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TRIBOLOGY IN HUMAN WALKING

Milan NIKOLIĆ[1,*], Dušan STAMENKOVIĆ[1], Miloš MILOŠEVIĆ[1], Milan BANIĆ[1]

[1]Faculty of Mechanical Engineering Niš, Serbia

*Corresponding author: milan.nikolic.nis@gmail.com

Abstract: *Statistical data shows that huge numbers of injuries are due to human slipping in streets, factory halls, open and close public areas, etc. Beside environmental conditions (temperature, humidity, etc) and pedestrian areas cleanliness, most important parameters are tribological properties of shoes and floors. Today in Europe there are different standards and methods for shoes and floors slip resistant determination, but manufacturers apply them only on special demands. In Serbia there are no standards in this field. Research was started at Faculty of Mechanical Engineering, University in Niš aimed to define test procedures for tribological properties of shoes and pedestrian areas and to determine the technical requirements in the production of footwear and flooring.*

Keywords: *coefficient of static friction, fall, slip, floor friction, shoe friction.*

1. INTRODUCTION

Statistical data in leading countries shows that huge numbers of injuries are due to human slipping in streets, factory halls, open and close public areas etc. In UK, data shows that injuries from slipping are the biggest class of injuries. In fact, slips, trips, and falls are a serious public health problem. One of the ways to reduce slips and falls mean to know and understand friction requirements of shoes and pedestrian walkways. When measuring the available friction on surfaces it is vitally important that a valid method is used. It is the most important which method is applied for establishing the value of slip resistant i.e. static friction coefficient of certain surface. Two methods are widely used in many European countries; the pendulum test and the ramp-based test.

It is very important in research of human walking and friction to know biomechanics of walking. Biomechanics of walking studies foot positions while walking, forces which act on human body (foot, leg, hip) and ground reaction forces. Due to importance of biomechanics, the chapter two of the paper discusses the noted field.

Chapter three of the paper discusses slips, falls, and side effects caused by low friction. The experimental research of static friction coefficient with samples of shoes sole and floor tiles covered with self-adhesive floor foil for advertising is described in chapter four. This research is extension of previous research presented at SERBIATRIB '13, when the static friction coefficient between samples of shoes sole and ceramic tiles was measured.

2. BIOMECHANICS OF HUMAN WALKING

Papers [1,2] explain in detail the biomechanics of human walking. It is known that walk cycle consists of two phases: stance phase (62 %) and swing phase (38 %). The duration between times when heel of one leg strikes the ground to the time at which the same leg contacts the ground again is one walk cycle.

A typical walk cycle lasts 1-2 sec, depending on speed.

Stance phase is the duration when the foot is in contact with the ground, the duration from heel strike to toe off. In stance phase, exist three sub phases (Fig. 1):

- initial contact period: from heel strike to foot flat;
- midstance period: from foot flat to heel off;
- propulsive period: from heel off to toe off.

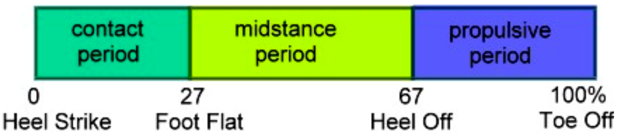

Figure 1. Periods during a stance phase [1,2]

Swing phase (recovery phase) is the duration when the foot is in the air, the duration from toe off to heel strike. In swing phase, exist three sub phases:

- acceleration;
- midswing;
- deceleration.

While walking cycle last there are forces that control walking process:

- gravity (body weight);
- air resistance;
- internal muscle forces;
- ground reaction forces.

There are two force components:

- normal component: vertical forces;
- shear component: anterior-posterior and medial-lateral friction forces.

Ground reaction force *F* is the force that has impact to the body by the ground, as opposed to those applied to the ground, when a human takes a step (Fig. 2), F_n is the normal component of ground reaction force, and F_{tr} is the tangential component of ground reaction force, i.e. friction force.

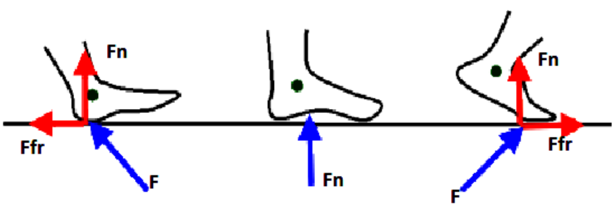

Figure 2. Forces in contact foot-ground

At heel strike, the centre of pressure is located lateral to the midpoint of the heel. At mid stance, the centre off pressure moves more laterally. From heel off to toe off, the centre of pressure moves medially from the metatarsal heads to the big toe (Fig. 3).

