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新鞋與舊鞋鞋底之粗糙度，耐磨性，紋路，與抗滑性的比較分析
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行政院國家科學委員會補助專題研究計畫 ■成 果 報 告
□期中進度報告

新鞋與舊鞋鞋底之粗糙度、耐磨性、 紋路
與抗滑性的比較分析

計畫類別：■ 個別型計畫　　□ 整合型計畫
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執行單位：中華大學工業工程與系統管理系

中　華　民　國　98　年　8　月　31　日

摘　要

影響鞋子抗滑性的因子包括鞋與地板材料、地面狀況、地板表面的粗糙度、與鞋底的紋路設計等在文獻上已經有許多的討論。然而大部份這類的研究都是根據新的鞋與地板的材料進行的。理論上來說，鞋材在日常使用中不斷的暴露於陽光與雨水中會逐漸的變質；鞋底紋路在地面上不斷的滑動會磨損；鞋底不斷的撞擊地面也會造成其物理性質的改變。本研究的假設為鞋材的不斷使用會因其物理性質改變而造成其抗滑性的降低，而這種抗滑性的降低與鞋底材料的種類有關。本研究的目的即是要檢驗這些假設。被分為兩組的 20 位受測者被招募來參加為期六個月的鞋子穿著實驗，同組成員將穿著同一種鞋子。新鞋與舊鞋鞋底材料的粗糙度、耐磨性、與抗滑性將被量測與比較。在考量新鞋與舊鞋鞋底材料的粗糙度、耐磨性、與紋路等物理性質的改變的情況下，本研究探討了鞋子之使用對於鞋底抗滑性的影響。研究結果顯示，經過六個月的穿著後，兩種鞋子之鞋底的硬度與耐磨耗值都未顯著改變，但鞋底的紋路與摩擦係數值均顯著的新鞋不同。

關鍵詞: 滑倒與跌倒、磨損、鞋材、抗滑性

Abstract

The factors affecting the slip-resistance of footwear such as footwear and floor materials, floor surface conditions, floor roughness, and shoe sole tread design have been discussed in the literature. However, most of the investigations were conducted using new footwear and floor materials. Theoretically, shoe sole materials change after repetitive exposure to the sun and rain during normal usage. Sliding of shoe sole on the floor results in the wear-out the tread patterns. Repetitive impact of shoe sole on the floor may also result in physical properties change. The hypotheses of this project were that footwear usage result in reduction in slip-resistance which could lead to higher likelihood of slip & fall incidence and the reduction in slip-resistance is footwear material-dependent. The objectives of this study were to test these hypotheses. Twenty male subjects, split into two groups evenly, were recruited and tested in a footwear usage experiment for six months. One type of footwear will be assigned to each group. The roughness, abrasion, and slip-resistance of the shoe sole of the new and used shoes were measured and compared. The effects of footwear usage on slip-resistance for two types of shoes tested were discussed along with the consideration of the changes in physical properties such as hardness, abrasion, and tread patterns. The results of the study show that the hardness and abrasive values of the shoe soles did not change significantly after a six month usage. The tread pattern, or sole-floor contact area, and the coefficient of friction of the used shoes were significantly different from those of the new shoes.

Keywords: slips & falls, wear, footwear material, slip-resistance

Introduction

The significance of slipping and falling has been well-established in the literature (Perkin, 1978; Strandberg and Lanshammar, 1981; Leamon and Murphy, 1995; Courtney et al., 2001). It was also known that the majority of slipping and falling occurred on level surfaces (Leamon and Murphy, 1995; Courtney, et al, 2001). Determining the factors affecting floor slip slipperiness is of paramount importance in developing interventions in the prevention of slip and fall incidents.

It is known that the friction between the sole of the shoe and floor plays a vital role in the occurrence of a slip. Factors affecting the friction at the footwear-floor interface have been identified in the literature (Andres & Chaffin, 1985; Chang & Matz, 2001; Chang et al., 2001b; Chang et al., 2003; Chang et al., 2006). Shoe sole and floor material are both significant factors affecting the friction between the shoe and floor. In one of the author's study (Li et al., 2004), four footwear materials including blown rubber, Neolite, leather, and EVA were tested on five floors including vinyl composition, granite, terrazzo, ceramic A, and ceramic B in a university campus environment. The results showed that both the footwear and floor materials are significant (p<0.0001) factors affecting the measured friction. The rank of the friction for the footwear material from high to low was blown rubber, Neolite, leather, and then EVA. The rank of the friction for the floors from high to low was ceramic A, ceramic B, granite, vinyl, and terrazzo. The interaction effects of footwear and floor was also significant (p<0.0001). Leather has significant (p<0.05) lower friction on granite as compared to EVA. On the contrary, EVA had significant (p<0.05) lower friction on ceramic A then leather. Similar results were shown in Li & Chen (2004, 2005) and Li et al. (2006).

