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INFLUENTIAL PARAMETERS OF FOOTWEAR SLIP RESISTANCE

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Abstract: Slip resistance of footwear sole and floor coverings is the characteristic which seriously depend on safety of human movement. There are some adopted standards which prescribe methods of slip resistance testing, but they are often criticized and revised. Tribological parameters are very important in human walking, running, jumping, etc. Friction mechanism of viscoelastic materials on hard bases is described in this paper. Also, influence of some parameters, like rubber hardness, rubber hysteresis, contact condition (dry and wet) and sliding speed are analysed according the testing results obtained in performed experimental research.

Keywords: Slip resistance, friction, footwear, viscoelastic materials, hysteresis.

1. INTRODUCTION

Friction between the footwear sole and floor coverings is necessary for human walking. Movement of the human foot on the floor is possible by the presence of the friction force. Skidding and injuries are happening in the cases of a lack of frictional force. There are many researches dealing with the tribological aspects of human walking which mostly refer to the footwear and floor slip resistance.

Authors in the paper [1] point out that categorization of slip resistance for sliding of footwear on floor should base on knowledge of mechanics and mechanism of friction. The fundamental characteristic of slip resistance is relativity ie. accidental. There are cases where one flooring material could be more slip resistant than another under one set of

conditions, but less slip resistant under another ones. Authors present the frictional model based on tribological system of the sliding interface between a shoe heel and floor surface.

Visco-elasticity and rubber state are described in [2]. Visco-elastic characteristics of polymers are very important in sliding of this type of material on rough hard surface why energy hysteresis exists.

Author in his extensive research [3] compares the mechanics in metallic friction and mechanics in rubber friction. A unified theory of rubber friction is presented in this work.

Author in his dissertation [4] makes a statement that four different mechanisms or physical principles at least exist in friction of elastic solids on hard and rough surfaces.

Author in his papers [5, 6] presents research of behaviour of the rubber sliding on the rough substrate. He describes how surface asperities of substrate exert oscillating forces on the rubber surface and according that energy dissipation which comes from internal friction in rubber.

Test methods for measuring and evaluating the slip resistance of footwear and flooring coverings, according the adopted standards are described and analysed in the paper [7]. One of the findings of this research is that the sole material of footwear is a main factor for safe walking in different cases like in leisure, travel or work.

Standards for foot protection are often reviewed according the current state of the art technology. The main changes are expected for the test methods and requirement of slip resistance [8]. In this article is indicated that slip should be given a high priority.

Investigation in area of the tribology in human walking that has been performed last five years at University of Niš [10, 11], treats tribology in human walking. Research of influential parameters of footwear slip resistance and analysis of friction mechanisms are presented in this paper. Experimental results refer that slip resistance of concrete footwear and floor is significantly accidental, but it is possible to affect on slip resistance using certain sole material for certain floor material and adjusting the movement according the currently environment conditions.

2. FRICTION MECHANISM OF VISCOELASTIC MATERIALS

Main goal of experimental researches in this area [2, 3, 4, 5, 6, 7, 10, 11] is determination of influential parameters of slip resistance and possibility of managing of frictional conditions in different circumstances. It is very important to introduce the friction mechanisms of viscoelastic materials.

The differences between the friction characteristics of metal and rubber are due to differences in the mechanism of frictional

force creation. This mechanism is different because of differences in physical and chemical properties between their materials. In the friction of metal surfaces, most of the roughness peaks in the contact of the two surfaces are in the range of plastic stresses, and it can be said that asperities of contact surfaces are connected by "cold welding". Plastic deformation occurs in the regions of real contact and friction junctions are formed. Surrounding regions are deformed elastically. Tabor and Bowden determined: "Friction is the force required to shear intermetallic junctions plus the force required to plow the surface of the softer metal by asperities on the harder surface" [9].

Accordingly, the total friction force can be expressed as a sum of molecular (adhesion) and mechanical (deformation) components:

$$F_t = F_{tmol} + F_{tmeh} = F_a + F_d \quad (1)$$

Rubbers or elastomers consist of long linear molecules that are twisted and knit together forming an amorphous solid structure. Viscoelastic bodies, such as rubber, generate friction in three main ways: adhesion, deformation and wear.

According these three mechanisms of friction generating, total friction force can be expressed:

$$F_t = F_a + F_d + F_w \quad (2)$$

Where: F_t – total friction force, F_a – friction force from adhesion, F_d – friction force from deformation and F_w – friction force from wear.

Friction force from deformation is very different in case of solid bodies and in case of viscoelastic bodies.

