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RESEARCH

Methods and Principles of Determining the Footwear and Floor Tribological Characteristics

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A B S T R A C T

There are many standards relating to the anti-slip properties of footwear and flooring. These standards describe the different test methods and procedures for determining the footwear and floor slip resistance in different conditions. In this paper authors systematize the standards in this field applied in the EU and in Serbia and cite the Serbian institutes which are certified for this type of testing. In addition, the authors have carried out an analysis and comparison of the tests that are defined in these standards, indicating their advantages and disadvantages. Importance of the static and kinetic friction testing in determining the anti-slip properties of footwear and flooring is specifically indicated. Considering the current standards in area of slip resistance of the footwear and floor covering authors have determined the testing conditions for laboratory measuring the friction forces of different floor and footwear materials. The laboratory measurement has carried out at Faculty of Mechanical Engineering in Niš. The measuring results and their analysis are presented in the paper, as well.

1. INTRODUCTION

Numerous accidents occur due to the slipping during human walking. Selection of appropriate shoes and floor combination, considering the slip resistance properties, is the most important measure for slipping accidents prevention. Evaluation of floor and footwear slip resistance should be based on understanding of basic tribological characteristics. There are different principles and methods to assess the slip resistance of flooring coverings and footwear.

Authors Wetzel et al. in their paper [1] describe the requirements concerning the slip resistance and the state of art of slip resistance measurement standards in the European Community. They note: ''Slip resistance is influenced by a numerous factors, such as: combination of shoe sole, floor covering, contaminants and their properties; surface structures of shoe soles and floor coverings and changes to them as a result of wear; motion speed and ambient parameters'' [1].

The comparison of the slip resistance of outdoor footwear and safety footwear according the performed experimental research is described in the paper [2].

In paper [3] author points out that there are many different standards and methods for assess the slip resistance, but there are no obligation to apply for the producers of footwear and floor. He indicates that evaluation of slip resistance should be based on understanding of basic tribological characteristics between the shoes and floors.

A number of organizations have developed standard tests for measuring friction force ie. coefficient of friction. These tests have numerous similarities, but vary greatly in type and purpose. List of tests that have been standardized by ASTM is presented in [4]. Some are directed towards a particular application, while others are for general evaluation of materials.

Structural, operation and interaction parameters should be taken into account in friction experimental research of solid elements [5]. The contact between rubber and hard material is specific compared to pure metal-metal contact. In contact between rubber and hard surface, friction depends significantly on load and on geometry of the surfaces [6]. The author in the paper [7] claims that friction force between rubber and rough (hard) surface can be described as the adhesion and hysteretic components.

There are different European standards that have adopted various test methods and rating systems [8-12]. These standards include test methods that are based on different principles and are used under different conditions. Analysis of their advantages and disadvantages are presented in papers [13-14].

Basic factors influencing accidents and injuries in human walking can be divided in next groups: footwear, floor, human factors and environment (location) [15]. Footwear factors: are sole construction, sole material, sole elasticity, sole hardness, tread pattern, wear etc. Floor factors are: material type, roughness, hardness, maintenance, wear, etc. Human factors represent individual characteristics of human such as gait, age, weight, mobility, etc. Environment factors are lighting, humidity, obstacles, changes of surface, contaminants, etc.

Due to the point of tribology view, footwear and floor factors in friction testing are considered in this paper.

2. BASIC PRINCIPLES OF FRICTION TEST METHODS

The basic principle of determining the footwear and floor slip resistance is testing the real materials in real conditions considering the tribological characteristics.

The possibility of determination of friction coefficient is presented on Fig. 1.