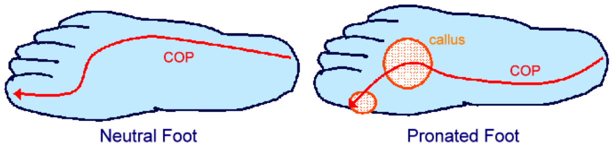

Figure 3. Centre of pressure

At heel strike, the line of action of the ground reaction forces passes posterior to the ankle joint, posterior to the knee joint, and anterior to the hip joint, leading to promote ankle plantar flexion, knee flexion, and hip flexion. To prevent collapse of the lower extremity, these external moments are counterbalanced by internal joint reaction moments that are created by ankle dorsiflexors, the knee extensors, and the hip extensors.

3. SLIPS AND FALLS IN HUMAN WALKING

Slips and falls are the biggest class of accidents reported to the United Kingdom's Health and Safety Executive (HSE). Statistics show slipping and tripping to be the most common causes of injuries in UK workplaces. Provisional statistics for 2008-09 show that slips and trips resulted in 10,626 major injuries (37 % of major injuries), and 24,000 over 3 day injuries (23 % of over 3 day injuries) reported to HSE In order to reduce the number of slip accidents, it is necessary to understand the friction requirements of people walking on pedestrian surfaces. It is the most important to choose the best method for measuring the surface slip resistant. For instance, two methods are mostly used in UK. The first of these is the pendulum coefficient of friction (COF) test. This test methodology can be applied to samples in the laboratory as well as on installation site. The second method is a laboratory based ramp method. This methodology uses trained operators walking at a controlled constant pace with standardised footwear soling materials and water as the contaminant. Surface micro roughness measurement can also be used as a simple tool to identify changing characteristics of surfaces in service [3].

Technical specifications for various ramp methods and the pendulum method developed in a European Standards Committee group (CENTC/339/WG1). Fall accidents have a serious social and economic impact. In 2007, Liberty Mutual (Insurance Company) reported that the total cost due to all fall accident injuries was approximately $13.9 billion [Liberty Mutual Research Institute 2009]. Slip and fall accidents has a significant risk, of all slip and fall accidents 50 % are attributed to improper flooring and 24 % are attributed to improper shoe material [National Floor Safety Institute 2010]. During walk, when the available coefficient of friction (COF) is less than the required COF between shoe and floor material, the probability of a slip and fall accident occurring increases [4].

The act of slipping occurs when a person's heel slides on a walking surface and causes a loss of balance. It occurs just as the heel contacts the floor and the weight shifts to the heel. Typically, slips occur when there is too little friction or traction between a person's foot and shoe and the walking surface. When a person slips, most often falls backward. Slips can occur due to faulty housekeeping, contaminants (such as oils, water, etc.), weather hazards, inappropriate or worn flooring, and improper or worn footwear [5].

Slip can result in a variety of injuries, including fractures, strains, cuts, abrasions, and even death. American National Safety Council reports more than 17,000 U.S. deaths due to falls in 2003. In the workplace, slips, trips, and falls are also a major concern. According to the 2006 Liberty Mutual Workplace Safety Index, the annual direct cost of disabling occupational injuries due to slip, trips, and falls is estimated to exceed $11 billion [5].

Germany and Australia have for over 10 years detailed flooring slip resistance standards based on some 150 specific situations, for example: external walkways, swimming pool decks, swimming pool stairs, commercial kitchens, hospital operating rooms, etc. Many architects in Europe have informally adopted them. In Serbia, there is no standard for flooring slip resistance but some manufactures accept foreign standards. *Zorka keramika* and *Kanjiža*, Serbian tile manufacturers test their products according German DIN 51130 and DIN51097 standards which is based on ramp test. The slip resistance ratings based on humans walking an oily or wet flooring sample in standard footwear and/or bare feet on a laboratory variable-angle ramp the repeatability of which was extensively documented [Jung and Schenk 1988]. However, the test results apply only to flooring before it installed. In some cases, initially good wet slip resistance is gone after the building has been open for only a few weeks. The ramp test cannot be used to assess safety of the flooring on site under the ambient conditions.

The United Kingdom has established since 1971 the slip resistance standards based on a portable test method, the pendulum. This test was developed for pedestrian traction [6].