In addition to footwear and floor materials, floor surface condition is also one of the leading factors affecting the friction at the footwear-floor interface. It is known that the floor becomes slippery when it is covered with liquids. The effect of liquids on the floor is to separate the shoe sole and the floor, thus reducing the friction available (Grönqvist, 1995; Leclercq et al., 1995). Manning and Jones (2001) pointed out that oil contamination is the most dangerous because measurements of dynamic coefficient of friction on such floors are invariably lower with oil contamination than with water. Similar results have been reported in the literature (Chang et al., 2004; Li, et al., 2004; Li & Chen, 2004, 2005: Li et al., 2007) that dry surfaces had significant (p<0.05) higher friction than wet surfaces, and wet surfaces had significant (p<0.05) higher friction than oil-contaminated surfaces. The effects of liquids on the floor on the friction may be explained using the squeeze-film effect. Moore (1972) explained this effect using the following equation:

$$t = \frac{K\mu A^2}{F_N}[\frac{1}{h^2} - \frac{1}{h_o^2}] \qquad (1)$$

where t is the time needed for the film thickness to decrease from the initial thickness h_o to a thickness h , F_N the normal force, K a shape constant, μ the viscosity of the liquid, and A the contact area between the footwear pad and the floor. On liquid-contaminated floors, the larger initial thickness (h_o), the longer the descending time (t), the more slippery the floor might be. In other words, the thicker the liquid on the floor, the lower the friction will be. A maximal h_o occurs when the thickness is controlled by the surface tension in an unconfined situation, which results in the most slippery condition for a certain liquid on the floor.

Not only liquids on the floor reduce the friction at the footwear-floor interface but also the solid particles. In the study of Li et al. (2007), the author and his colleagues conducted friction measurements on dry, wet, and sand-covered covered floors. The results indicated that floors coved with sand had significantly (p<0.001) lower measured coefficients of friction as compared to those of the wet floors. A treatment-by-treatment test results indicated that the wet surfaces of seven out of the nine footwear material-floor conditions had significant (p<0.001) higher measured coefficients of friction than those of the sand-covered surfaces. The two exceptions were the leather-ceramic and PVC-terrazzo combinations where the sand-covered surfaces had significantly (p<0.001) higher COF values than those of the wet surfaces. Details of the effects of sand particles on the friction at the footwear-floor interface were discussed in Li et al. (2007).

In addition to footwear material, floor material, and surface condition, the surface textures of both the shoe sole and floor surface are also important factors. It is generally believed that rougher floors provide higher friction than smoother floors. The effects of floor roughness have been discussed by Chang (1998, 1999, 2001, 2002a) and Chang et al. (2001a). It is common that floor tiles embedded grit to form a spiked surface. The projections on these tiles provide a better capability for the floor in penetrating the film under liquid contamination condition so as to provide a higher friction. Tread groove designs significantly affected the friction of the shoe sole on the floor. Supporting by three National Science Council research projects, the authors has studied the effects of the width, orientation, and depth of the tread grooves on the footwear pads on the measured friction. The results showed that the width, orientation, and depth were all significant factors (p<0.0001) affecting the friction. Linear and non-linear regression models describing the relationships between the tread groove design parameters (width, orientation, and depth) and the measured coefficient of friction have been established. These models are useful in predicting the slip-resistance for various tread groove designs of shoe soles. The results were published in Li & Chen (2004, 2005) and Li et al. (2006).

