The slip-resistance effect evaluation of floor roughness under different liquid viscosity

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Abstract

Slipping, tripping and falling which causes serious damages and losses happen all the time within household and work areas. According the formula of squeeze film, when the floor is contaminated with liquid, the higher the liquid viscosity the longer time to connect shoes with floor, the higher the risk of falling. The appropriate roughness of floor surface could be effective to improve the squeeze film effect caused by liquid while the floor is contaminated by liquid or oil. In kitchens, oil, sauces and liquid with higher viscosity are easily spread on floor. Therefore, this study discussed the influences of liquid viscosity and floor roughness upon slip-resistance effect adopting two shoe materials, six liquid with different viscosity and six floors with different roughness. The results demonstrate that the higher the liquid viscosity the lower the coefficient of friction. No matter how rough the floor is, the coefficient of friction approaches zero while the viscosity larger than 38 mPa.s. With the liquid (water or soda) viscosities were lower than 2mPa.s, the slip resistant effect only shown as the floor roughness (Ra) was larger than 28\(\mu\)m and Rt must be greater than 145\(\mu\)m. The slip resistant effect shown as the floor roughness (Ra) must be much greater than 40\(\mu\)m and Rt must be much higher than 185\(\mu\)m while the floor contaminated by liquid with viscosities higher than 2mPa.s. Therefore, the best strategy to prevent slips/falls should be keeping the floor dry all the time.

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1. Introduction

Almost everyone has experienced slip/fall at home or working environment. National Safety Council [1] estimated that during 2010 there are 8.5 million people sent to the emergency room due to slip/fall including 25 thousand deaths. Leamon and Murphy [2] reported that there are 65% of claim cases and 53% of claim costs in total direct worker’s compensation for occupational injuries due to slips and falls which happened on the same level. The reports of Liberty Mutual indicated that in USA almost 60 billion US dollar losses due to the occupation injuries and falls on same level which is ranked at 2nd place of all occupational incident. Falls on same level are 15.4% of all occupational incidents and cost 9.19 billion USD. Slip or trip without fall is ranked at 7th of all occupational incidents which take 3.6% of all occupational incidents and cost 2.17 billion USD [3].

According to Federal Institute for Occupational Safety and Health [4], there were over 20% of occupational incidents caused by falling which produced 300 million euro dollars insurance benefits as well as 8 billion euro dollars losses. Slip and fall accounted for a third of occupational incidents in British which cause more than 5 million Pounds direct and indirect costs and 80 billion Pounds [5].

Leamon and Murphy [2] pointed out there are two third of falling were leaded by slipping. Falling mainly happens while the friction between shoe sole and floor is not enough. Coefficient of Friction (COF) is one of the most important factors to measure the degree of friction between shoe sole and floor. Chang et al.[6] described that COF is the main item to measure the degree of slippery between shoes and floor; the higher the COF is, the higher the degree of anti-slippery will be.

To prevent incidents of slips and falls, friction is widely used as a key indication of floor slipperiness [7]. The floor materials, floor roughness, liquid/solid contaminants on floor and the groove design of shoes are all factors influencing the measurement of COF [8-10]. In working places and public area, the floors are often contaminated by water. When the floor covered by water, detergent, oil, or other liquid, those liquid will increases the time to contact the tread with the floor. Before the liquid is discharged from the surface between tread and floor, the friction could not be produced. Therefore, the slip-resistance effect will decrease significantly and the falling and slipping will happen dramatically. When the shoes tread on the surface covered by liquid, the influences can be described by squeeze-film effect.


\[
t = \frac{K\mu A^2}{F_N} \left( \frac{1}{h^2} - \frac{1}{h_0} \right)
\] (1)

Where \( t \) is the time needed to reduce the liquid thickness from initial \( h_0 \) to \( h \), \( F_N \) is the normal forces, \( K \) a shape constant, \( \mu \) the viscosity of liquid, and \( A \) the contact area between the surface. From the squeeze film equation, it is easily to find that the time of falling has positive relationship with the thickness of liquid. The higher the viscosity of an object is, the longer the falling time (t) will be. Therefore, when a person treads on the floor covered by liquid, \( t \) is longer or \( \frac{dh}{dt} \) is smaller, the contacts between shoe sole and floor will be delayed and the opportunity to fall will be increased.