In the USA, architects and designers generally look for a wet static coefficient of friction of 0.60 or higher by ASTM method C 1028 to assess potential safety for wet areas of level floors. This can give deceptive results, applying "safe" ratings to some flooring samples that are in fact very slippery when wet [Powers et al. 2007]. The method is now acknowledged by ASTM [2005], Ceramic Tile Institute of America [2001], and Tile Council of North America [Astrachan 2007] to be inadequate for assessing safety. Experience has shown that what is specified and ordered is not always, what is delivered, and it is prudent for property owners to verify that flooring meets their slip resistance specification both before installation and at turnover of the property for occupancy. Monitoring of slip resistance every 3 to 12 months, after that can further protect pedestrian, owner, and other duty holders [6].

4. EXPERIMENT

Footwear produced most from rubber, because of its good frictional, elastic and other properties.

Experimental determination of the static friction coefficient between different samples of footwear soles and flooring was performed at Faculty of Mechanical Engineering, University of Niš. Static friction force can be measured only in the moment of sliding beginning for the reason that in next moment, after sliding start, this values falls on friction kinetic force value. According that this, specific device for static friction force measuring was designed. Schematic review of this device is presented in Figure 4 [7].

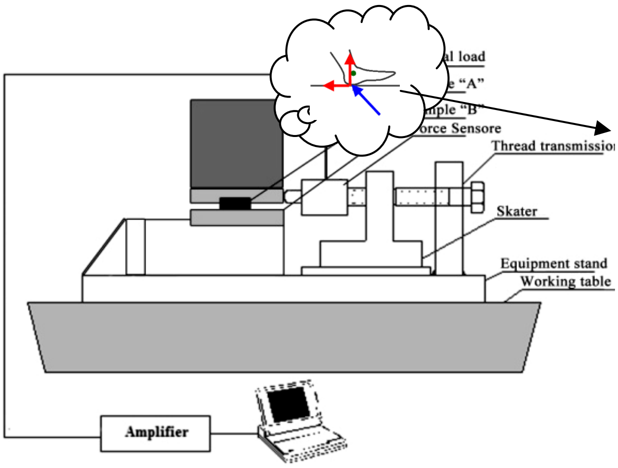

Figure 4. Schematic review of device for measuring static friction force

Measuring process was done by turning the screw that moves the skater and force sensor fixed on skater. The force sensor pushes sample A (footwear sole sample). Sample A starts to slide on the sample B that fixed in the base of device and pushing (friction) force is measured. Static friction force occurs in the moment of sliding start. Figure 5 shows the measuring system and samples.

Samples used in this experimental investigation are with following characteristics.

Footwear sole samples (sample A) are prism shaped and formed by cutting the soles and glued on a piece of chipboard. Nominal contact area is 30 × 30 mm = 900 mm^2. For this research, there are two sole samples: worn (used) rubber with texture and flat used rubber.

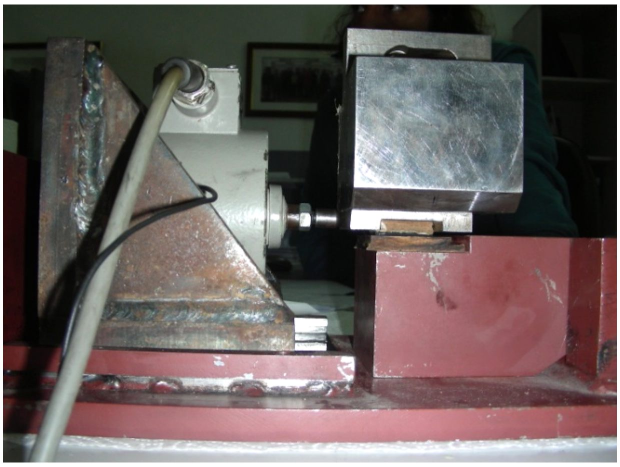

Figure 5. Measuring system

The floor samples (sample B) were prepared from used plates of rough ceramic tile, smooth ceramic tile, laminate and concrete block. All floor samples covered with floor foil for marketing on pedestrian areas. Foil thickness is 0.5 mm. Dimensions of floor plates were 60 × 75 mm according the measuring device.

Surface roughness of floor samples is measured by roughness measuring device MahrSurf XR-1 (Fig. 6). Average maximum height of the profile *Rz* was 27.1 µm.

Figure 6. Roughness measuring device

Measurements were done with weight (normal force) variations so that contact pressure was 48 kPa, 86 kPa and 140 kPa.

Static friction coefficient was calculated with formula $\mu = F_\mu/F_n$, where F_μ is static friction force measured by force sensor and F_n is the normal force, i.e. weight placed on the footwear samples. Measuring was conducted in two regimes: dry and wet condition. Values of static friction coefficient estimated in the test are presented in Table 1.

