Vol. 44, No. 2 (2022) 244-252, DOI: 10.24874/ti.1188.09.21.11

Tribology in Industry

www.tribology.fink.rs

RESEARCH

Friction Coefficient of Rubber Shoe Sole Sliding Against Different Rubber Floor Tiles

Mohamed Ahmed Ramadan[a,*]

[a]*Mechanical Engineering Department, Faculty of Engineering, Helwan University, Helwan, Egypt.*

Keywords:

Friction
3D surface map
Rubber tiles
Grooved tiles
Slips and fall

* Corresponding author:

M.A. Ramadan
E-mail:
eng_mohamedramadan@yahoo.com

Received: 17 September 2021
Revised: 30 October 2021
Accepted: 18 November 2021

ABSTRACT

Slips and falls can occur in any part of the flat, workshop, outside the pool, or gym, but they are more common in children's areas with lots of movement. The friction between different types of floor tiles and rubber footwear is investigated in this study. The tests were conducted with particular test rig that could measure the friction coefficient between the shoe sole and rubber tiles. The tests were carried out by sliding the shoe sole against three different types of commercial rubber tiles (floors) under three different conditions (dry, mixture of water & soap and paraffin oil). Surfer13 software was used to analyze the surface texture of the flooring samples, which processed and converted the images into a 3D surface map. The data of 2d surface profile was imported into Origin software and the surface roughness data was calculated. COF results were compared to the standards safety guidelines. This study yielded important tribological findings that could help to guide the approach to reducing indoor slips and falls injuries. Based on findings, the friction coefficient has affected by lubrication on the contact surface, Surface texture of the contact surfaces, Surface roughness and normal load through the sliding. The investigation findings might serve as guidance for preventing slip and fall injuries. The surface roughness data obtained by digital image processing was in a good agreement with that obtained by conventional roughness testing machine.

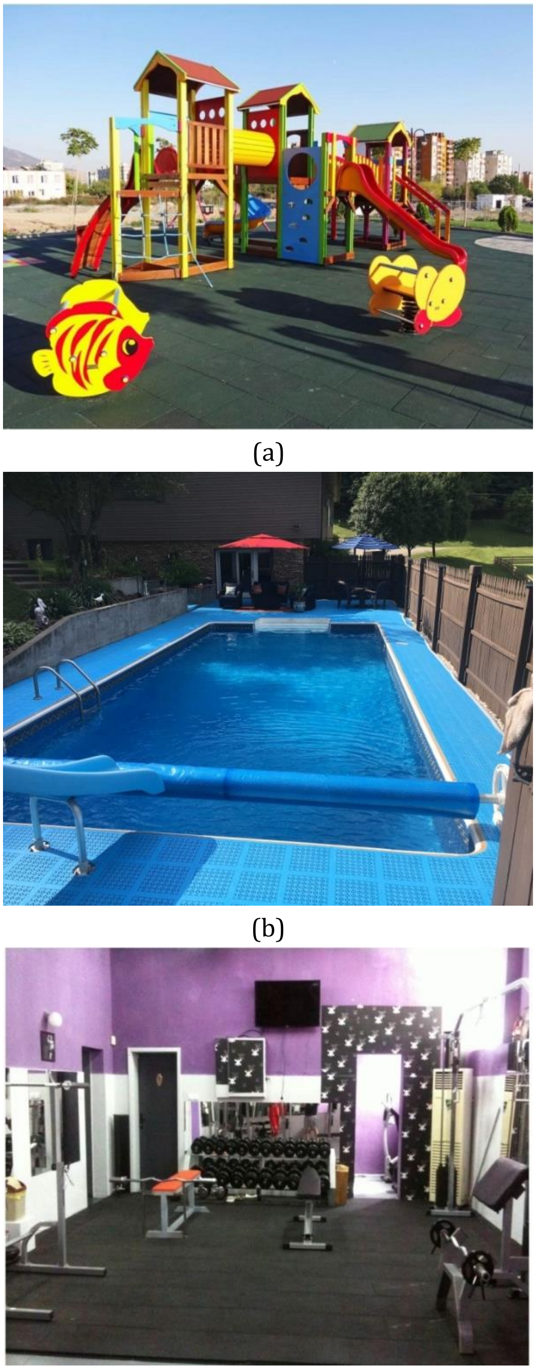
1. INTRODUCTION

Falling and slipping can result in numerous accidents and injuries. Slippery accidents can be dangerous because of inadequate geometric design and materials in footwear or flooring. Some studies have been carried out in order to discover solutions. Assessing the slip resistance of athletic socks and footwear on various household flooring materials by studying the coefficient of friction between a footwear sliding against different flooring materials [1]. To reduce the danger of falling when walking on a wet floor surface, a high slip-resistant footwear outsole with a hybrid rubber surface design was created [2]. These investigations also aid in the development of novel flooring materials that prevent slipping, such as rubber sheets with grooves and tread patterns.