The factors affecting the slip-resistance of footwear such as footwear and floor materials, floor surface conditions, floor roughness, and shoe sole tread design have been discussed in the literature (Chang 1998, 1999, 2001, 2002a; Li, et al., 2004; Li & Chen, 2004, 2005; Li et al., 2007). However, most of the investigations were conducted using new footwear and floor materials. Theoretically, the physical properties of shoe sole materials change after repetitive exposure to the sun, rain during normal usage. Sliding of shoe sole on the floor results in the wear-out the tread patterns. Repetitive impact of shoe sole on the floor may also result in shoe sole surface changes. The hypotheses of this project are that footwear usage will result in reduction in slip-resistance which will lead to higher likelihood of slip & fall incidence and the reduction in slip-resistance is footwear material-dependent. Different footwear materials may experience different changes, after been used for a certain period of time, in roughness, abrasion, tread patterns, and even hardness which could lead to different slip-resistance. The objective of this study is to test these hypotheses.

Methods

A friction measurement study under real footwear usage scenario will be conducted.

Footwear & floors

Two type of footwear commonly worn both at workplace and daily activities were tested. One of them was a work shoes with hard rubber soles. The soles of rubber-soled shoes have a high Shore-A hardness value of 79.9 (±1.5). The other type of footwear was a sneaker with a shoe sole material of EVA with a shore-A hardness of 28.4 (±1.5). The high elasticity of EVA provides better cushion effects and generally makes people feel more comfortable when walking. But it is normally less abrasive than rubber.

Fourteen pairs of shoes of each type were purchased. Ten pairs for each type were worn by the subjects in the usage test. Others were tested for unused condition in the laboratory. The floors tested in the laboratory were vinyl and terrazzo.

Hardness gauge

A Shore-A hardness gauge was used to measure the Shore-A hardness of footwear materials.

Profilometer

The roughness of the floors samples was measured using a Mitutoyo® SJ-301 surface roughness tester. The cut-off length and the measurement length used for roughness measurements were 2.5 and 12.5 mm, respectively. Both the R_a, also known as the center line average of surface heights (CLA) and the R_{tm}, or average of peak to valley height in each cut-off length, were measured. The measurements on the floors were made at the four locations 1 cm away from the adjacency edges of each corner of the footwear pad striking area.

Abrasion tester

A NBS Shoe Sole Abrasion Tester was used to measure the abrasive of shoe sole materials. The measurements of the abrasive of the footwear samples requires that the tested sample being worn out and then compare the reading with that of a standard rubber sample to calculate the abrasive index. Measurement of shoe sole abrasion will follow the ASTM-D1630 standard.

Slipmeter

A Brungraber Mark II slipmeter was used in this study for friction measurements. This slipmeter has been used in many studies (Power et al., 1999; Chang et al., 2004; Chang et al.; 2006; Li, 2003; Li & Chen, 2004; Li et al., 2004; Li & Chen, 2005; Li et al, 2006a; Li et al., 2006b; Li et al., 2007). The standard test method of using the BM II is published by the American Society for Testing and Materials (ASTM, F-1677) (2005). The measurement protocol refined by Chang (2002b) was adopted.

Human Subject

Twenty adult male subjects were recruited for footwear usage test. These subjects were split into two groups. One group included office staffs in an organization. The other group comprised of college students. The age, stature, and body weight for the office clerks were 42.8 (±9.7) yrs, 168.7 (±7.7) cm, and 73.7 (±2.7) kg, respectively. The age, stature, and body weight for the college students were 22.0 (±1.1) yrs, 168.6 (±6.6) cm, and 73.7 (±17.3) kg, respectively.

Experimental Procedure

The shoe sole of four new shoes were cut into samples. The hardness, abrasion and slip-resistance of these samples were measured. Friction measurements were also conducted on terrazzo and vinyl floors. The surface conditions were either dry or wet. The testing conditions in our previous studies (Li & Chen, 2004, 2005; Li et al., 2004; Li et al., 2006a; Li et al., 2006b) were adopted.

The experiment involved the human subjects encompassed a longitudinal study. Each subject received one pair of shoes. The rubber-soled shoes were distributed to the office clerks and the EVA-soled shoes were distributed to the college students. The subjects were required to wear the experimental shoes for eight hours per day and three says per week (or equivalent to 24 hours per week) for six month (or 26 weeks) either at work or at school. Each subject have worn the test shoes for at least 624 (26 week *3 day *8 hour) hours during the experiment.