Table 1. Friction coefficient values

Floor sample foil on concrete	Contact pressure [kPa]			Mean value friction coefficient
	48	86	140	
Flat rubber dry	0.7315	0.724	0.7315	0.729
Flat rubber wet	0.6424	0.6431	0.6928	0.659
Rough rubber dry	0.6661	0.648	0.6144	0.643
Rough rubber wet	0.4672	0.4857	0.4816	0.478

Floor sample foil on smooth ceramic tile	Contact pressure [kPa]			Mean value friction coefficient
	48	86	140	
Flat rubber dry	0.795	0.762	0.748	0.768
Flat rubber wet	0.593	0.643	0.610	0.615
Rough rubber dry	0.643	0.656	0.616	0.638
Rough rubber wet	0.624	0.585	0.561	0.590

Floor sample foil on rough ceramic tile	Contact pressure [kPa]			Mean value friction coefficient
	48	86	140	
Flat rubber dry	0.725	0.754	0.735	0.738
Flat rubber wet	0.659	0.688	0.646	0.664
Rough rubber dry	0.731	0.766	0.689	0.729
Rough rubber wet	0.627	0.515	0.467	0.536

Floor sample foil on laminate	Contact pressure [kPa]			Mean value friction coefficient
	48	86	140	
Flat rubber dry	0.755	0.793	0.825	0.791
Flat rubber wet	0.623	0.601	0.553	0.592
Rough rubber dry	0.656	0.678	0.679	0.671
Rough rubber wet	0.556	0.525	0.522	0.534

It is particularly interesting how the value of static friction coefficient was changed when the ceramic tile is covered with floor foil. Next diagrams show comparative values of static friction coefficient for measuring without and with floor foil. Figure 7 presents the comparative values in case of smooth ceramic tile, and Figure 8 presents the comparative values in case of rough ceramic tile.

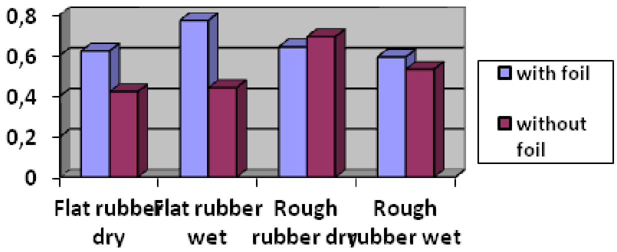

Figure 7. Comparative static friction coefficient values in case of smooth ceramic tile with and without foil

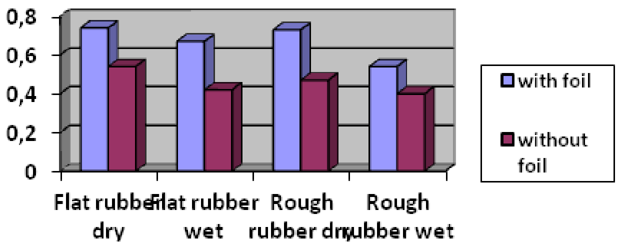

Figure 8. Comparative static friction coefficient values in case of rough ceramic tile with and without foil

Friction coefficient diagrams show that friction coefficient rises with foil usage. Only in case of rough rubber with smooth ceramic tile under dry condition, friction coefficient is less than with foil attached.

5. CONCLUSION

This paper indicates that slips and falls are very important part of tribology. The research of slips and falls is a multidisciplinary research, where biomechanics is very important. Biomechanics investigate which forces that affect the human body. Slips and falls are often investigated topic in the world because of huge impact on economy and society. Insurance companies are very interested in noted research because they give huge money due to slips and falls injuries. In Serbia, there is not research in this area. At Faculty of Mechanical Engineering, the preliminary research started in

2013. The paper presents the continuation of the noted research with different tribological conditions. The anti-slip foil over floor samples was tested and friction coefficient was determined. Content of new research will include the collection of the data about slips and falls in Serbia, and the investigation of places in pedestrian areas where slips and falls occurred mostly. This kind of research should have an effect to reducing slips and falls and thus indirectly the cost, as well as increasing the health of people. The preliminary testing was already performed under laboratory conditions, where some examples of floors and shoe soles under various condition (dry, wet, soap lubricated etc) were tested. The newest research performed by testing anti-slip advertising foil friction properties. Testing data show that this foil gives good friction results, respectively friction increases with foil applied on floor samples. Future investigation will cover critical places in pedestrian areas and friction conditions on them. Some of them are white stripes in pedestrian crossing, tiles in public areas, roadside places, building stairs, etc.

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