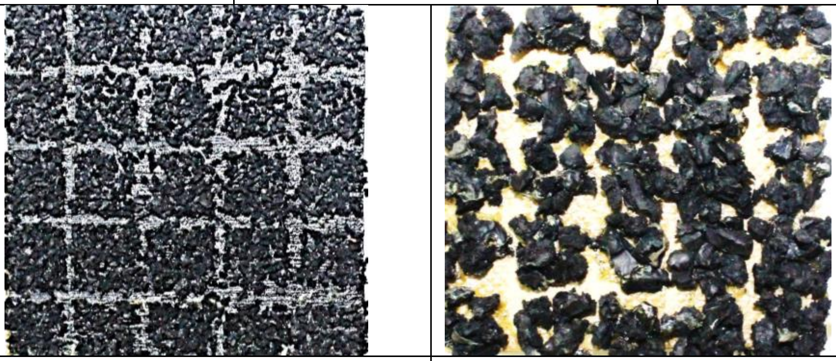
cement and marble. Among the tested materials, wood displayed the highest friction values. Introducing semispherical cavities in the rubber surface was investigated, [20], where increasing the height of the cavity caused significant friction increase. Formation of leakage grooves as well as holes in the rubber surface increased the friction due to their ability to leak water through the holes and grooves out of the contact area. It was proved that the type of floors can influence the values of static friction coefficient during sliding against rubber, [21 – 25]. The ability of generating electrostatic charge showed great effect on the friction behavior.

In the present work, comparative performance friction tests, between smooth and treaded recycled rubber of different particle size slid against ceramic tiles to determine friction coefficient at different sliding conditions, were accomplished.

EXPERIMENTAL

An apparatus had been constructed to measure the static friction coefficient of the tested rubber soles made of recycled rubber and sliding against ceramic tiles. The friction and normal forces had been measured. The tested soles were pressed and slid against the surface of the ceramic tile placed in a base supported by two load cells. One cell measures the tangential force (friction force) and the second can measure the applied normal load. Coefficient of friction was calculated by the dividing the value of friction force by the normal load.

1.0 mm Particle Size. **2.0 mm Particle Size.** **3.0 mm Particle Size.**



1.0 mm Particle Size. **5.0 mm Particle Size.**

Fig. 1 Photomicrographs of the smooth and treaded recycled rubber.

The tested rubber soles were made of recycled rubber granulates. The particle size of the rubber was 1.5, 2, 3, 4 and 5 mm. Treaded test specimens were prepared for comparison. The photomicrographs of the test specimens are shown in Fig. 1. The soles were made of recycled rubber bonded by polyurethane adhesive. The soles, in form of 50 × 50 mm and 5 mm thickness were adhered to wooden cube, Fig. 2. Friction test was carried out by pressing the soles against ceramic tile applying variable forces up to 200 N. Friction coefficient was plotted against load then friction values were extracted from the figures at 50, 100, 150 and 200 N. The soles were pressed and slid against dry, water and water + 1.0 vol. % detergent wet and oily soles. The ceramic tile was rinsed by 300 ml water to guarantee water film that simulates water wet sliding. A 1.0 vol. % detergent solution was ueed. Paraffin oil was used to lubricate the ceramic tiles.

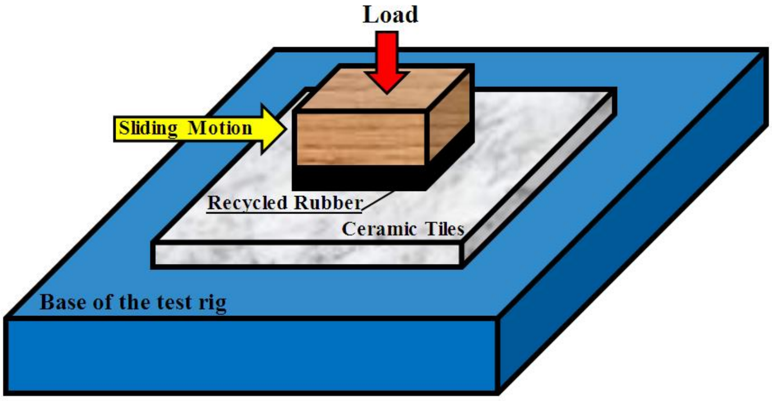


Fig. 2 Schematic illustration of the experimental procedure.

The results of friction coefficient exhibited by the sliding of the recycled rubber, are shown in Figs. 3 – 10. At dry sliding, Fig. 3, it is clearly shown that particle size of treaded rubber had significant effect on the frictional behavior, where friction coefficient slightly grew up to maximum at 1.5 mm particle size then decreased with increasing rubber particle size at 50 N load. As the load increased, friction coefficient recorded slight decreasing trend. The highest friction values reached 0.59 at 50 N load. It seems that as the load increases, heat generated from friction increases and consequently the shear strength of the rubber decreases so that friction coefficient decreased.