According to Moor [11], the thicker the liquid viscosity is, the longer the time to contact the tread with the floor and the higher the risk of slipping will be. Procter and Coleman [12] use the hydrodynamic squeeze-film theory, demonstrated that a certain level of surface texture is needed to increase friction. Chang et al. [7] showed that at the surface contaminated by liquid or oil, rough surface of floor will be helpful on improving the squeeze film effect caused by liquid. Lemon and Griffiths [13] pointed out that the contaminants with higher viscosity required greater levels of surface roughness to provide equivalent levels of slip resistant effect, as the thickness of the squeeze film formed between the floors and treads increased as the contaminant’s viscosity increased. The level of floor surface roughness required to provide satisfactory levels of slip resistance effects with a range of viscosity of different liquid contaminants (Table 1).
Chang et al. [6] point out to reduce the risk of falling/slipping, the floors with appropriate roughness should be adopted. William English [15] also indicated that the squeeze-film effect caused by liquid could be improved by using floors with enough roughness while the floor contaminated by oil or water. The COF could be increased by design the floor with sharper and higher peak or dense projections, that is, the higher the floor roughness, the better the effect of slip resistance. Therefore, most of the researchers believed that the floor roughness is a key factor to control the effect of squeeze-film. Except the roughness of floor, prior researchers considered that tread grooves are able to release the liquid contaminants, increase the speed of contacting time between shoes and floors as well as reduce the risks of slipping[16-18].

Most of the researches discussed the relationship between various roughness and COF and focused mainly on the situations of water contaminants. Inside the working fields of restaurants, the situations of sauces/ juice spreading on floors happen all the time. However, the studies toward those liquids which are stickier than water are rare. Therefore, this study explored the influences of different liquid viscosity with different floor roughness on slip resistance.

2. Research methods

The study performed a 3 factors experiment including 2 different tread, 6 different liquid with various viscosity and 6 floors with different roughness. Each treatment measures 6 times of friction coefficient and 432 measurement values in total. The measurement of COF was conducted by Brungraber Mark II (BM II) under the average temperature of \(24.4 \pm 0.9^\circ C\) and relative humidity of \(65.5 \pm 5.0\%\). BM II is a wild adopted equipment to measure COF by using gravitation [8, 10, 19]. BMII was operated according to the steps and suggestions proposed by American Society for Testing and Materials (ASTM) F-1677:2005 [20] and Chang [8].

2.1. Shoe material

Tread and non-tread Neolite shoe materials with hardness of \(91 \pm 1.73\) were adopted in the study. Neolite shoe materials are standard testees which commonly used in prior studies. Neolite has the features of anti-abrasion and liquid contamination free. The differences between tread and non-tread Neolite shoe materials are the tread shoe material was crave with 1mm width and 3mm deep grooves separated every 3mm on the sole to simulate the situation of shoes with or without tread groove design.

2.2. Liquid viscosity

There are 6 different liquid applied in this study to simulate the conditions of floor contaminants. The viscosity was tested by LVDV-I Pro produced by BROOKFIELD. To reduce the influence from temperature, the liquids had set inside an environment with room temperature between \(23^\circ C\) to \(26^\circ C\) for 6 hours to match the temperature of liquid and room before each experiment. The 6 liquids and their viscosity values showed as Table 2.
Table 2. Liquid Viscosity.

<table>
<thead>
<tr>
<th>Scope of Viscosity (mPa.s)</th>
<th>Liquid</th>
<th>Viscosity (mPa.s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \eta \leq 1 )</td>
<td>Water</td>
<td>0.98</td>
</tr>
<tr>
<td>1 (&lt;\eta \leq 10 )</td>
<td>Soda (Cola)</td>
<td>1.33</td>
</tr>
<tr>
<td>10 (&lt;\eta \leq 20 )</td>
<td>Soy Sauce</td>
<td>11.50</td>
</tr>
<tr>
<td>20 (&lt;\eta \leq 50 )</td>
<td>Blended Edible Oil</td>
<td>38.00</td>
</tr>
<tr>
<td>50 (&lt;\eta \leq 100 )</td>
<td>Pure Olive Oil</td>
<td>52.20</td>
</tr>
<tr>
<td>100 (&lt;\eta \leq 200 )</td>
<td>15W40 Engine Oil</td>
<td>187.20</td>
</tr>
</tbody>
</table>

After each COF tested with BM II, the liquid was drained and cleaned, then, 10 cc (0.5 mm thickness) of liquid was added to perform the next experiment to avoid the influence from the thickness of liquid.