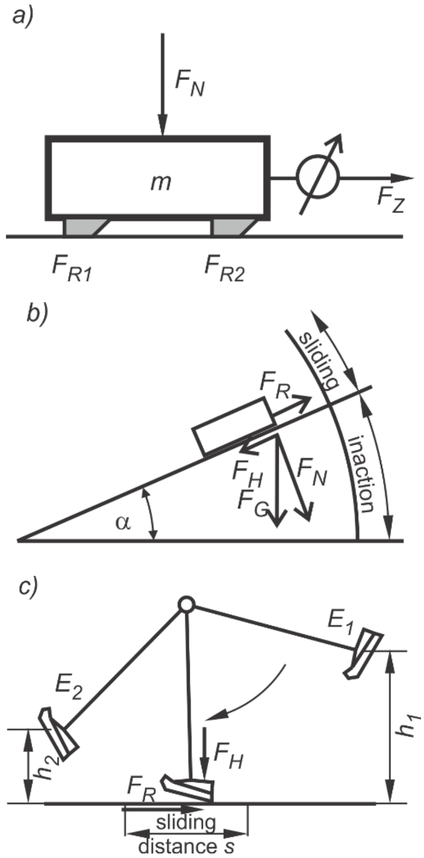

Fig. 1. Friction coefficient determination by pulling force (a), friction angle (b) and energy loss (c).

Main principles of friction coefficient determination are testing with measuring the pulling force (Fig. 1a) where friction coefficient is depending from pulling force (F_Z) and pulled mass (m), and it is determined according to the formula (1):

$$\mu = \frac{F_{R1} + F_{R2}}{F_N} = \frac{F_Z}{m \cdot g} \quad (1)$$

testing with measuring the friction angle (Fig. 1b) where friction coefficient is in function of friction angle (α), and it is determined according to the formula (2):

$$\mu = \tan\alpha \quad (2)$$

and testing with measuring energy loss owing to friction (Fig. 1c) where friction coefficient directly depends on the difference of potential energies (E1 – potential energy at the start, E2 – potential energy at the end of measurement) and it is determined according to the formula (3):

$$\mu = \frac{m \cdot g \cdot (h_1 - h_2)}{s \cdot F_N} \quad (3)$$

These three principles of friction coefficient determination are the most often used in order to assess the slip resistance characteristics of the footwear and floorings.

2.1 Static and dynamic coefficient of friction

There are static and dynamic (kinematic) friction force and according that static and dynamic coefficient of friction. There are opposing views about the importance of static and dynamic coefficient of friction in slip measurement. Some engineers claim that the dynamic coefficient of friction is a more important value than the static coefficient.

The static coefficient of friction is usually greater than the dynamic coefficient of friction and it is the initial barrier against slippage. If slippage has begun, a higher dynamic coefficient of friction may help one to recover from a slip, but it is better to prevent the slippage and static friction is relevant for that.

Static friction is friction between two bodies that are not moving relative to each other. The static friction force must be overcome by an applied force before an object can move. The static friction has an important role in transport means, especially in railway and road vehicles, and also in human walking. Regardless of the installed power of the drive units, motion of a vehicle is only possible if there is an adequate static friction between drive wheels and the ground. In the same way static friction between shoes sole and floor coverings is necessary for human motion.

2.2 Basic group of parameters in a friction test

In a friction test the resulting tribometric characteristics data must be understood as tribological systems characteristics associated with the following group of parameters [5]:

- **Structural parameters**, which characterize the components (materials, lubricant, and environment) involved in the friction process and their physical, chemical, and technological properties;
- **Operational parameters**, that is, the loading, kinematic, and temperature conditions and their functional duration;
- **Interaction parameters**, which characterize, in particular, the action of the operating parameters on the structural components of the tribological system and define its contact and lubrication modes.

Structural parameters include triboelements, interfacial element such as lubricant or dirt particles, and environmental medium such as air or moister. Structural parameters can be divided in:

- Geometric parameters (geometry dimensions, surface topography, etc);
- Microstructural parameters (grain size, dislocation density, etc);
- Mechanical parameters (elastic modulus, hardness of triboelements; viscosity and viscosity-pressure of interfacial elements and environmental medium, etc)
- Chemical parameters (volume composition and surface composition of triboelements; composition of interfacial elements and environmental medium such as acidity and humidity, etc)
- Physical parameters (density, thermal conductivity, etc).