It is possible to explain the complex mechanisms involved in footwear–surface contact [3]. Surface texture, surface roughness, normal load, hardness, crystal structure, and lubrication were all investigated as a function of steady state and stick-slip motion [4]. FCC metals, alloys, and materials with higher hardness showed a steady state frictional response, whereas soft metals showed a stick-slip frictional response. The friction coefficient was studied in relation to the hardness of recycled rubber flooring tiles sliding against the rubber sole [5]. It was observed that when the hardness of the flooring tiles increased, the friction coefficient decreased dramatically under dry conditions.

The frictional performance of flooring materials sliding against soft and hard rubbers (ceramic, PVC, parquet, marble, and epoxy tiles) was studied [6]. When slid on ceramic tiles in a dry condition, soft rubber had a higher friction coefficient than hard rubber. At dry conditions, parquet and PVC tiles had the lowest friction coefficients, whereas ceramic and marble had the highest one. Rubber sliding against several types of flooring materials with varying surface roughness was studied [7,8]. The friction coefficient decreased with increased surface roughness in dry conditions, according to the findings.

The friction coefficient of flooring materials beside their ability to generate electric static charge was studied. Based on the findings of that study, it is advised that flooring materials be chosen based on their resistance to the generation of electric static charge [9]. The importance of determining the reasons of slips and trips is critical, as it emphasizes the need of floor safety. In order to prevent slips and falls in the apartment, pool, gym, and especially in Kid's areas with lots of movement, Fig. 1, this research examined the friction coefficient between rubber shoe soles and different types of rubber floor tiles. Also, based on image processing, a new approach has been presented for nondestructive, rapid, and low-cost surface roughness evaluation of rubber samples.


(a)

(b)

(c)

Fig. 1. Rubber floor tiles [10,11], (a) Kids area rubber tiles, (b) Pool rubber tiles, (c) Gym rubber tiles.

2. EXPERIMENTAL

The experiments were carried out with the help of a special test rig [12,13] that was actually built to measure the friction coefficient between the shoe sole and the floor tiles by measuring both friction and normal forces. The loads were measured using two strain gauge load cells with a load capacity of 400 kg each. Figure 2 shows how one was fixed vertically to measure friction and the other was fixed horizontally to measure normal force. Three commercial rubber flooring tiles, (50 x 40 x 1 cm) with different surface roughness and features were used as test specimens in this experiment.

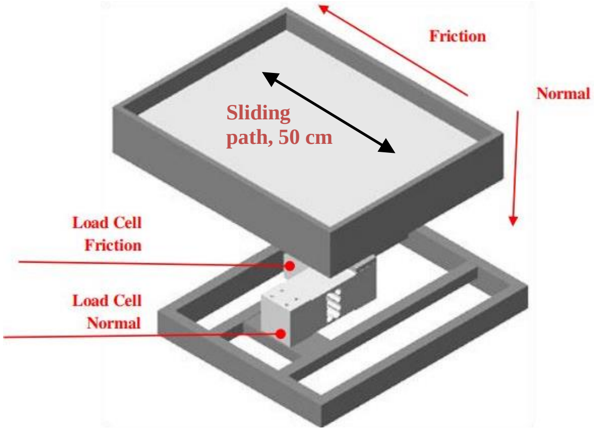
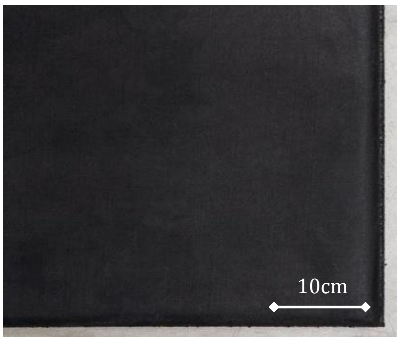
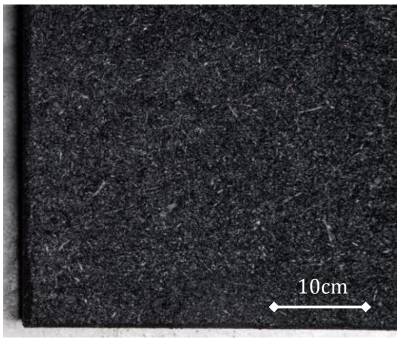


Fig. 2. Test rig arrangement.

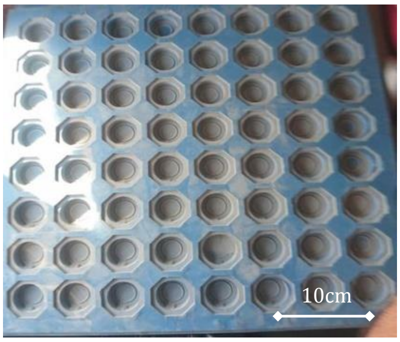
Figures 3a and 3b show two free grooves, one with a low surface roughness (smooth) and the other with a higher surface roughness (gruff). This type of rubber flooring tile can be found in a variety of places, including the home, the kids' area, the gym, and so on. Figure 3c shows a rubber tile with grooves on the top. Frequently used in areas where the floor is likely to be wet most of the time, such as an outdoor pool floor. At a time, one specimen (rubber tile) was adhered to the test rig's base, (50 x 40 cm) and supported by two load cells.