When the contact area increased for smooth test specimens, friction coefficient showed significant increase, Fig. 4, where the maximum value reached 0.72 at 50 N load. Friction coefficient significantly increased up to maximum at 2 mm rubber particle size then slightly decreased with increasing rubber particle size. It seems that increase of the contact area and rubber deformation are responsible for friction increase.

When the water covered the sliding surface, friction coefficient showed decreasing trend down to minimum then increased as the rubber particle size increased, Fig. 5. It seems that the spaces between the particles stored water and distributed on the ceramic surface. As the particle size increases the spaces between the rubber particles and ceramic surface allowed the water to go out the contact area causing an increase of the partial rubber/ceramic contact and consequently friction coefficient increased. Relatively smaller particles facilitated the water to be formed on the surface area causing the decrease of friction coefficient. The minimum value of friction coefficient

was 0.17 at 2.0 mm particle size and 200 N load. Considering the friction values, the sliding can be classified as unsure and slippery because friction coefficient was between 0.15 and 0.19.

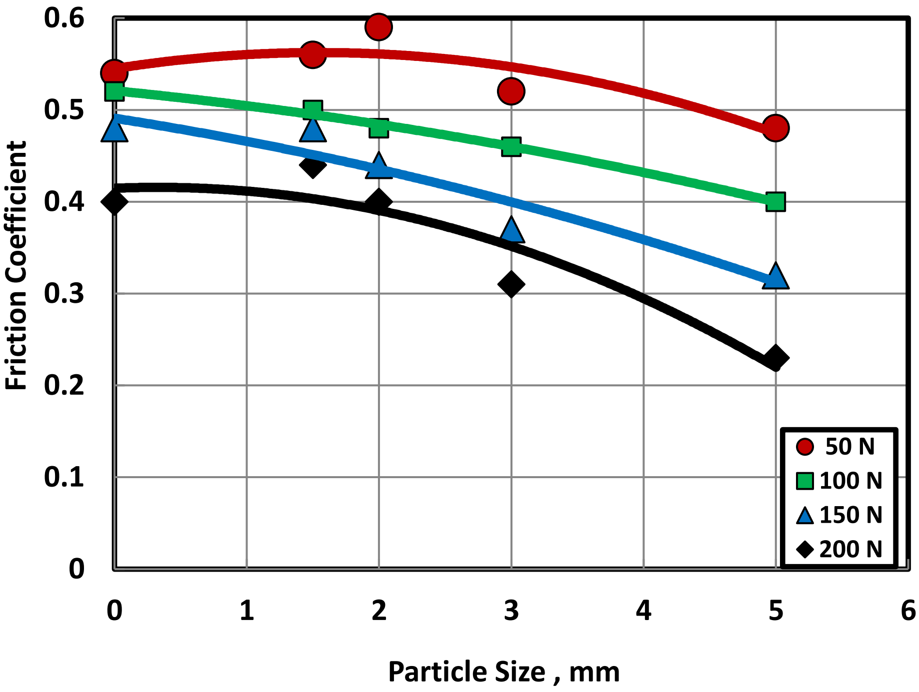


Fig. 3 Friction coefficient as a function of particle size for treaded recycled rubber sliding on dry ceramic tiles

