Jurnal
Teknologi

Full Paper

FLOOR SLIPPERINESS MEASUREMENT UNDER SPILLAGE CONDITION

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Article history
Received
30 July 2015
Received in revised form
30 September 2015
Accepted
31 October 2015

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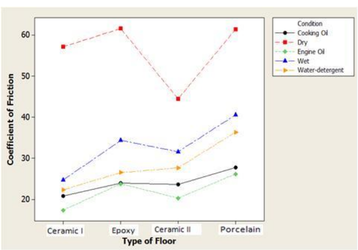
Graphical abstract



Abstract

To understand the risk of slipping accidents in the industry, it is imperative to measure the coefficient of friction (COF) between footwear and floor. In this study, COF values were measured for four types of floor with five surface conditions that represent dry conditions and four liquid spillage conditions. A portable skid-resistance tester was used to measure the COF with three footwear materials attached on the slider. The results show that the interaction between floor type, footwear material, and surface conditions was significant ($p < 0.0001$). Variation of COF value was found due to different footwear materials and floors involved during the interaction. The friction loss results also conclude that the COF became reduced significantly in all footwear-floor conditions (in the range of 17% to 78%) in the presence of spillage on the floor.

Keywords: Coefficient of friction (COF); portable skid-resistance tester; spills on floor; industry

Abstrak

Untuk memahami risiko kemalangan akibat tergelincir di industri, ukuran pekali geseran (COF) antara kasut dan lantai menjadi penting. Dalam kajian ini, pengukuran COF empat jenis lantai dengan lima keadaan permukaan yang mewakili keadaan kering dan tambahan empat keadaan tumpahan cecair. Penguji skid-rintangan mudah alih telah digunakan dalam kajian ini untuk mengukur COF dengan tiga jenis bahan kasut dipasang pada penggelongsor. Hasil menunjukkan bahawa jenis lantai, bahan kasut dan faktor-faktor keadaan permukaan adalah signifikan($p < 0.0001$)dimana interaksi antara faktor-faktor tersebut juga penting. Perubahannilai COF didapati disebabkan oleh perbezaan bahan kasut dan lantai semasa interaksi. Disamping itu, COF berkurang dengan ketara dalam semua keadaan kasut-lantai (dalam julat 17% hingga 78%) dengan kehadiran tumpahan pada permukaan lantai dengan merujuk keputusan kehilangan geseran.

Kata kunci: Ukuran pekali geseran (COF); penguji skid-rintangan mudah alih; tumpahan pada lantai; industri

1.0 INTRODUCTION

Instead of running, walking can be considered as locomotion. Slip and fall incidents can occur just by normal walking. In movies and cartoons we see people slip on banana peel and fall, but that is not the reality in life. Slipping and falling is not a laughing matter when we know the impact of the accident on our health and safety. The incident can happen for many reasons, most likely from a combination of factors such as floors, footwear, and surface condition [1,2,3,4,5]. These factors have been significant in slip and fall cases in the Malaysian manufacturing industry [6,7].

Insufficient friction between footwear and floor may cause a person to slip. The friction can be identified statistically as static coefficient of friction (SCOF) or dynamically as dynamic coefficient of friction (DCOF) [8]. SCOF is generally accepted as the significant parameter of slipperiness because it can determine whether a slip may occur [9,10]. DCOF on the other hand becomes the priority in affecting slipperiness during human locomotion (foot motion) where the shoe is in contact with floor [11]. However, it is difficult to control the motion between two interaction surfaces [8] thus the SCOF measurement is considered easier than the DCOF measurement.

It is well known that friction is an indicator of slipperiness. Although a few studies have highlighted the COF measurement between footwear material and floor [8,12,13],none have included the type of floors commonly used in the industry. Only few studies have included spillage of oil condition in friction measurement [8]. Hence the objectives of this study are twofold:(a) to identify the characteristic of type of floor, footwear materials, and surface condition based on friction measurement, and (b) to establish the interaction between type of floor, footwear material, and surface condition with COF. Therefore, some types of industrial floors were tested to express the characteristics of surface by COF measurement and to ascertain the interaction between the parameters.