(a)



(b)



(c)

Fig. 3. Test specimens: (a) Smooth rubber tile (sample A), (b) Gruff rubber tile (sample B), (c) Grooved rubber tile (sample C).

The friction force was measured while the normal load was applied to the rubber tile using footwear sliding manually against the tile at a constant sliding speed of 0.16 m/s, [12,14,15]. The outsole of the footwear was chosen as soft rubber, 65 Shore A hardness without grooves to resemble the worst sliding case. The outsole rubber was cut as square form (8 x 8 x 0.5 cm) and adhered to wood base (8 x 8 x 2 cm) as shown in Fig. 4.

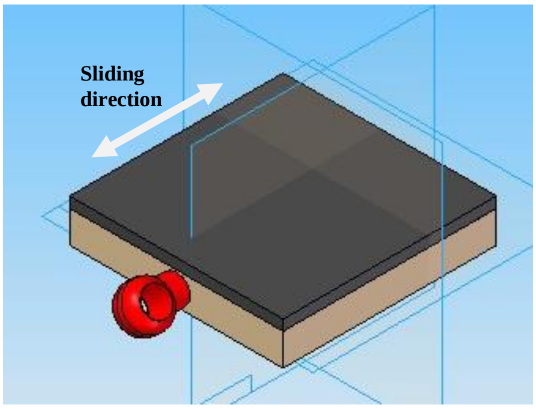


Fig. 4. Outsole of the footwear.

Then, using a cord, let the loaded rubber (shoe sole) to uniformly slide against the rubber samples. The nominal contact area was 64 cm^2 and the contact pressure at 160 N normal load was 25 kPa. The coefficient of friction of rubber shoe sole sliding against the different rubber tiles was investigated. All specimens were tested in three different conditions; dry, mixed (water and soap) and oily condition (paraffin oil). Through the different conditions mentioned, coefficients of friction were calculated for each condition. The friction coefficient was determined by dividing the friction force by the normal load. The viscosity of lubricants was measured using absolute viscometer. Water and soap had a viscosity of 10 cP, but paraffin oil had a viscosity of 22 cP. All of the tests were carried out at room temperature, 25 ^{0}C and Humidity of 70 % with different normal loads of 100, 120, 140, and 160 N. To simulate the service environment, different test conditions were used. Each experiment was carried out three times to ensure that the data was reliable and accurate. As shown in Table 1, the hardness of matting surfaces was measured using (Shore A Durometer). Surfer13 software was used to process the samples images and convert them to a 3D surface map in order to analyze the surface texture of flooring samples, Figs 5 - 7.

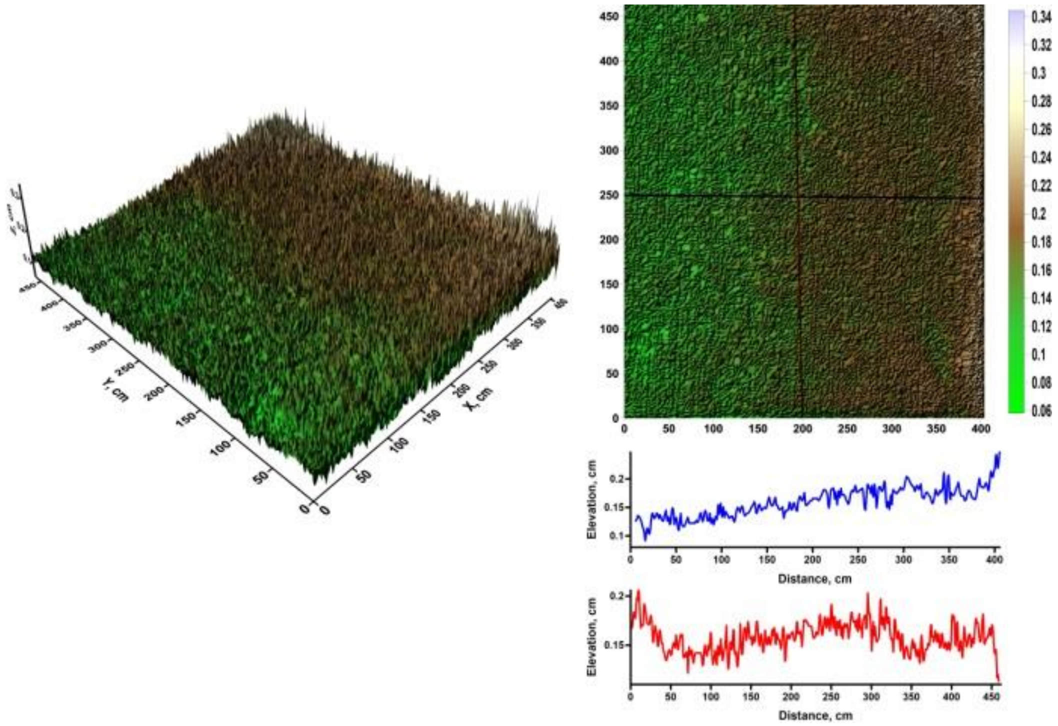


Fig. 5. 3D surface texture map and 2D surface profiles of sample A.