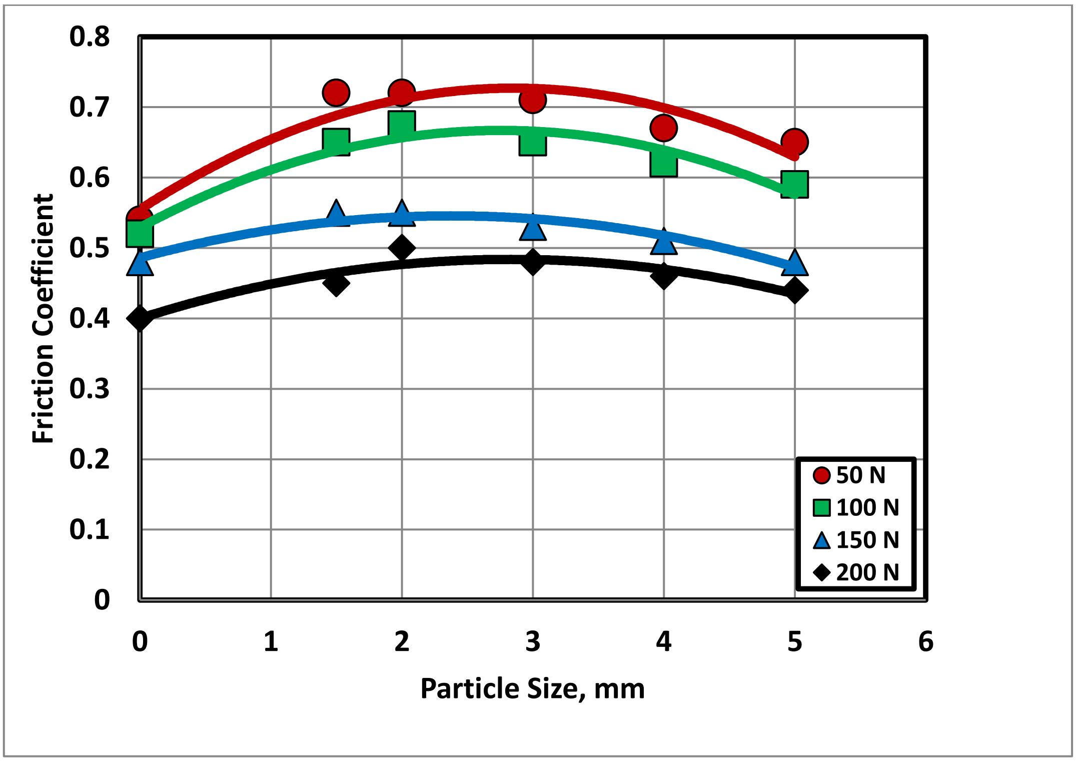


Fig. 4 Friction coefficient as a function of particle size for smooth recycled rubber sliding on dry ceramic tiles

Slight friction decrease was observed for smooth test specimens, Fig. 6. This behavior may be from capability of the smooth rubber to trap water than the treaded specimens. The minimum of friction value was 0.16 at 2.0 and 3.0 mm particle size and 200 N load. According to that behavior, it is proposed to apply treaded rubber in wet floor tiles.

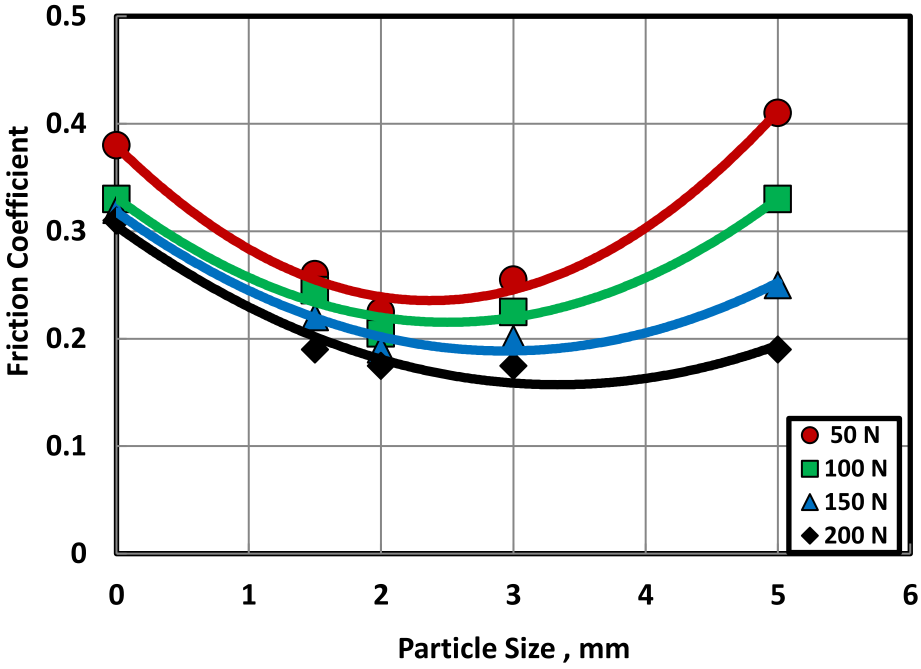


Fig. 5 Friction coefficient as a function of particle size for treaded recycled rubber sliding on water wet ceramic tiles.

The same trend was noticed at detergent wet surfaces, Fig. 7, where increasing rubber particle size decreased friction coefficient. Friction showed lower values than water wet surface. It seems that the relatively strong adhesion of detergent particles into rubber and ceramic tile was the reason for the friction decrease. The lowest friction values were displayed at 200 N load. Smooth surface displayed the highest friction values. It can be seen that rubber particle size showed slight influence on the value of friction coefficient. The relatively high difference in friction reveals that rough specimens can store detergent better than smooth rubber.

The effect of particle size of smooth recycled rubber is shown in Fig. 8. Friction coefficient recorded higher values than treaded rubber. It seems that adhesion of detergent molecules into floor surface is much stronger than rubber. This observation is in contradiction to water wet sliding.