The basic operational parameters in tribology are:

- Type of motion (sliding, rolling, spin, and impact; the kinematics can be continuous, intermittent, reverse, or oscillating);
- Load, defined as the total force (including weight) that acts perpendicular to the contact area between triboelements;
- Velocity, to be specified with respect to the vector components and the absolute values of the individual motions of triboelements;
- Temperature of the structural components at stated location and time,

that is, the initial (steady state) temperature and the friction-induced temperature rise;

- Time dependence of the set of operational parameters;
- Duration of operation or test.

2.3 Friction conditions in contact rubber - substrate

Rubber is the most often used material for shoe sole and contact between rubber and hard material should be considered. Rubber friction differs in many ways from frictional properties of most other solids due to the fact that rubber has very low elastic modulus and high internal friction.

In situation of contact between rubber and hard surface the friction depends markedly on load and on geometry of the surfaces [6]. Rubber is a truly elastic solid and if the sliding surfaces are flat so that they touch over a large number of contact regions the area of contact and friction force are more nearly directly proportional to the load.

Deformation of the rubber exists when a hard steel ball slides over a clean rubber surface but the friction is dominated by the adhesion between the surfaces. When the surfaces are thoroughly lubricated the friction is dominated by the deformation of the rubber due to elastic hysteresis losses [6].

The friction force between rubber and rough (hard) surface can be described as the adhesion and hysteretic components [7].

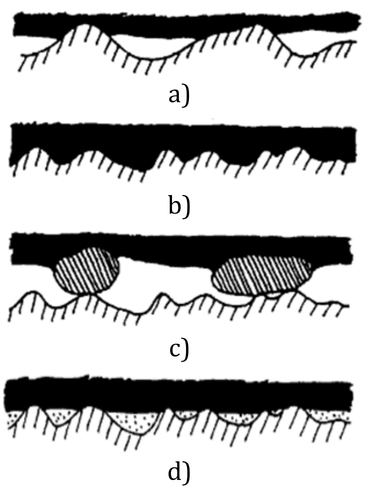

Fig. 2. Rubber in contact with a hard substrate with a rough surface [7].

Contact of rubber and hard substrate with a rough surface is presented in Fig. 2 in different conditions [7].

Rubber on a hard substrate with long-wavelength surface roughness is shown in Fig. 2a. Because of adhesion to the substrate rubber in contact area deforms in such manner as to completely follow the short- wavelength surface roughness profile of the substrate (Fig. 2b). Rubber surface dusted by small particles sliding on a hard substrate is presented in Fig. 2c and rubber sliding on a water covered surface is presented in Fig. 2d.

3. FOOTWEAR AND FLOOR SLIP RESISTANCE STANDARDS

Testing and assessment of anti-slip characteristics of footwear and floor is of major importance for the prevention of slipping accidents. Numerous different methods and devices have been developed over the years to measure the slip resistance of floor and footwear. Different European countries have adopted various test methods and rating systems. Because these test methods are based on different principles and are used under different conditions there is no correlation between them. No single test currently in use is perfect. All have their advantages, but also their own particular disadvantages [14].

The most often used standard tests for floor testing are Ramp test according to the German norms DIN 51130 and DIN 51097, Pendulum test according to the British and EU norm BS EN 13036-4, and tribometer test according to the norms DIN 51131 and BS EN 13893. The principle of ramp test is measuring the friction angle; the principle of pendulum test is measuring the energy loses owing to the friction and the tribometer test is based on measuring the pulling force which is actually the friction force.

In the ramp test (DIN 51130), a test person (operator) is wearing standard footwear and walks backwards and forwards over a sample of a flooring material that has been evenly coated with oil (Fig. 3). The angle of the ramp is increased until the operator slips [8]. The acceptance angle obtained is used to express the degree of slip resistance. In the ramp test (DIN 51097) the operator walks barefoot.

Fig. 3. Ramp test.

According the angle of ramp there are five class of slip resistance that is shown in Table 1.

Table 1. Slip resistance classes of floorings according to the norm DIN 51130.

Classification	R 9	R 10	R 11	R 12	R 13
Slip angle [o]	6÷10	10÷19	19÷27	27÷35	>35

The pendulum test measures the loss of energy due to friction as the standard rubber-coated slider assembly slides across the test surface [9]. Pendulum friction tester is presented in Fig. 4. It provides a standardized value of slip resistance. This is the pendulum test value (PTV).