The subjects returned the shoes at the end of the six month period to the laboratory. The tread patterns on the soles were examined to record the degree of shoe sole worn-out. Area and percentage of the worn-out area on each sole were measured. The tread on the sole reduce the area that a shoe sole contact with the floor. The increase of the contact area between the shoe sole and the floor may be adopted to indicate the degree of worn-out of the sole. The contact area of a shoe sole sample on the floor was determined by putting ink on the sample and then had the sole sample sealed on a paper. The area of the seal was measured. Ten shoe sole of each type of the experiment shoes were then cut into samples for hardness, abrasion, and slip-resistance measurements. Shore-A hardness, friction, and abrasive measurements were conducted for these used shoes.

Statistical Analysis

Descriptive and student *t*-test were conducted for the Shore-A hardness, shoe sole contact area, abrasion, and slip-resistance for the new and used shoes. Comparisons were made between the new and used shoes and between the two footwear materials. Statistical analyses were performed using the SPSS® 10.0 computer software.

Results

The R_a for the vinyl and the terrazzo were 0.66 (±0.23) μm and 1.12 (±0.33) μm, respectively. The R_{tm} for the two floors were 6.82 (±3.29) μm and 11.61 (±2.28) μm, respectively.

Figures 1 & 2 show the tread design of the EVA and rubber-soled shoes, respectively.

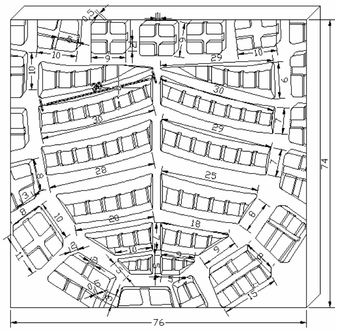

Figure 1. Tread design of the EVA-soled shoes (unit: mm)

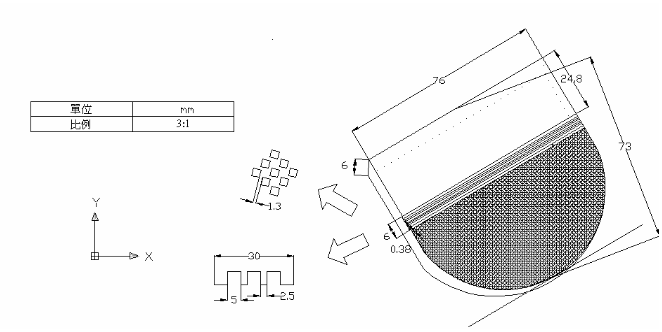

Figure 2. Tread design of the rubber-soled shoes (unit: mm)

The results of the contact area between the sole and the floor for the new and used shoe soles for both of the rubber and EVA samples are shown in Figure 3. The standard deviations for the rubber-soled samples were very small and the value for the new samples was near zero. The contact area for the used rubber sole was significantly (p<0.0001) higher than that of the new ones. For the EVA samples, the standard deviation of the used samples was larger than that of the new samples. The difference between the new and used samples was, however, not statistically significant.

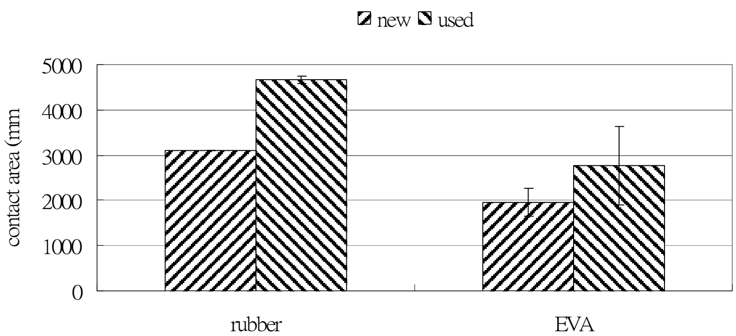

Figure 3. Contact area between the shoe sole and the floor

The abrasive indexes for both of the new and used shoe sole for the two types of shoes were measured. The results are shown in Figure 4. Independent sample t-tests were conducted to compare the difference between the new and used shoe sole for both of the rubber- and EVA-soled samples. The results for both tests did not reach the α=0.05 significance level. The difference between rubber and EVA samples for both the new and used samples were also tested. For both the new and used samples, the abrasive indexes for rubber were significantly (p<0.0001) higher than those of the EVA samples.