The effect of particle size of recycled rubber is shown in Fig. 9. Smooth surface showed drastic decrease in friction. Friction coefficient increased as the particle size increased. That phenomenon can be interpreted on the basis that spaces and gaps between the

particles facilitated the oil to leak out of the contact area. It is of general knowledge that relatively high static friction coefficient can provide safe walking. The degree of risk of slip depends on the static friction coefficient. Values of friction shown for oil lubricated surface define that the sliding condition was very slippery. Smooth recycled rubber sliding against oil lubricated ceramic tiles showed no effect on friction coefficient, Fig. 10, compared to treaded rubber. The high viscosity of oil impedes its flowing outside the contact area through the treads.

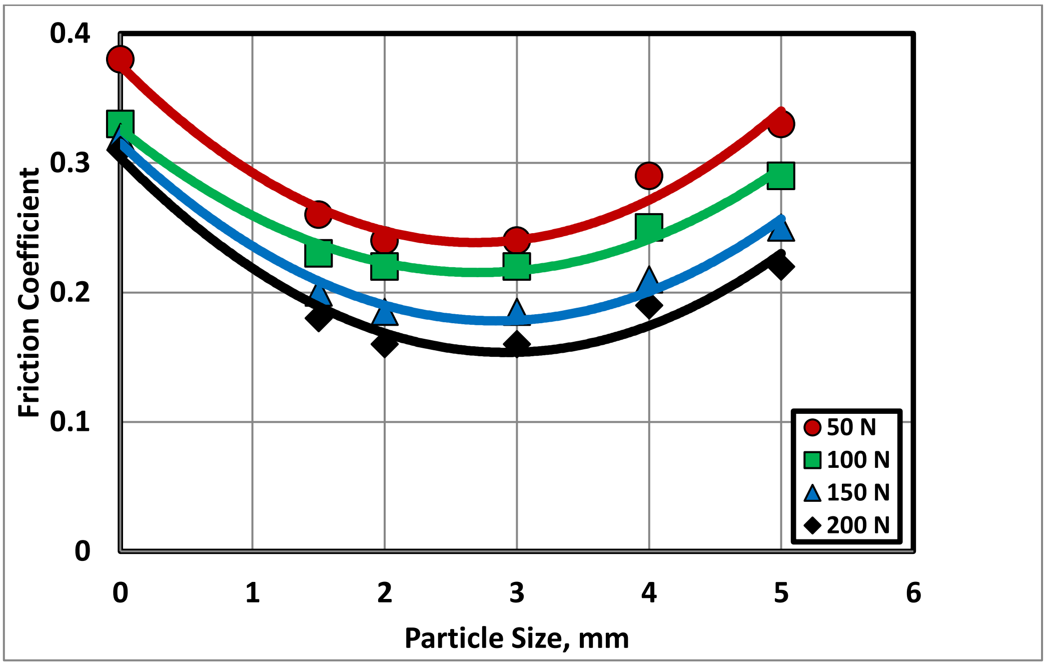


Fig. 6 Friction coefficient as a function of particle size for smooth recycled rubber sliding on water wet ceramic tiles

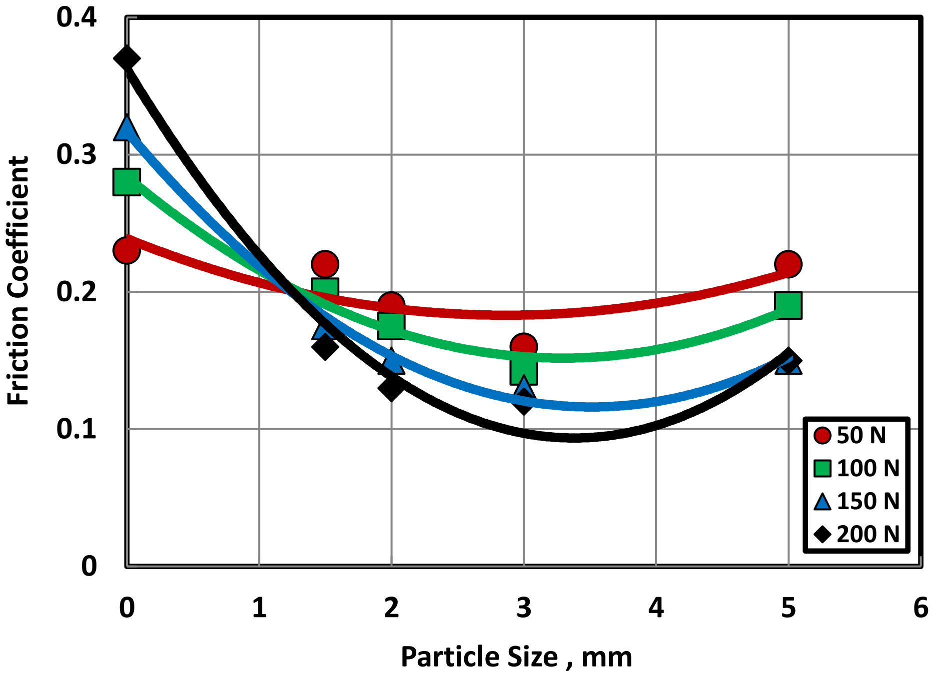


Fig. 7 Friction coefficient as a function of particle size for treaded recycled rubber sliding on detergent wet ceramic tiles.