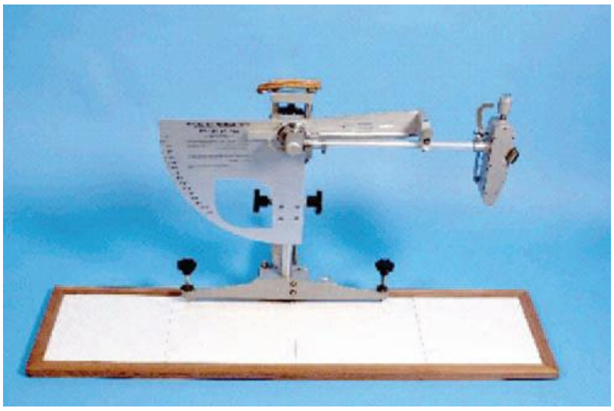

Fig. 4. Pendulum friction tester.

The pendulum is the preferred test method in the United Kingdom. Relative risk of slipping is determined with PTVs (Table 2).

Table 2. Slip potential due to PTV.

Slip potential	***PTV***
HIGH	0÷24
MODERATE	25÷35
LOW	>36

Tribometer test method is based upon a friction force measurement [10,11]. A body equipped with sliders is pulled at a constant speed over the flooring surface. The force required to pull the body is determined over the length of the measuring distance. An example of a tribometer tester according to the norms DIN 51131 [11] is shown in Fig. 5.

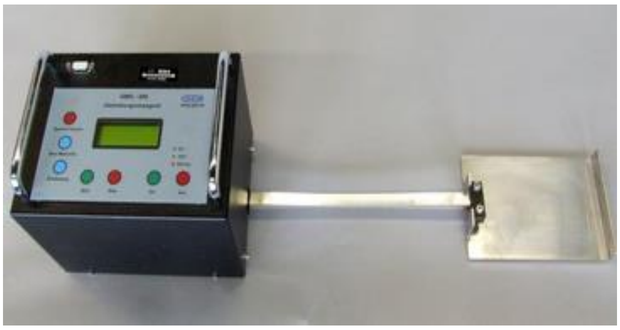

Fig. 5. An example of a tribometer tester.

In order to determine the sliding friction coefficient, this force is divided by the vertically acting force. This test can be carried out in wet and in dry conditions both in a laboratory and on-site. This device is predominantly used in Germany, Poland and Austria [14].

The method for measurement of the slip resistance of shoes is described in EN 13287 [12].

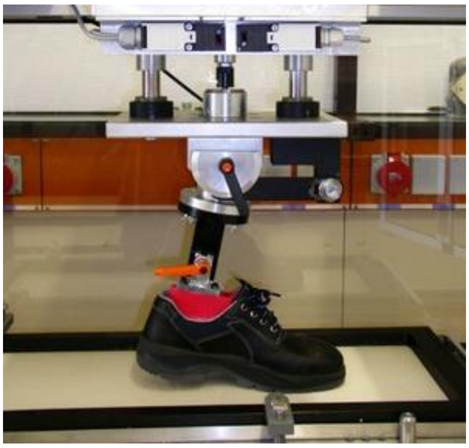

Fig. 6. Test equipment for measurement the slip resistance of footwear.

The footwear to be tested is placed on the base of ceramic tile or steel floor, subjected to a given normal force (Fig. 6). The base is moved horizontally and sliding of footwear occurs. Dynamic coefficient of friction is calculated according the measured frictional force. Glycerin or sodium lauryl sulphate solution acts as contaminant on the surface.

Some EU standards related with measuring of slip resistance of footwear and floor coverings are adopted in Serbia. There are:

- SRPS EN ISO 13287:2014 - Personal protective equipment - Footwear - Test method for slip resistance;
- SRPS EN 13036-4:2012 - Road and airfield surface characteristics - Test methods - Part 4: Method for measurement of slip/skid resistance of a surface: The pendulum test;
- SRPS EN 13893:2011 Resilient, laminate and textile floor coverings - Measurement of dynamic coefficient of friction on dry floor surfaces.