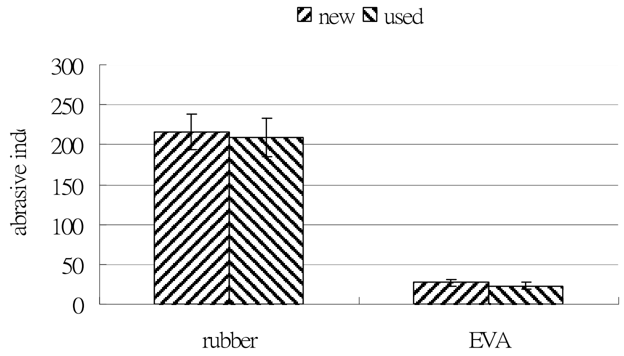

Figure 4. Abrasive index for new and used shoe soles for the types of footwear materials tested

The mean (±std) shore-A harness for the rubber-soled and the EVA-soled new shoes were 79.9 and 28.4, respectively. The mean (±std) shore-A harness for the rubber-soled and the EVA-soled used shoes were 80.4 (±1.2) and 28.3 (±2.6), respectively. The difference between the new and used shoes for both of the rubber-soled and EVA-soled shoes did not reach the 0.05 statistically significance level. Figure 5 show the mean (±std) COF for the new and used shoe soles under the floor material, footwear material, and floor surface conditions. Student *t*-tests were conducted to compare the differences between the new and used shoe soles for each floor-footwear-surface condition. The results of all the *t*-tests were statistical significant (p<0.0001). The new shoe soles had significant higher COF then those of the used ones except for the wet vinyl and terrazzo floors tested using the rubber soles.

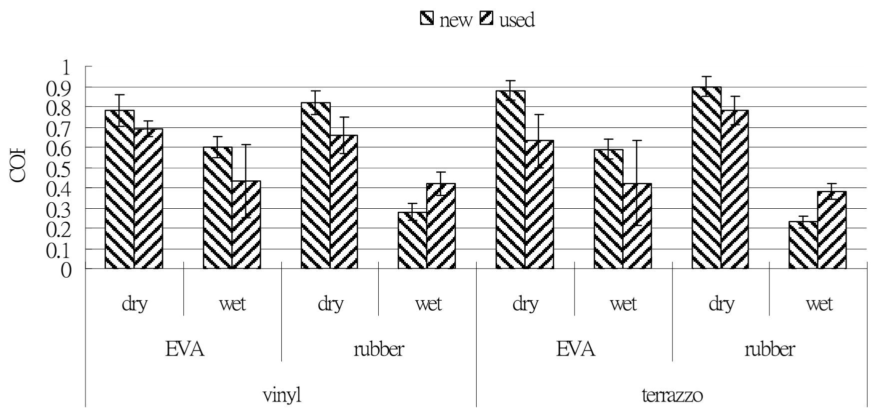

Figure 5. COF for the new and used shoe soles under floor-footwear material-surface conditions.

Discussions

After a usage of six months, the used rubber sole samples had significant (p<0.0001) larger contact area than those of their new counterparts. The difference between the new and old samples for the EVA was, however, not statistically significant. The changes for both of the hardness and abrasion for both of the rubber and EVA samples were not statistically significant.

On dry vinyl and terrazzo floors tested, the COF values decreased after a six month usage for both of the rubber and EVA samples. The COF values also decreased for the same period for EVA samples under wet conditions on both floors. The COF of the used rubber samples increased, however, on wet vinyl and terrazzo floors as compared to their new counterparts. The changes in the COF values may be attributed to the worn-out effects as the contact area at the footwear samples and floors was the only significant factor found on this study. It is, therefore, concluded that the worn-out of shoe sole is the major factor affecting the change of the slip-resistance of the shoes in a six month period of usage. Theoretically, the tread on the shoe soles worn out after a period of usage. The squeeze film effects for such a change between the sole and the floor would result in the decrease of slip-resistance of the sole samples on, especially, the wet floor. This was consistent with our results in the EVA samples but not the rubber ones. The reasons why the used rubber-soled samples testing on both the vinyl and terrazzo floors under wet condition had higher COF values than their new counterparts were not clear. A future study is required to study the difference between the EVA and rubber sole materials more thoroughly.

The results of this study provide information for footwear designers and manufacturers in understanding the footwear usage problems in terms of footwear tread design, roughness, abrasion, and slip-resistance.

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計畫成果自評

This project was complete on schedule. The results of the study will be presented in a forth coming scientific conference. The manuscript to be submitted to a scientific journal will be also finalized. The contents of the project will be written as a master thesis for one of the participant graduate students.