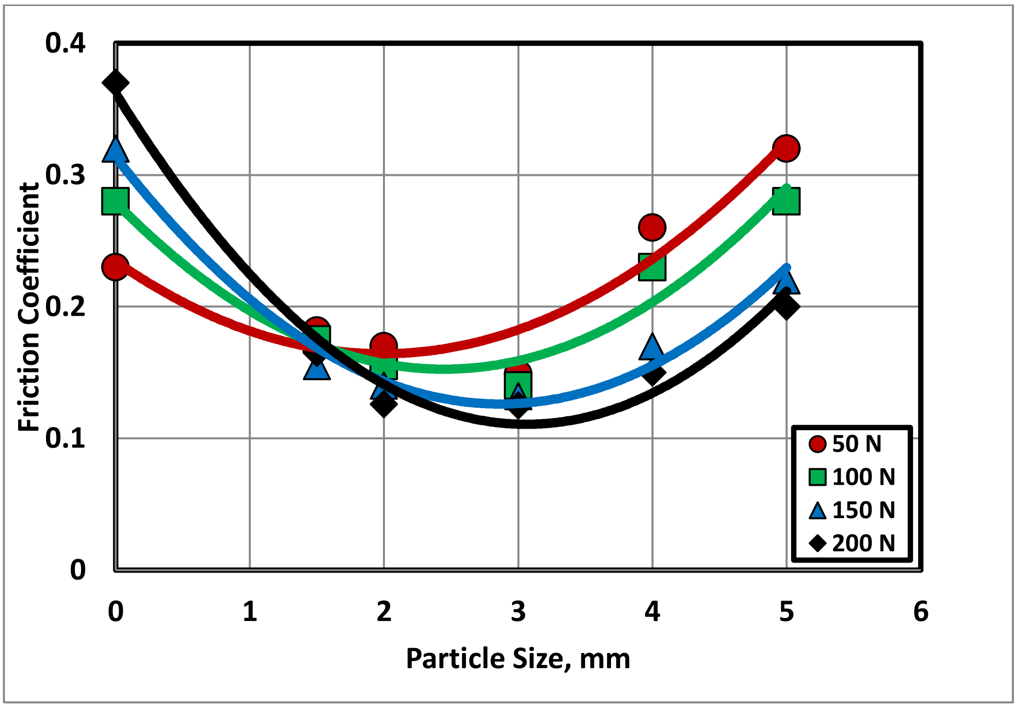


Fig. 8 Friction coefficient as a function of particle size for smooth recycled rubber sliding on dry ceramic tiles.

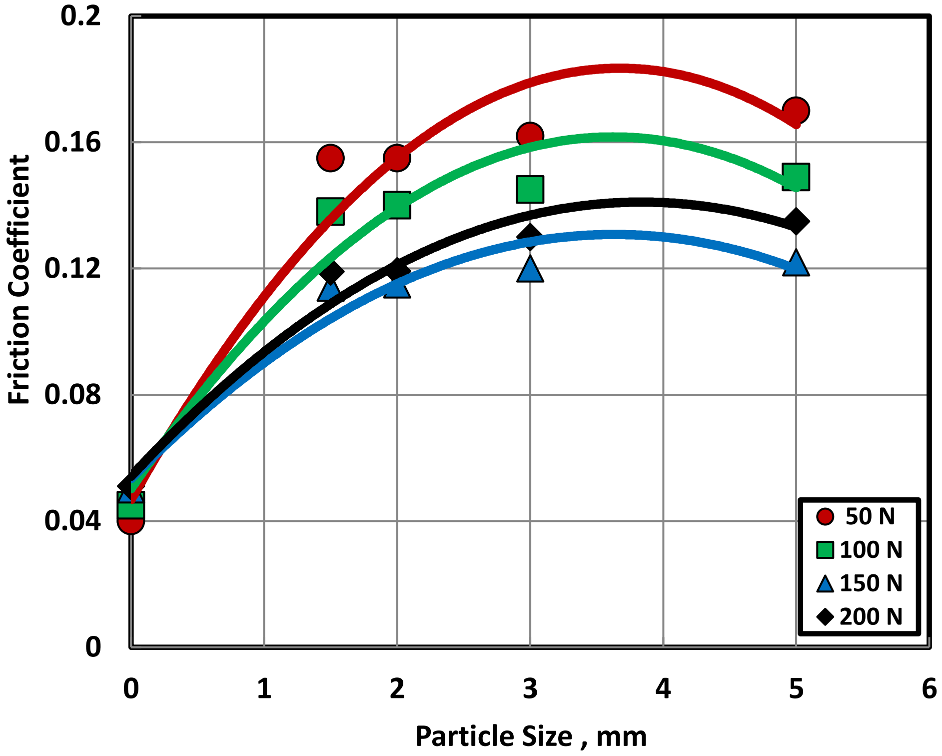


Fig. 9 Friction coefficient as a function of particle size for treaded recycled rubber sliding on oil lubricated ceramic tiles.