The appearance of adhesion allows the body surface to „be glued“ to other materials, i.e. to join. Adhesion is the result of molecular bonds between the two surfaces. The true area of the contact depends on the contact bodies shapes, the surface roughness, the material properties and the contact pressure. The larger real contact surface means greater adhesion between the surfaces and higher friction force. It is believed that this mechanism is

important for sliding rubber on clean and relatively smooth surfaces, e.g. on glass.

Figure 1. Contact between rubber and hard roughness surface

When rubber gets in contact with the rough surface of a rigid body (Fig. 1), the mechanism of the friction force generations due to deformation is dominant. The sliding of the rubber block on a rough hard surface causes rubber deformations due to the surface asperities. The load of the rubber causes the asperities to enter the rubber and rubber to wrap the asperities (Figure 1). The energy required for the asperities of the rubber is due to the difference in pressure between the asperities, due to the difference in pressure ahead and behind the asperities.

The friction force from the deformation represents the greatest part of the friction that occurs between the rubber and the wet surface, because the wet surface disables contact of the rubber and the surface, preventing the formation of adhesive force.

Viscoelasticity is the characteristic of rubber and some similar materials that when loaded and after unload, part of the energy is absorbed, i.e. hysteresis losses occur. Rubber with a small hysteresis (loss of energy) rapidly returns to its original position, while rubber with high hysteresis slowly returns to its initial state after deformation.

During the translational movement of the rubber on a hard rough surface, the surface asperities will cause pulsating rubber deformations, leading to viscoelastic dissipation of energy in the greater area of the rubber, which is a significant part of the friction. This energy dissipation mechanism is often called viscoelastic friction or a hysteresis share of friction.

Persson studied rubber friction for a rubber block that slides on a hard and rough surface with roughness on a number of different longitudinal wavelengths [4]. According to this study, the dissipation of energy from viscoelastic deformation of the rubber caused by surface roughness of the substrate requires that all the wavelengths scale of the roughness in the analysis be included because they can be equally importance. For example, the short wave wavelength component with wavelength λ_1 and amplitude h_1 can give the same contribution as a long wavelength component with λ_0 and h_0 if the ratio is $h_1 / \lambda_1 = h_0 / \lambda_0$.

Figure 2. Viscoelastic deformation of the rubber due to surface roughness of the substrate on two different longitudinal wavelengths [4]

The dissipated (lost) energy per unit of rubber volume, as shown in Figure 2, is the highest in areas of contact with small asperities.

In addition to adhesion and deformation shares of friction, rubber produces cohesion-loss friction i.e. wear friction. During the sliding, rubber can wear, and on that occasion small particles of the rubber are formed by the formation (spreading) of the cracks. As deformation forces and slip speed increase, local stress exceeds the tensile strength of the rubber, especially around the sharp asperities. Large local stress can deform the inner structure of the rubber and overcome the elasticity limit. When the chains of polymer and transverse bonds are strained to the stress of breaking point, the rubber can no longer be recovered completely and this causes rupture. Breaking (rupturing) absorbs energy, causing additional friction force in contact.

3. SLIP RESISTANCE OF FOOTWEAR

Footwear producers have complex task to make comfortable and long lasting shoes. There are numerous types of footwear which are used in different conditions and different requirements. There are specific requirements for sports footwear, due to sports disciplines and the different ground and floor surfaces. Safety footwear (personal protective equipment) is special and their production is performed by specialized companies. Footwear outsole has a decisive influence on the slip resistance of footwear and is made of different types of viscoelastic materials like rubber, plastics, leather, etc. The surface of the soles is most often made with different relief structures, which have the function of preventing sliding (Fig. 3).

Figure 3. Different types of footwear outsole

Contact pressure depends on the person's weight and surface texture and shoe soles, and the relief (texture) of substrate. Velocity of sliding corresponding to human stroke has a great range, from slow walking to running.

Based on previous experience in friction research [10, 11], in experimental determination of friction coefficient it is significant to provide the following:

- Experimental samples should be made of real shoes sole/floor materials with determined mechanical properties,
- Surface structure (macro and micro structure, roughness, etc.),
- Contact pressure,
- Sliding velocity,
- Contact condition (temperature of contact bodies, lubricant, contaminants, etc.),
- Environment (temperature, humidity, etc.).

Determination of floor and footwear slip resistance is often conducted by measuring the coefficient of friction. Kinetic coefficient of friction is the most often determined, but static coefficient of friction is very important as well. Coefficient of friction can be determined by measuring of pulling force, friction angle (Ramp test) or energy loss (Pendulum test).