2.0 MATERIALS AND METHODS

To achieve the objectives in this study, factors and conditions that need to be considered in floor friction measurement are discussed. The factors and conditions include measurement device, footwear samples, floor, surface conditions, and measurement procedures.

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2.1 Measurement Device

A portable skid-resistance tester known as British pendulum tester (BPT) was used in this study. The portable tester is used to measure micro texture friction by using static methods. This instrument basically measures the frictional resistance between a rubber slider and a surface to simulate a sliding between a vehicle tire and a road [14]. The operating principle of this tester is based on the concept of swinging and imitation heel. The rear and pinion of the tester is very important because it is used to release the mechanism, control the movement of the pendulum head, carry the swinging arm, and graduate the scale and pointer. In this study, the existing rubber slider was modified and was attached with three types of footwear sample materials, which are nylon, rubber, and polyvinyl chloride (PVC). The footwear sample was approximately 7.6 cm by 2.5 cm and was based on the standard size of rubber slider. Repeating the measurement was important to obtain a better representation of the floor conditions. Five successive readings were recorded because repeated swings were required if the data differed by more than three units. Then, if the range was greater than before, three successive readings that have constant value were considered to be recorded [14].

2.2 Sample Preparation

Glazed ceramic (ceramic I), unglazed ceramic (ceramic II), epoxy, and porcelain floor were selected for the study. Ceramic I floor is more commonly used in office and indoor space compared to ceramic II floor, which is harder and can be applied outdoor such as forthe main entrance of a building. Epoxy floor can be found in various commercial premises and laboratories while porcelain floor has been widely used in many types of industries, workshops, or laboratories. For each floor, the middle of the floor sample area was selected because no standard is established for selecting a location for friction measurement. Footwear materials such as nylon, rubber, and polyvinyl chloride (PVC) were used in this study. Those samples were supplied by a shoe manufacturer. All the sample materials were flat with no tread duringthe testing. The limitation in this study concerns the COF measurement; a flat footwear material may not represent the actual friction on the tested floors.

2.3 Test Condition

The floors were measured under dry, wet, water-detergent, and oily condition (cooking oil and engine oil-SAE40). In this study, wet and water-detergent condition can simulate the floor condition after the cleaning process. Oily condition can be found at cafeterias, canteens, and cooking oil manufacturing premises while spills of engine oil can be found at workshops due to leakage of machinery. For wet condition, 10 ml of water was replenished while 5% (by volume) detergent solutions was applied for water-detergent condition. To achieve oily condition, 10 ml of oil was spread evenly on each of the tested floors. For the cleaning process, absorbent papers were used after measurements were taken for each of the tested conditions. Next, a detergent solution was used for mopping during the cleaning process of the oily condition.

2.4 Friction Measurement

During the data collection, the three types of footwear materials that were fitted on the head of pendulum were forced using a spring system. The pendulum was released out of the horizontal position when the footwear materials touched the tested surface. Friction values can be read from the measuring scale after the tester completed the skid resistance. Five measurements were taken for each footwear materials/floor/testing condition in the direction of the walking path thus a total of 300 (5 measurements x 4 floors x 3 footwear x 5 conditions) measurements were made in this study. Footwear materials and floors were cleaned using 50% ethanol solution before commencing any measurement. Once the measurements were completed, the footwear materials were cleaned using absorbent papers and 5% detergent solutions to remove any excessive contaminants, and the floor surfaces were rinsed with water and were dried using a hair dryer.