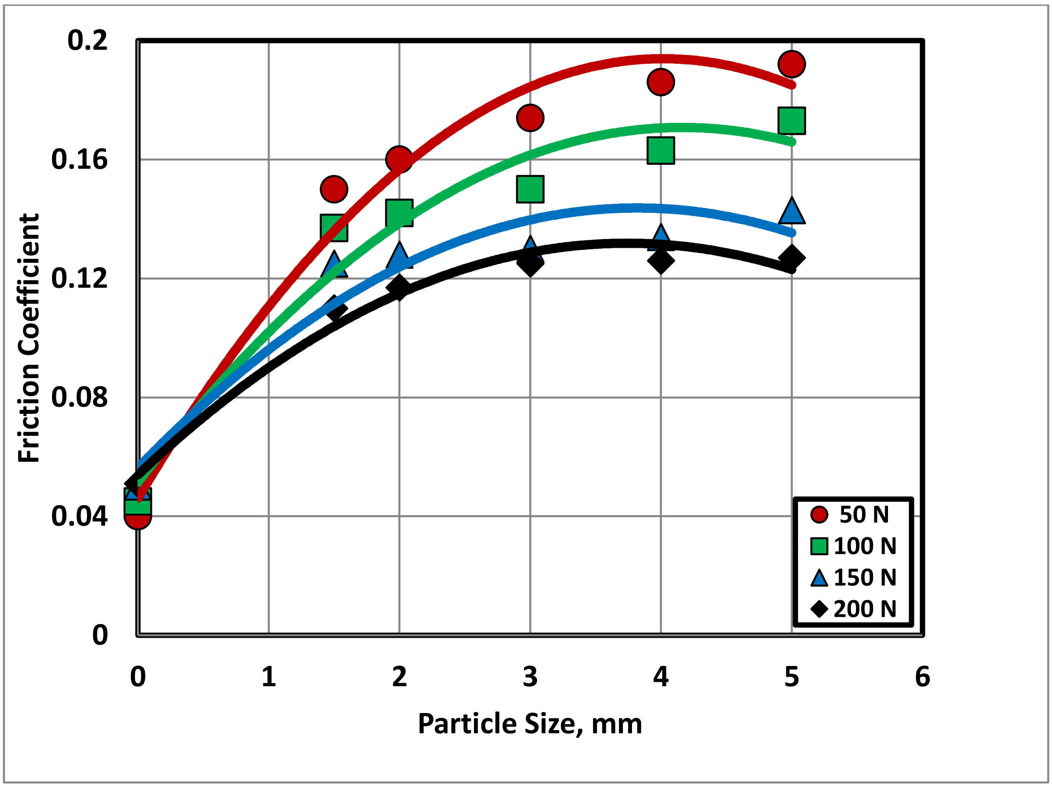


Fig. 10 Friction coefficient as a function of particle size for smooth recycled rubber sliding on oil lubricated ceramic tiles.

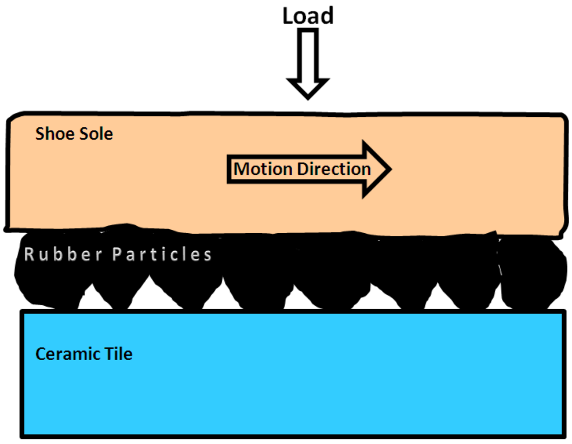


Fig. 11 Contact between relatively big rubber particles and ceramic surface.