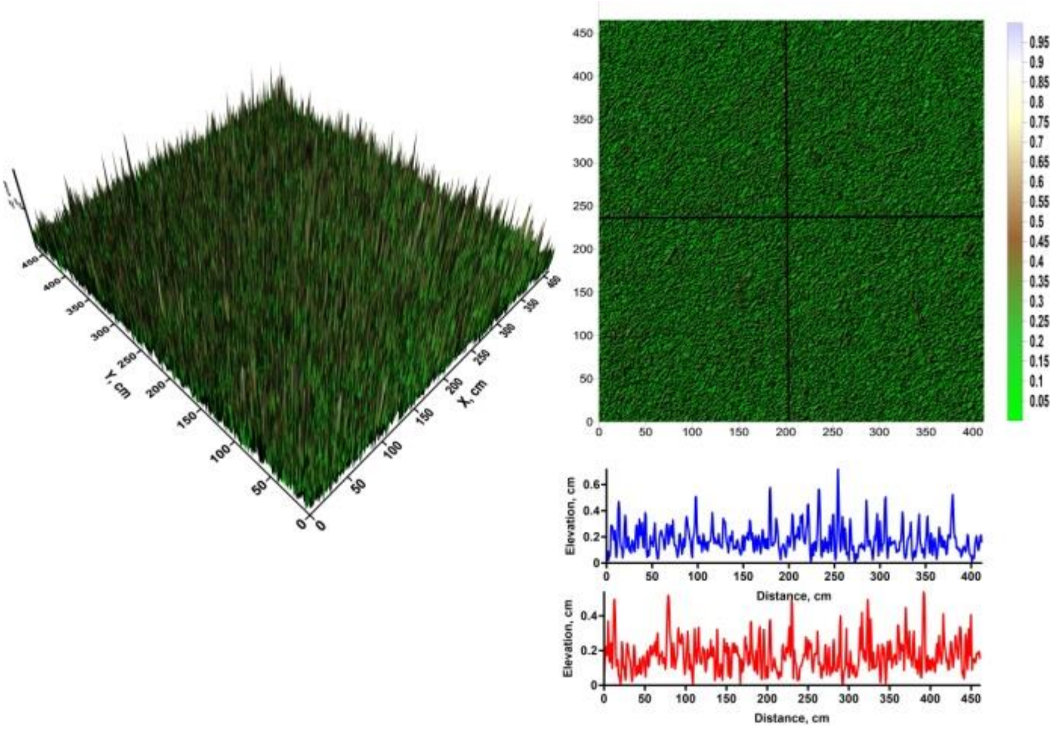


Fig. 6. 3D surface texture map and 2D surface profiles of sample B**.**

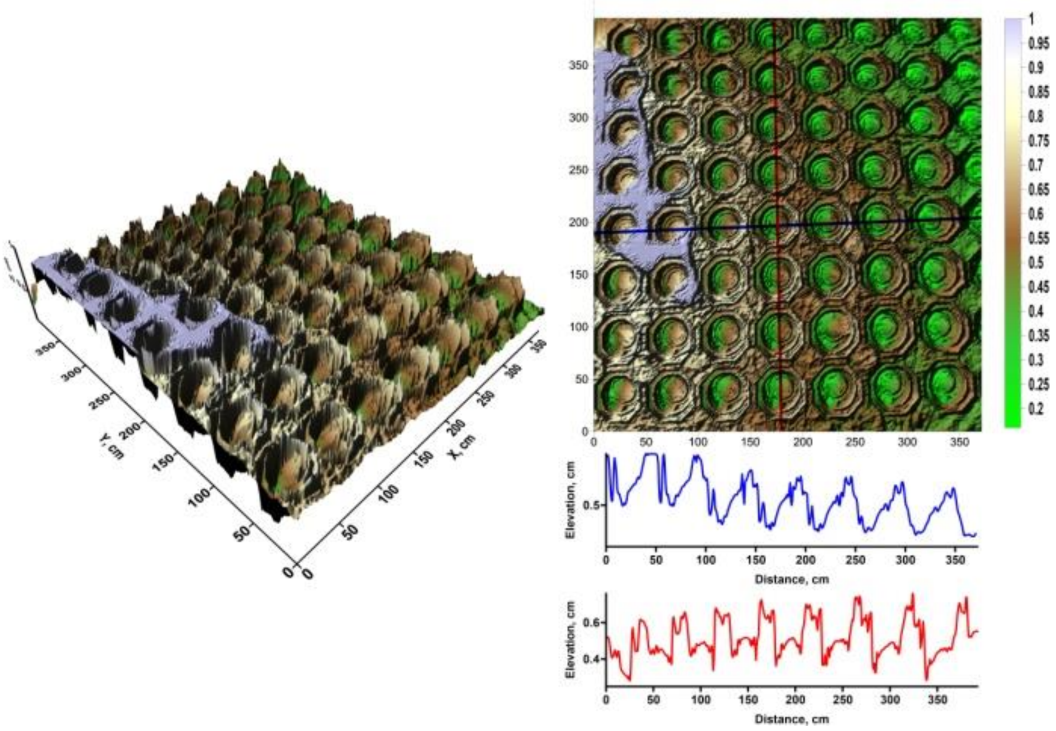


Fig. 7. 3D surface texture map and 2D surface profiles of sample C.