Friction loss can be determined by using Eq.1 to compare the COF of four contaminated conditions to the dry condition [6]:

$$\text{Friction loss} = (COF_{contaminant} - COF_{dry}) / COF_{dry} \times 100\% \quad (1)$$

3.0 RESULTS

The measured COF under all tested conditions showed that friction was high on a dry condition. PVC recorded smaller COF compared with nylon and rubber materials. In addition, the mean COF values on ceramic I floor for PVC is considered to have high slip potential [15], with mean COF below than 25. Only rubber has consistent friction measurement; the material recorded high means of COF values in every tested condition on the porcelain floor. The effect of floor, footwear, and tested condition on measured COF was performed by using analysis of variance (ANOVA). The analysis showed that the effects of the three factors on COF were statistically significant ($p< 0.0001$); all two-way and three-way interaction effects were also significant ($p< 0.0001$). This result is supported by a previous study [8].

Tables 1, 2 and 3 show the results of Duncan's multiple range tests for floors, footwear materials, and surface respectively. As shown in Table 1, the COF values for each floor are significantly different from one another. The order from high to low is porcelain, epoxy, ceramic II, and ceramic I. Table 2 shows that all footwear materials are also significantly different from one another. Rubber shows the highest COF values followed by nylon and PVC, while from Table 3, dry floor shows the highest COF, followed by wet, water-detergent, cooking-oiled, and engine-oiled floor. For surface condition, cooking-oiled surface showed a higher COF value compared with engine-oiled surface. In contrast, a previous study found that engine-oiled surface has a higher COF value than vegetable-oiled surface [8].

Table 1 Duncan's multiple range test results for floor

Floor	Mean COF	Group
Ceramic I	28.48	A
Ceramic II	29.53	B
Epoxy	34.04	C
Porcelain	38.41	D

Table 2 Duncan's multiple range test results for footwear

Footwear	Mean COF	Group
PVC	21.45	A
Nylon	32.02	B
Rubber	44.38	C

Table 3 Duncan's multiple range test results for surface condition

Surface condition	Mean COF	Group
Engine Oil	21.92	A
Cooking Oil	24.03	B
Water-detergent	28.22	C
Wet	32.8	D
Dry	56.12	E

Figures 1, 2 and 3 presents the two-way interaction of the three factors. As shown in Fig. 1, the COF values are generally reduced because the floors were covered by liquid (any contaminant) compared to the floors in dry condition. This finding clearly shows that COF values are reduced significantly on ceramic I and epoxy floors compared to ceramic II and porcelain floors. In contaminated conditions (for liquid and oil condition), porcelain floor recorded higher COF values in the range of 26 - 61 compared with other tested floors. In Fig. 2, rubber recorded a huge different value of COF on porcelain floor while nylon and PVC showed a higher COF on epoxy floor compared with other tested floors. The mean COF of rubber under all surface condition were in the higher range of 36-63, compared with nylon in the range of 29-37 and PVC with 18-24. Next, Fig. 3 presents the interaction between footwear materials and contaminated conditions. In dry conditions, nylon, rubber, and PVC showed the highest values of COF compared with all liquid-covered conditions. Rubber shows the highest COF value on contaminated conditions while PVC has the lowest mean of COF value in every contaminated condition.

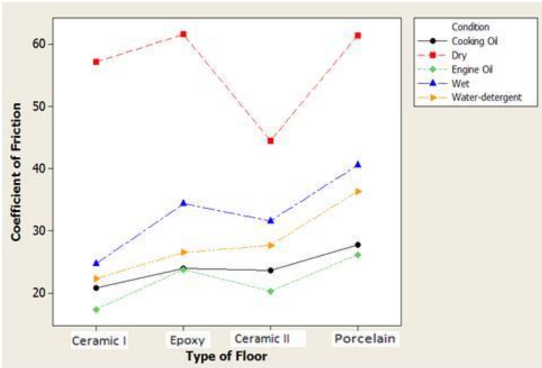

Figure 1 Interaction between floors and contaminants. (COF values are averaged for footwear materials).