2.3. Floor roughness

There were 6 tiles with different roughness was measured. Since the coefficient of Ra was wildly accepted while measuring roughness [6-7, 17, 21-24], the 6 different levels of roughness including <5μm, 6-10μm, 11-15μm, 16-20μm, 21-30μm and 31-40μm were separated according to Ra. The roughness was measured by Mitutoyo® SJ-301 surface roughness tester. The measurement followed the principles suggested by Chang [25] and cut the tiles into 2.5mm and 12.5mm separately. And the value of Ra and Rtm (Rz) was adopted as the measurement parameters where Ra is the average height of central lines on vertical section and Rtm (Rz) is the average height between the higher and lower point of the surface. The 6 levels of floor roughness was listed in Table 3. To avoid the water absorption of tile, the tiles were soaking inside the liquid used for each experiment for 6 hours to maintain the moisture of each tile.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Range of roughness(μm)</th>
<th>Ra(μm)</th>
<th>Rtm=Rz(μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1≤Ra&lt;5</td>
<td>3.34(±0.44)</td>
<td>20.76(±3.82)</td>
</tr>
<tr>
<td>B</td>
<td>5≤Ra&lt;10</td>
<td>7.02(±1.07)</td>
<td>50.16(±12.14)</td>
</tr>
<tr>
<td>C</td>
<td>10≤Ra&lt;15</td>
<td>13.13(±2.96)</td>
<td>66.8(±23.28)</td>
</tr>
<tr>
<td>D</td>
<td>15≤Ra&lt;20</td>
<td>17.05(±2.08)</td>
<td>94.29(±16.85)</td>
</tr>
<tr>
<td>E</td>
<td>20≤Ra&lt;30</td>
<td>28.45(±6.10)</td>
<td>145.37(±24.09)</td>
</tr>
<tr>
<td>F</td>
<td>30≤Ra&lt;40</td>
<td>36.32(±6.13)</td>
<td>185.48(±37.43)</td>
</tr>
</tbody>
</table>

2.4. Data analysis

SAS® 9.0 was applied to analyze the data and the description statistics and ANOVA were used to explore the influence of shoe materials, liquid viscosities and floor roughness upon COF. While the factor reached the significant level of \( \alpha = 0.05 \), Duncan Multiple Range was used to discover the differences between significant factors.

3. Results and discussions

The COF average of two different treads tested under various floor roughness and liquid was shown in Table 4. The relationship between non-tread and tread shoe materials with various floor roughness and liquid viscosities was shown as figure 1 and 2 separately. The results of ANOVA analysis demonstrate that the influences of shoe material, floor roughness and liquid viscosity on COF are all significant (\( p < 0.05 \)) and the two-way and three-way
interaction effects are also significant (p<0.05). The results of Duncan’s multiple range test demonstrated that the COFs of tread shoe materials (0.17) were higher than those of non-tread (0.07). The liquid viscosities are also significantly affect COF (p<0.05); where the average COF of water was the largest (0.31), followed by soda (0.24), soy sauce (0.16), blending edible oil (0.04), olive oil (0.04) and engine oil (0.03). The influence of different floor roughness on COF were also significant (p<0.05). The rougher the floor is, the higher the COF could be. The COFs for floor A to floor F were 0.06, 0.10, 0.09, 0.11, 0.18 and 0.20 in sequence.

Table 4. The averages of COFs.