Table 1. The hardness of matting surfaces.

Matting surfaces	Hardness (Shore A)
Shoe sole	65
Smooth rubber tile (sample A)	72
Gruff rubber tile (sample B)	76
Grooved rubber tile (sample C)	80

The surface roughness (Ra) and (RMS (Rq)) are computed using the data points from a 2D surface profile imported into the Origin software, according to [16,17], where the impacts of filtering techniques for eliminating the long wavelength surface on the precision of image processing data were considered. These values of surface roughness are verified by the conventional portable surface roughness tester Mitutoyo Surftest SJ-210. Table 2. shows very little difference between values obtained by Origin program and values obtained by the device Mitutoyo Surftest SJ-210.

Table 2. Surface roughness values.

Matting surfaces	Surface roughness values evaluated by Origin program (μm)				Surface roughness values evaluated the device Surftest SJ-210 (μm)			
	Ra		RMS		Ra		RMS	
	vertical	lateral	vertical	lateral	vertical	lateral	vertical	lateral
Smooth rubber tile (sample A)	0.31	0.28	13.49	12.58	0.33	0.27	13.66	12.46
Gruff rubber tile (sample B)	0.42	0.44	18.38	19.21	0.41	0.45	18.22	19.15
Grooved rubber tile (sample C)	0.42	0.43	18.64	19.16	0.42	0.44	18.55	19.50
Shoe sole rubber	NA	NA	NA	NA	0.32	0.33	14.22	14.65

3. RESULTS AND DISCUSSION

The relation between friction coefficient and the normal force was plotted for each condition (dry, soapy and oily). The friction coefficient exhibited by smooth rubber tile (sample A) sliding against shoe sole surface is shown in Fig. 8. There was a slight decrease in friction with increasing load due to the more asperities which come into the contact surface area as a result of load increase. At dry condition, the friction coefficient was higher than those at mixed (water and soap) and oily conditions. This is lies to the lubrication nature of oil and soap. Frictional interactions and asperity geometry have a complicated and poorly understood connection. It has been observed that increasing roughness can result in lower frictional interactions in some conditions, whereas smoother surfaces can actually display high levels of friction due to large real contact area [18].

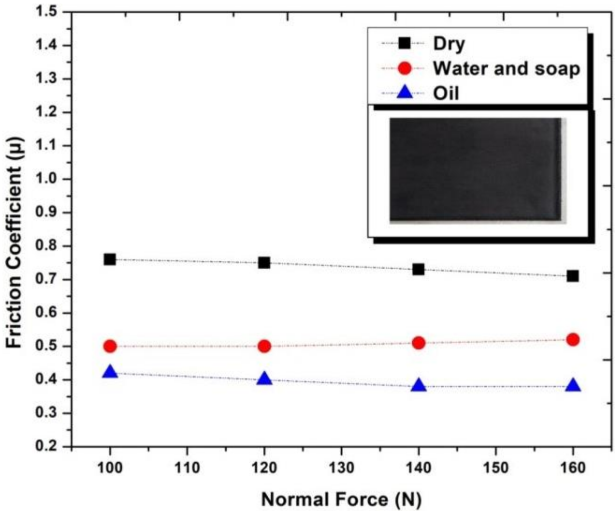


Fig. 8. Friction coefficient displayed by sample (A) sliding against shoe sole surface at different condition.

Figures 5, 6, and 7 show the 3D surface texture and 2D surface profiles of sample A, sample B, and sample C, respectively. Sample A has the lowest surface roughness, as shown in Table 2. As can be seen, Fig. 9 was drawn according to Peter Fino and Thurmon Lockhart, [19], to study slipping and compare our results with the required friction coefficient during waking speed. The required friction coefficient during walking should be 0.35 for slow walking, 0.45 for normal walking, and 0.54 for fast walking, as shown in Fig. 9.

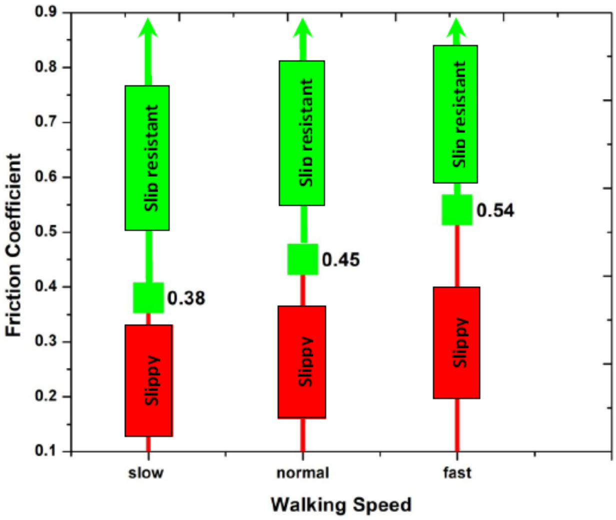


Fig. 9. The required coefficient of friction during walking speeds [20].