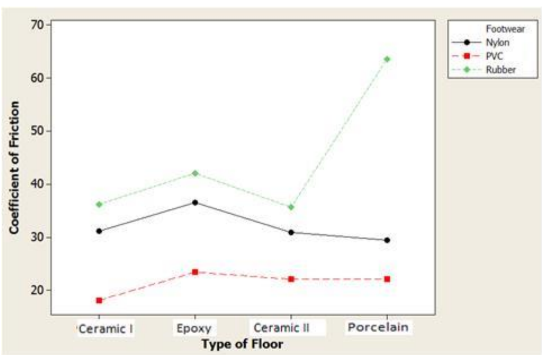

Figure 2 Interaction between floors and footwear materials (COF values are averaged for contaminated conditions).

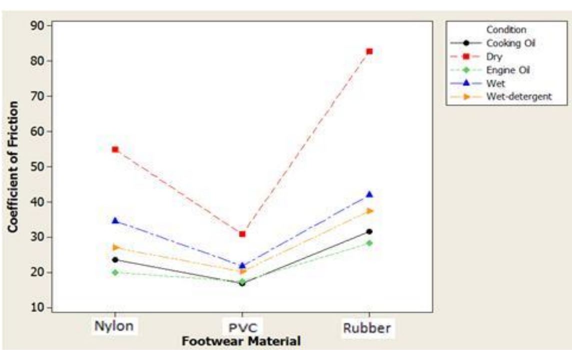

Figure 3 Interaction between footwear materials and surface condition. (COF values are averaged for floor types)

In all footwear-floor conditions, the friction loss under spillage condition was in the range of 17% to 78%. Under wet condition, nylon on porcelain floor lost only 17.07% while PVC lost 17.39% on ceramic I floor. However, friction loss of rubber and nylon under engine-oiled condition is considered high (in the range of 53.66% to 77.91%) on each type of floor.

4.0 DISCUSSION

Selecting a floor type with suitable COF is crucial in slip prevention. This study has established that COF depends not only on type of floors but also on type of footwear and surface condition, and this conclusion is supported by a previous study [8].

In this study, rubber showed the highest friction values on most types of tested floors under contaminated condition. Hence, rubber can be considered the best soling material for footwear such as safety shoes, which are widely used on epoxy and porcelain floors. A previous study [8] found that blown rubber (BR) provided more consistent values of friction on all tested floors (terrazzo, granite, vinyl, ceramic A and ceramic B) and BR is considered a better choice of footwear material for use around the floor campus. On the other hand, microcellular polyurethane (AP66033) was found to be a better soling material for use on oily surface compared with oil-resistant rubber (ORR) material and dual density polyurethane (DDP) material. This is because rubber is not quite suitable to be used as safety footwear for oil-contaminated floor [16].

The COF value on water-detergent floors was significantly higher than the values on cooking- and engine-oil-covered floors. This finding is supported by a previous study [8], which concludes that vegetable oil and cooking oil were used to represent an oily floor condition. This occurs because thicker liquid on floor produces lower COF value. In this study, the squeeze-film effect on COF was significant because a flat footwear material was used. COF is significant when a flat footwear interacts with a smooth floor surface [17]. This concept explains why low COF values were obtained on ceramic I, ceramic II, and epoxy floors under all contaminated liquid. Porcelain floor has commonly been used in factories as slip-resistance surface due to heavy wear and tear and due to the oily and chemical characteristic of many manufacturing facilities. However, in a campus environment, ceramic floor becomes a more suitable floor because of its higher COF values compared with other tested floors, such as terrazzo, granite, and vinyl [8].

5.0 CONCLUSION

It is significant that friction is affected by footwear material, floor type, and the presence of contaminant on the floor. A COF value becomes varied due to different footwear materials and floor presence during interaction. Hence, proper footwear/shoes and type of flooring become important to prevent slipping. Based on the friction loss results, it is important to remove any contaminant or spillage on the floor because when spillage exists on the floor, the COF is significantly reduced due to squeeze-film effect.