Different countries in Europe and the world have adopted different methods of testing and evaluation of slip resistance. Since these methods are based on different principles and are used in different conditions, there is no direct and precise correlation between them. No one of these methods is ideal and has certain advantages, but also certain disadvantages.

4. EXPERIMENTAL RESEARCH

Pulling force measurement, usually known as tribometric test method, is based on the measurement of the friction force (Figure 4 a). The body equipped with sliders is pulled at constant speed over the floor surface, at a certain length. Such a device was used in the research at the Faculty of Mechanical Engineering of the University of Niš (Figure 4b).

a)

b)

Figure 4. Pulling force measurement method (a) and measuring equipment (b)

Applied measuring method is based on settings in standards EN 13893 and DIN 51131. The measurement was carried out on dry and wet surfaces. The test facility is equipped with sliders which are pulled parallel to the surface of the floor covering.

Three sliders with dimensions 10x40 mm are placed on the underside of the load (Fig. 5). Materials of sliders were rubber for shoe sole 80 Sh hardness, tensile strength 5.6 MPa and Yertzley hysteresis of 46.2 %. Yertzley hysteresis is determined on equipment in Laboratory at Faculty of mechanical engineering Nis according the standard ASTM D945, with compression test method (Fig. 6).

Figure 5. Sliders on the underside of the experimental load

Figure 6. Deflection of sample in dynamic test according ASTM D945

Experimental samples of flooring covers were prepared from five different materials: ceramic tiles, granite tiles, laminate, vinyl and parquet. Values of surface roughness of experimental floor coverings samples are presented in Table 1. Contact pressures were 75 kPa and 140kPa. Sliding distance was about 500mm. Sliding velocities were: 5, 10 and 50 mm/s.

Table 1. Measured surface roughness parameters of experimental floor coverings samples

	Floor coverings	R_a (μm)	R_z (μm)	R_{max} (μm)
1.	Ceramic tiles	0.63	2.34	3.57
2.	Granite tiles	0.06	0.34	0.51
3.	Laminate	1.50	4.59	6.18
4.	Vinyl	0.83	3.54	5.51
5.	Parquet	0.42	1.90	2.77

A typical example of measured friction coefficient is presented in Figure 7.

Figure 7. Friction coefficient measured in sliding rubber sole sample on parquet

There are numerous measuring data and friction coefficient values are very variable, ie, stochastic. Mean values of friction coefficient measured in experiment is presented in Table 2.

Table 2. Mean values of friction coefficient masured in experiment

Floor coverings	Contact pressures		Contact condition	
	75 kPa	140 kPa	Dry	Wet
Ceramic tiles	0.434	0.447	0.4167	0.4648
Granite tiles	0.692	0.835	0.8321	0.6956
Laminate	0.758	0.788	0.8232	0.7234
Vinyl	0.745	0.8545	0.7951	0.8046
Parquet	0.715	0.8230	0.7506	0.7881

In order to estimate the influence of individual parameter, comparing the friction coefficient values can be noticed in case of granite tiles, which have the smallest surface

roughness, that friction coefficient values are bigger when contact pressure is bigger and also in the dry condition. That means that adhesive component of friction force is the most influential in that case. It is very similar (same trend) in case of laminate samples which have the biggest measured parameters of surface roughness, but laminate has smaller surface hardness.

In case of ceramic tiles friction coefficient is so similar in case of smaller and in case of bigger contact pressure, but in wet condition it is 11 % bigger than in dry condition.

In case of parquet samples coefficient of friction is 15 % bigger when contact pressure is bigger than in smaller pressure condition and 5 % bigger in wet than in dry condition.

The minimum values of friction coefficient are measured with floor sample from ceramic tiles in case of contact pressure 75 MPa and in sliding on 5 mm/s speed in dry condition, and their mean value is 0.37

The maximum values of friction coefficient are measured with floor sample from materials vinyl and laminate in case of contact pressure 140 MPa and in sliding on 50 mm/s speed in dry condition, and their mean value is 1.06.

5. CONCLUSION

In order to prevent the slip accident it is necessary to investigate and examine the friction influential parameters and according that it should be implemented certain measures. Knowledge of friction mechanism of viscoelastic materials is very useful for establishing the friction circumstances in human walking. According this knowledge can be estimated the most influential part of mechanism: adhesion, deformation and wear.

In performed experimental research, measuring data show that for the same shoe sole sample there are a wide range of friction coefficients values for different floor and conditions. Maximum value of friction coefficient is three time bigger than minimum value for same sole material sliding on

different floor materials, like ceramic tiles and vinyl and laminate.

Some type of shoe sole material can't be the best on all different types of coverings and contaminants, and because of that it is necessary to investigate different combinations of materials and friction conditions.

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