Also, according to OSHA (Occupational Safety and Health Administration) safety guidelines, the required coefficient of friction for fast turning is > 0.50 [19]. According to these guidelines, Sample A is safe in dry and soapy conditions but not in oily conditions, especially when walking at normal and fast speeds with a coefficient of friction less than 0.45.

Friction coefficient displayed by rubber shoe sole sliding against gruff rubber tile, sample (B) at different condition is shown in Fig. 10. This type of rubber tile obtained higher COF than that obtained by smooth rubber tile, (sample A) as its hardness and surface roughness is higher than those for sample A as shown in Table 2. and Table 1. It's worth noting that as the load increases, the friction coefficient decreases slightly. It is well known that as the load increases, the friction coefficient of polymers and elastomeric materials decreases. Furthermore, the viscoelastic properties of mating surfaces might be influenced by the high temperature generated for the higher load which is responsible for the decrease in friction [12]. The friction coefficient values obtained in the mixed (water and soap) condition are significantly lower than those obtained in the dry condition, where the friction was highest. This is due to the presence of (water and soap) on the sliding surfaces, which acts as a lubricant and reduces the friction coefficient. As the normal force increases, the coefficient of friction remains constant. This might be attributed to the presence of water at the contact surfaces, which helps to normalize the effect of the higher load's higher temperature, resulting in the stability of the friction coefficient value. While at oily condition, the values of the friction coefficient slightly decreased as the load increased but still lower than those obtained at dry and (water + soap) conditions. This may be due to that the oil is lubricant, which facilitates the movement of weights and reduces the value of friction coefficient. According to Peter Fino and Thurmon Lockhart [19] and OSHA (Occupational Safety and Health Administration) safety guideline, sample B is safe at dry and soapy conditions but not at oily condition, (COF < 0.5) particularly at fast walking and fast turning at which COF should be ≥ 0.54.

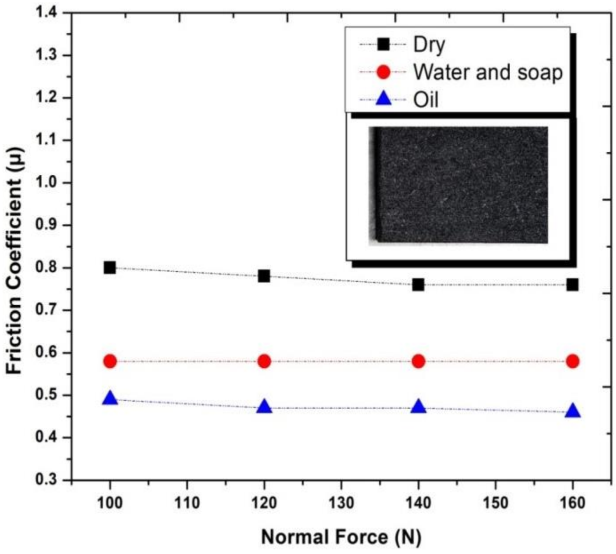


Fig. 10. Friction coefficient displayed by sample (B) sliding against shoe sole surface at different condition.

Figure 11 depicts the friction coefficient displayed by grooved rubber tile (sample C) sliding against shoe sole surface at different conditions. At both dry and (water + soap) conditions, the values of the friction coefficient dropped considerably as the load increased. The rubber deformed further as the load increased, pushing water and soap back into the contact area and serve as lubrication [13]. Friction coefficient values for rubber tiles with grooves (sample C) were also found to be lower than those for rubber tiles with free grooves (sample A and sample B). This might be attributed to a reduction in surface contact area as a result of the sample's increased grooves.

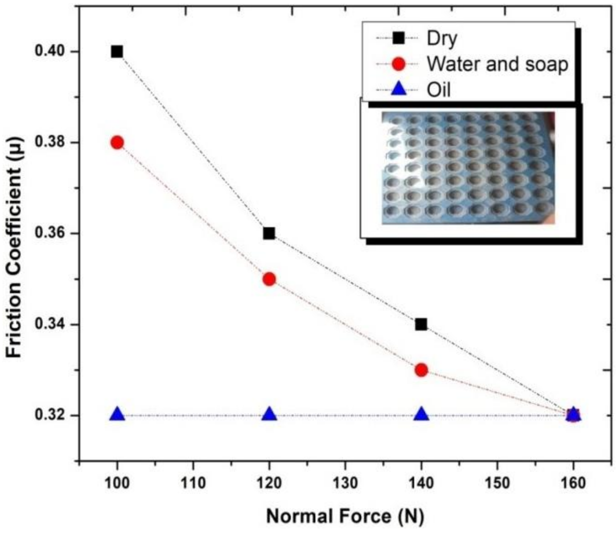


Fig. 11. Friction coefficient displayed by sample (C) sliding against shoe sole surface at different condition.