<table>
<thead>
<tr>
<th>Shoe materials</th>
<th>Floors (Ra, Rtm=Rz) μm</th>
<th>Water (0.99 mPa.s)</th>
<th>Soda (1.33 mPa.s)</th>
<th>Soy sauce (11.50 mPa.s)</th>
<th>Blend edible oil (38.00 mPa.s)</th>
<th>Olive oil (52.20 mPa.s)</th>
<th>Engine oil (187.20 mPa.s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-tread shoe materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A(3.34, 20.76)</td>
<td>0.09</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>B(7.02, 50.16)</td>
<td>0.08</td>
<td>0.07</td>
<td>0.02</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>C(13.13, 66.80)</td>
<td>0.04</td>
<td>0.03</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>D(17.05, 94.29)</td>
<td>0.16</td>
<td>0.13</td>
<td>0.04</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>E(28.45, 145.37)</td>
<td>0.42</td>
<td>0.39</td>
<td>0.19</td>
<td>0.04</td>
<td>0.03</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>F(36.32, 185.48)</td>
<td>0.49</td>
<td>0.41</td>
<td>0.19</td>
<td>0.04</td>
<td>0.03</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Tread shoe materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A(3.34, 20.76)</td>
<td>0.26</td>
<td>0.25</td>
<td>0.13</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>B(7.02, 50.16)</td>
<td>0.45</td>
<td>0.28</td>
<td>0.28</td>
<td>0.07</td>
<td>0.06</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>C(13.13, 66.80)</td>
<td>0.34</td>
<td>0.23</td>
<td>0.28</td>
<td>0.08</td>
<td>0.08</td>
<td>0.05</td>
<td></td>
</tr>
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<td>D(17.05, 94.29)</td>
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<td>0.27</td>
<td>0.27</td>
<td>0.09</td>
<td>0.09</td>
<td>0.07</td>
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<td>0.40</td>
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<td>0.07</td>
<td>0.06</td>
<td>0.07</td>
<td></td>
</tr>
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<td>F(36.32, 185.48)</td>
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<td>0.42</td>
<td>0.26</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. The COFs of non-tread shoe materials under different floor roughness and viscosity.
When the liquid viscosities were lower than 2 mPa.s such as water or soda, the non-tread shoes can resist slippery under the situation that the floor roughness (Ra) at less larger than 28 μm. This results are different from the research outcomes of Ra should between 7-9 μm proposed by Grönqvist [18] and Wieder [26]. However, with tread shoe materials, once the floor roughness (Ra) reached 7 μm, the slip-resistances were significant under the condition of water contamination. The results were consistent with the researches proposed by Grönqvist [18] and Wieder [26]. The results about the tread groove design could improve the COFs between shoes and floors and reduce slips/falls were same as the results proposed by [16-18]. Wieder [26] pointed out that Ra should be over 35 μm and Lloyd and Stevenson [27] indicated Ra should be over 46 μm to provide the anti-slip effect under the conditions of oil contaminants. However, the results could not confirm those ideas in this study. No matter the shoe materials were tread or non-tread, the required floor roughness (Ra) needed to be higher than those researches proposed to perform slip resistant effect. As for the coefficients of roughness Rtm (Rz), the required Rtm were higher than the suggestions proposed by [13, 21, 28] from the study results. However, the differences could be caused by the shoe materials and measurement equipment used in the experiments.

4. The conclusions

The study explored the influences of liquid viscosity and floor roughness on floor slip resistance. The results demonstrated that shoe materials, floor roughness and liquid viscosity affected slip resistance significantly. The shoe materials were the most important factors affecting COF, liquid viscosities were the second, and floor roughness was the last. The interactions between three factors were all significant. The higher the floor roughness was, the higher the COF would be. The larger the liquid viscosities were, the lower the COF should be. Liquid viscosity was the most powerful factor affecting COF. When the viscosity was larger than 38.00 mPa.s, the values of COF turned to be low significantly and closed to zero whether the shoe materials were tread or non-tread. With the liquid (water or soda) viscosities were lower than 2 mPa.s, the slip resistant effect only shown as the floor roughness (Ra) was larger than 28 μm and Rtm (Rz) was greater than 145 μm. The slip resistant effect shown as the floor roughness (Ra) must be much greater than 40 μm and Rtm (Rz) must be much higher than 185 μm while the floor contaminated by liquid with viscosities higher than 2 mPa.s. Therefore, the best strategy to prevent slips/falls should be keeping the floor dry all the time.
Acknowledgements

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References