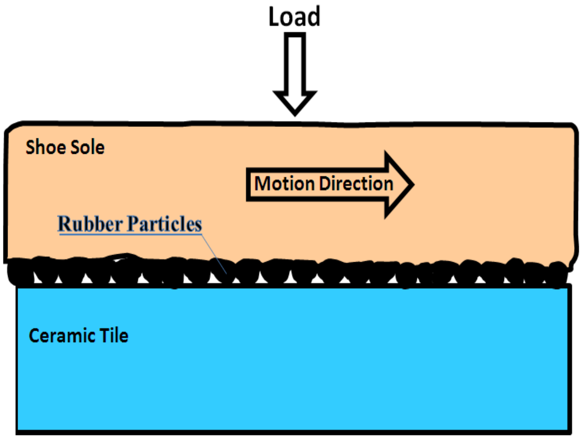


Fig. 12 Contact between relatively small rubber particles and ceramic surface.

The schematic illustrations, Figs. 11 and 12, show that the contact area between rubber particles and ceramic surface differs according to the rubber particle size. As the particle size increases the contact area decreases, which interprets the decrease of friction coefficient with increasing particle size at dry sliding. The optimum particle size of rubber was 2.0 mm, which produces the highest friction coefficient. When the fluid covers the ceramic surface, the volume of the spaces between particles and ceramic can control the amount of the fluid to be stored in, therefore the contact area of rubber/ceramic can be controlled. The capability of the rubber surface to trap fluid increases and changes the wet sliding to be partially dry as the particle size increases. This discussion may explain the increase of friction with increasing rubber particle size. The best performance, observed for the test specimens and the ceramic surface were lubricated by oil, was observed for the relatively high rubber particle size, where the friction coefficient significantly increased.

CONCLUSIONS

1. At dry sliding, particle size of treaded rubber had significantly influenced the frictional behavior. As the load increased, friction coefficient recorded slight decreasing trend. For smooth test specimens, friction coefficient showed significant increase. Increasing rubber particle size increased friction coefficient. Further increase in particle size caused slight decrease.

2. When water rinsed the sliding surface, friction coefficient decreased down to certain values. As the rubber particle size increased friction coefficient increased. Slight friction decrease was observed for smooth test specimens. It is proposed to apply treaded rubber in water wet floor tiles.

3. The same trend was noticed at detergent wet surfaces, where friction coefficient showed decreasing trend with increasing rubber particle size. The relatively high difference in friction reveals that rough specimens can store detergent better than smooth rubber. Friction coefficient of smooth rubber displayed higher values than that recorded by treaded rubber. It seems that adhesion of detergent molecules into ceramic

surface is much stronger than rubber. This observation is in contradiction to that observed for water wet sliding.

4. At oil sliding, smooth surface showed minimum friction values. As the particle size increased, friction coefficient increased. Smooth rubber showed no effect on friction coefficient compared to treaded rubber. The high viscosity of oil impedes its flowing outside the contact area through the treads.

REFERENCES

1. Elham B. R., Khashaba M. I. and Ali W. Y., "Friction Coefficient of Smooth and Rough Recycled Rubber Flooring Tiles", Journal of the Egyptian Society of Tribology Vol. 9, No. 3, July 2012,pp. 53 – 65, (2012).

2. Elham B. R., Khashaba M. I. and Ali W. Y., "Effect of Filling Materials on the Friction Coefficient of Recycled Rubber Flooring", Journal of the Egyptian Society of Tribology Vol. 10, No. 1, January 2013, pp. 1 – 12, (2013).

3. Elham B. R., Khashaba M. I. and Ali W. Y., "Effect of Surface Roughness on Friction Coefficient of Recycled Rubber Floorings", Journal of the Egyptian Society of Tribology Vol. 10, No. 1, January 2013, pp. 13 – 25, (2013).

4. Samy A. M., El-Sherbiny Y. M. and Ali W. Y., "Friction Coefficient of Recycled Rubber Tiles of Different Porosity", Journal of the Egyptian Society of Tribology Vol. 10, No. 1, January 2013, pp. 38 – 49, (2013).

5. El-Sherbiny Y. M., Mohamed M. K., Ali W. Y., "Friction Coefficient and Wear of recycled Rubber Floor Mat", KGK, 01/2014 Januar/Februar, pp. 27 – 32, (2014).

6. Mai K. M., Khashaba M. I., Mousa M. O. and Ali W. Y., "Friction Coefficient Displayed by Sliding of Rubber Sole Against Recycled Rubber Flooring Tiles", EGTRIB Journal, Vol. 12, No. 4, October 2015, pp. 28 – 39, (2015).

7. Manning D. P., Jones C., “The effect of roughness, floor polish, water, oil and ice on underfoot friction: Current safety footwear solings are less slip resistant than microcellular polyurethane”, Applied Ergonomics 32, pp. 185 – 196, (2001).

8. Proctor T. D., Coleman V., “Slipping, tripping, and falling accidents in Great Britain ‒ Present and future”, Journal of Occupational Accidents 9, pp. 269 – 285, (1988).