The grooved samples revealed the lowest friction coefficient when there was oil on the contact surface. As the normal load increases, the coefficient of friction values are clearly demonstrated to be minimal and constant. This might be due to the presence of cavities that function as an oil reservoir, allowing oil to easily escape. As the load increases, this helps to provide a steady layer of oil on the contact surface area. Also, as a consequence of the high number of grooves, sample C had the lowest friction coefficient due to the decrease of real contact area. Comparing COF results to Fig. 9., sample C is not safe for weights over 100 N at all condition (dry, soapy, oily), for all walking speed (slow, normal, fast).

Friction is generated by viscoelastic materials like rubber in three ways: adhesion, deformation, and wear. The real area of the contact is controlled by the texture of the contact bodies, surface roughness, material characteristics, and contact pressure [20]. Greater adhesion between the surfaces and a higher friction force are the results of a higher real contact area. This can illustrate how sample C varies from other samples (samples A and B) in terms of friction. The real contact area of the textured sample (sample C) was approximately one third (1/3) of that of plain ones (samples A and B). The greater the number of texturing grooves, the smaller the contact area and the lower the friction coefficient [12].

The friction coefficient is impacted by surface roughness not only through influencing the true area of contact, but also by affecting the work of adhesion on the contact surfaces. The roughness of the surfaces has a significant impact on adhesion work. The difference in friction coefficient values amongst the tested samples might be attributable to a variation in adhesion work caused by a combination of surface roughness and viscoelastic crack propagation energy enhancement [21]. As the surface roughness increased, the coefficient of friction also increased. When the surface roughness of the rubber grows, the effect of hysteresis friction becomes more substantial, whereas the effect of adhesion friction inhibition induced by lubrication gets more significant as the surface roughness deceases [22].

4. CONCLUSIONS

Following are the conclusions achieved as a consequence of the experiments:

1. The friction coefficient is controlled by:
   - The lubrication on the contact surface.
   - Surface texture of the surfaces.
   - Surface roughness of the surface.
   - The normal force during the sliding.
2. For all types of rubber tiles, the highest friction coefficient values were obtained while the tiles were dry.
3. When a mixed (soap and water) was applied to the tile contact surface, the friction coefficient values were lower than when the sample was dry.
4. Friction coefficient values were lower in oily sliding circumstances than in other conditions.
5. The sample with grooves (sample C) revealed the lowest friction coefficient.
6. Smooth surfaces have a lower friction coefficient, whereas rough surfaces have a higher friction coefficient.
7. The surface roughness results produced through digital image processing agreed well with that acquired by a traditional roughness testing machine.

5. RECOMMENDATIONS

We can extract the following recommendations from the current work, which may serve as guidance for preventing slip and fall injuries indoors:

1. Sample A (smooth rubber tile) is safe in dry and soapy circumstances, but not in oily conditions, especially when walking at normal and rapid speeds with a coefficient of friction less than 0.45.
2. Sample B (gruff rubber tile) is safe in dry and soapy circumstances, but not in oily conditions (COF 0.5), especially while walking and turning rapidly, where the COF should be less than 0.54.
3. Sample C (grooved rubber tile) is unsafe for weights more than 100 N in any state (dry, soapy, or oily), and at any walking speed (slow, normal, and fast).

6. FUTURE WORK

The future study will focus on using waste tiers (recycled rubber composites) as flooring materials. Also epoxy matrix composite tiles will be explored because of its tribological capability, as proven in previous study [23-25].

REFERENCES

[1] D.G. Curry, A. Mathias, *Slip Sliding Away – Slip Resistance of Athletic Socks on Indoor Flooring*, Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 53, iss. 9, pp. 568–571, 2009, doi: 10.1177/154193120905300906

[2] T. Yamaguchi, K. Hokkirigawa, *Development Of A High Slip-Resistant Footwear Outsole Using A Hybrid Rubber Surface Pattern*, Industrial Health, vol. 52, iss. 5, pp. 414–423, 2014, doi: 10.2486/indhealth.2014-0105

[3] B. Barry, P. Milburn, *Tribology, friction and traction: understanding shoe-surface interaction*, Footwear Science, vol. 5, iss. 3, pp. 137–145, 2013, doi: 10.1080/19424280.2013.797030

[4] P.L. Menezes, K.S.V. Kishore, M.R. Lovell, *Factors Influencing Stick-Slip Motion: Effect of Hardness, Crystal Structure and Surface Texture*, in International Joint Tribology Conference, 24-26 October, 2011, Los Angeles, California, USA, pp. 71–73, doi: 10.1115/IJTC2011-61225

[5] K.M. Mai, M.I. Khashaba., M.O. Mousa, W.Y. Ali, *Friction Coefficient Displayed by Sliding of Rubber Sole Against Recycled Rubber Flooring Tiles*, Journal of the Egyptian Society of Tribology, vol. 12, iss. 4, pp. 28–28, 2015.

[6] M.K. Mohamed, A.A. ElKattan, W.A. Ali, *Friction Coefficient Displayed By Rubber Sliding Against Flooring Tiles*, International Journal of Engineering & Technology IJET-IJENS, vol. 12, no. 6, pp. 144–149, 2012.