Acknowledgement

The project was sponsored by the Kementerian Pendidikan Malaysia (KPM) through grant scheme

(R.J130000.7809.4F355). The authors would also like to thank the Research Management Centre, Universiti Teknologi Malaysia, for managing the project.

References

[1] Li, K.W., Huang, S.Y. and Wang, C.W. 2013b. Relationship between Floor-type Gait Adaptations and Required Coefficient of Friction. *Human Factor.* IEEE Conference

[2] Kim, I.J., Hsiao, H., Simeonov, P. 2013. Functional levels of floor surface roughness for the prevention of slips and falls: Clean-and-dry and soapsuds-covered wet surfaces. *Applied Ergonomics.* 44: 58-64.

[3] Jia, L., Zhang, Y., Niu, Y., Du, S. and Li, J. 2011. Effect of surface roughness on slip resistance of rubber. *Advanced Materials Research.* 189-193: 1538-1542

[4] Liu, L., Li, K.W., Lee, Y.H., Chen, C.C. and Chen, C.Y. 2010. Friction measurements on 'anti-slip' floors under shoe sole, contamination and inclination conditions. *Safety Science.* 48: 1321-1326.

[5] Li, K.W., Hsu, Y.W, Chang, W.R. and Lin, C.H. 2007. Friction measurements on three commonly used floors on a college campus under dry, wet, and sand-covered conditions. *Safety Science.* 45: 980-992.

[6] Department of Occupational and Safety (DOSH), Malaysia Ministry of Human Resources, *"Occupational AccidentsStatistics by Sector 2012-2015"*. From: http://www.dosh.gov.my/. [Accessed on 25 June 2015].

[7] Social Security Organization (SOCSO), Malaysia Ministry of Human Resources, *"Annual Report 2012-2013"*. From: http://www.perkeso.gov.my/. [Accessed on 1 June 2015].

[8] Li, K.W., Chang, W.R., Leamon T.B. and Chen, C.J. 2004. Floor Slipperiness Measurement: Friction Coefficient, Roughness of Floors, and Subjective Perception under Spillage Conditions. *Safety Science.* 42: 547-565.

[9] Brungraber, R.J. 1967. An overview of floor slip-resistance research with annotated bibliography (NBS Technical Note 895). National Bureau of Standards, Washington, DC.

[10] Perkins, P & Wilson, M. 1983. Slip Resistance Testing of Shoes – New Developments. *Ergonomics.* 26: 73-82.

[11] Tisserand, M. 1985. Progress in the prevention of falls caused by slipping. *Ergonomics.* 28: 1027-1042.

[12] Leclercq, S. 1999. The Prevent of Slipping Accidents: A Review and Discussion of Work Related to The Methodology of Measuring Slip Resistance. *Safety Science*. 31: 95-125.

[13] Chang, W. R., Matz, S. 2001. The slip resistance of common footwear materials measured with two slip meters. *Applied Ergonomics.* 32: 549-558.

[14] Road Research Laboratory. 1969. *Road Note: Instructions for using the portable skid-resistance tester.* 2nd ed. Crowthorne, Berkshire: Ministry of Transport.

[15] Health and Safety Executive. 2012. *Assessing the slip resistance of flooring: A technical information sheet*. From: http://www.hse.gov.uk/. [Accessed on 23 June 2015].

[16] Manning, D.P. and Jones, C. 2001. The Effect of Roughness, Floor Polish, Water, Oil and Ice on Underfoot Friction: Current Safety Footwear Solings are Less Slip Resistant that Microcellular Polyurethane. *Applied Ergonomics.* 32: 185-196.

[17] Moore, D.F. (1972). The friction and lubrication of elastomers. In: Vaynor G V, ed. Int. Series of Monographs on Material Science and Tech. Oxford: Pergamon Press.