9. Strandberg L., “The effect of conditions underfoot on falling and overexertion accidents”, Ergonomics 28(1), pp. 131 – 147, (1985).

10. Strandberg L., Lanshammar H., “The dynamics of slipping accidents”, Journal of Occupational Accidents 3, pp. 153 – 162, (1981).

11. Ezzat F. H., Abdel-Jaber G. T. and Ali W. Y., “Dry Sliding of Rubber on Glazed Ceramic Tiles”, Proceedings of the 7th International Conference of Tribology, EGTRIB 7, December 27 - 28, 2006, Faculty of Engineering, Cairo University, pp. CI, 1 – 9, (2006).

12. El-Sherbiny Y. M. Ramadan M. A. and Ali W. Y., "Frictional Behaviour of Rubber Flooring Mat Fitted by Rectangular Treads", Journal of the Egyptian Society of Tribology, Vol. 11, No. 2, April 2014, pp. 39 – 52, (2014).

13. Elhabib O. A., Mohamed M. K., AlKattan A. A. and Ali W. Y., "Triboelectrification of Flooring Polymeric Materials", International Journal of Scientific & Engineering Research,Volume 5, Issue 6, June 2014 , pp. 248 - 253, (2014).

14. Shoush K. A., Elhabib O. A., Mohamed M. K., and Ali W. Y., "Triboelectrification of Epoxy Floorings", International Journal of Scientific & Engineering Research, Volume 5, Issue 6, June 2014, pp. 1306 - 1312, (2014).

15. Lanshammar H., Strandberg L., “Horizontal floor reaction forces and heel movements during the initial stance phase”, In: Matsui, H. and Kobayashi K. (Eds.), Biomechanics VIII. University Park Press, Baltimore, pp. 1123 - 1128, (1983).
16. Li K. W., Chen C. J., "The effect of shoe soling tread groove width on the friction coefficient with different sole materials, floors, and contaminants", Applied Ergonomics 35, pp. 499 – 507, (2004).
17. El-Sherbiny Y. M., Mohamed M. K., Ali W. Y., “Friction Coefficient Displayed by Footwear Walking Against Rubber Floorings Fitted by Cylindrical Treads”, Journal of the Egyptian Society of Tribology, Vol. 8, No. 1, January 2011, pp. 1 – 12, (2011).
18. El-Sherbiny Y. M., Samy A. M. and Ali W. Y., “Friction Coefficient of Rubber Sliding Against Dusty Indoor Flooring”, Journal of the Egyptian Society of Tribology, Vol. 7, No. 2, April 2010, pp. 11 – 25, (2010).
19. El-Sherbiny Y. M., Hasouna A. T. and Ali W. Y., "Friction Coefficient of Rubber Sliding Against Flooring Materials", Journal of the Egyptian Society of Tribology Vol. 8, No. 4, October 2011, pp. 1 – 11, (2011).
20. Samy A. M., El-Sherbiny Y. M. and Hasouna A. T., "Reducing the Slip of Rubber Mats on Ceramic Floorings", EGTRIB, Journal of the Egyptian Society of Tribology, Vol. 8, No. 3, July 2011, pp. 1 – 14, (2011).
21. Samy A. M., El-Sherbiny Y. M., and Khashaba M. I., "Friction Coefficinet of Perforated Bathroom Rubber Mats with Leakage Grooves", EGTRIB, Journal of the Egyptian Society of Tribology, Vol. 8, No. 2, April 2011, pp. 1 – 12, (2011).
22. Mai K. M., Khashaba M. I., Mousa M. O. and Ali W. Y., "Effect of Hardness and Thickness of Recycled Rubber Tiles on Electric Static Charge Generated from their Contact and Separation with Rubber Sole", International Journal of Materials Chemistry and Physics, Vol. 1, No. 3, pp. 352 – 358, December (2015).
23. El-Sherbiny Y. M., Abdel-Jaber G. T., Ali W. Y., "Proper Selection of Indoor Floor Based on Friction Coefficient and Electric Static Charge", EGTRIB Journal, Vol. 13, No. 1, January 2016, pp. 1 – 14, (2016).
24. El-Sherbiny Y. M., Ali A. S. and Ali W. Y., "Triboelectrification of Shoe Soles and Floor in Hospitals", EGTRIB Journal, Vol. 12, No. 3, July 2015, pp. 1 – 14, (2015).
25. Esraa S. S., Khansaa A. M., Rasha A. A., Sahar A. K., Sandra E. S., Ali W. Y., "Proper Selection of Foot Wearing Socks Textiles Based on Friction Coefficient Displayed by Sliding Against Indoor Floors", EGTRIB Journal, Vol. 13, No. 2, April 2016, pp. 15 – 24, (2016).