[7] F.H. Ezzat, A.T. Hasouna, W.Y. Ali, *Friction Coefficient of Rough Indoor Flooring Materials*, Journal of King Abdulaziz University-Engineering Sciences, vol. 19, no. 2, pp. 53–70, 2008, doi: 10.4197/Eng.19-2.4

[8] Y.M. El-Sherbiny, A.T. Hasouna, W. Ali, *Friction Coefficient of Rubber Sliding Against Flooring Materials*, Journal of the Egyptian Society of Tribology, vol. 8, iss. 4,pp 1–11, 2011.

[9] Y. M. El-Sherbiny, G. T. Abdel-Jaber, W. Y. Ali, *Friction Coefficient and Electrostatic Charge Generated From Rubber Footwear Sliding Against Flooring Materials*, Journal of the Egyptian Society of Tribology, vol. 11, iss. 4, pp. 13–24, 2014.

[10] *Rubber tiles*, available at: http://www.eposegypt.com, accessed: 29.08.2021.

[11] *Most popular flooring*, available at: www.gymrubberfloor.com, accessed: 29.08.2021.

[12] M.A. Ramadan, *Effect of treads pattern of rubber floor mat on the friction coefficient*, Tribology - Materials, Surfaces & Interfaces, vol. 11, iss. 3, pp. 156-167, 2017, doi: 10.1080/17515831.2017.1397311

[13] Y.M. El-Sherbiny, M.A. Ramadan, W.Y. Ali, *Frictional Behaviour of Rubber Flooring Mat Fitted by Rectangular Treads*, Journal of the Egyptian Society of Tribology, vol. 11, iss. 2, pp. 39-58, 2014, doi: 10.21608/jest.2014.80261

[14] C. Aschan, M. Hirvonen, T. Mannelin, E. Rajama, *Development and validation of a novel portable slip simulator*, Applied Ergonomics, vol. 36, iss. 5, pp. 585–593, 2005, doi: 10.1016/j.apergo.2005.01.015

[15] J. Kim, *Comparison of Three Different Slip Meters under Various Contaminated Conditions*, Safety and Health at Work, vol. 3, iss. 1, pp. 22-30, 2012, doi: 10.5491/SHAW.2012.3.1.22

[16] M. Drbúl, P.J. Martikáň, Bronček, I. Litvaj, J. Svobodová, *Analysis of Roughness Profile on Curved Surfaces*, MATEC Web of Conferences, vol. 244, pp. 1-7, 2018, doi: 10.1051/matecconf/201824401024

[17] M. Imran, M. Shah, S. Mehmood, Z. Abbas, F. Qayyum, *Characterization of EDM Surface Morphology of Al-6061using Different Dielectrics*, Technical Journal, vol. 22, iss. 3, pp. 51-87, 2017.

[18] B. Zappone, K.J. Rosenberg, J. Israelachvili, *Role of nanometer roughness on the adhesion and friction of a rough polymer surface and a molecularly smooth mica surface*, Tribology Letters, vol. 26, iss. 3, pp. 191–201, 2007, doi: 10.1007/s11249-006-9172-y

[19] P. Fino , T.E. Lockhart, *Required coefficient of friction during turning at self-selected slow, normal, and fast walking speeds*, Journal of Biomechanics, vol. 47, iss. 6, pp. 1395–1400, 2014, doi: 10.1016/j.jbiomech.2014.01.032

[20] D. Stamenković, M. Banić, M. Nikolić, A. Miltenović , P. Đekić, Influential Parameters of Footwear Slip Resistance, Proceedings on Engineering Sciences, vol. 1, no.1, pp. 601-303, 2019, doi: 10.24874/PES01.01.078

[21] A. Tiwari, L. Dorogin, A.I. Bennett, K D. Schulze, W.G. Sawyer, M. Tahir, G. Heinrich, B.N.J. Persson, *The effect of surface roughness and viscoelasticity on rubber adhesion*, Soft Matter, vol. 13, iss. 19, pp. 3602-3621, 2017, doi: 10.1039/c7sm00177k

[22] T. Ido, T. Yamaguchi, K. Shibata, K. Matsuki, K. Yumii, K. Hokkirigawa, *Sliding friction characteristics of styrene butadiene rubbers with varied surface roughness under water lubrication*, Tribology International, vol. 133, pp. 230-255, 2019, doi: 10.1016/j.triboint.2019.01.015

[23] M.A. Ramadan, *Friction and Wear of Carbon Fiber Reinforced Epoxy*, Journal of the Egyptian Society of Tribology, vol. 16, iss. 4, pp. 1-12, 2019.

[24] M.A. Ramadan, *Tribological Properties of Epoxy Reinforced by Randomly Oriented Chopped Carbon Fibers*, Journal of the Egyptian Society of Tribology, vol. 16, iss. 3, pp. 48-62, 2019.

[25] M.A Ramadan, R. Reda, CNTs, Al2O3 and SiO2 Reinforced Epoxy: Tribological Properties of Polymer Nanocomposites, Tribology in Industry, vol. 39, no. 3, pp. 357-363, 2017, doi: 10.24874/ti.2017.39.03.11