Manufacturers and distributors of protective footwear in Serbia are usually required to test their products according to standard SRPS EN ISO 13287. But manufacturers and distributors of other types of footwear rarely present the slip resistance properties of their products. In rare cases they advertise the slip resistance of their shoes referring to standards EN ISO 13287 and DIN 51130.

Manufacturers and distributors of sports flooring in Serbia presenting their products usually refer to standard EN 13036-4 (Pendulum test). Manufacturers and distributors of laminate and textile floor coverings most often refer to standard EN 13893. Other manufacturers and distributors of floor coverings refer to standard DIN 51131, DIN 51130 and DIN 51097.

4. EXPERIMENTAL INVESTIGATION

Determination of floor and footwear slip resistance is often conducted by measuring the friction force and calculating the coefficient of friction. Kinetic coefficient of friction is most often determined.

The requirements setting in the standard very often are not in compliance to the real conditions. For example in standard DIN 51130 specimens of floor material is the same material as the application, but footwear is special, and walking of test person is with low speed. Also, this way of walking on ramp isn't the same as walking on horizontal surface. In pendulum test sliders are made of materials with specific characteristics which are not similar to the shoe sole. The kinematic of pendulum isn't similar with kinematic of human walking/running, as well.

The 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.

Importance of dynamic and static coefficient of friction should be considered as the equal.

Based on the above, 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).

In order to estimate the laboratory test procedure and check the test conditions experimental research is performed at Faculty of Mechanical Engineering in Nis, Serbia.

Principle of determining the friction coefficient in performed experimental research is measuring the pulling force. 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.

Materials of sliders were shoe sole made of rubber and leather (three pieces with dimensions 10x40 mm) cut from the real shoes. Experimental samples of flooring covers were three different materials: laminate, ceramic tiles and linoleum (vinyl). Contact pressure was 91 kPa.

Sliding distance was 500-800 mm. Sliding velocities were: 2, 10, 50 and 250 mm/s.

Friction force was measured and coefficient of friction was calculated in experimental research. The test equipment is shown in Fig. 7.

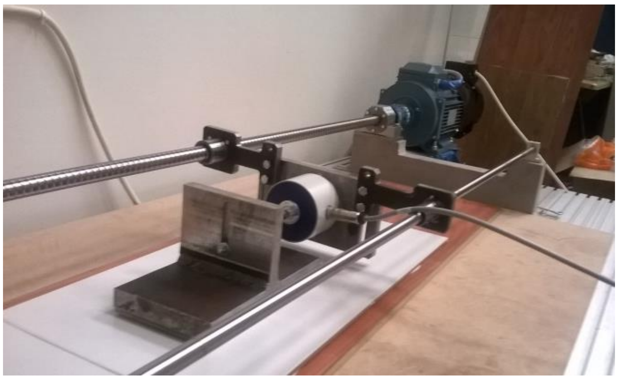

Fig. 7. Test equipment in laboratory at Faculty of mechanical engineering in Niš.

A typical example of measured friction force is presented in Fig. 8.

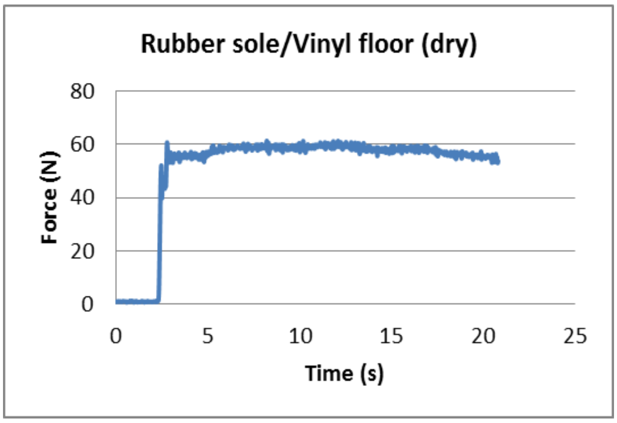

Fig. 8. Measured friction force in sliding rubber sole sample on vinyl floor covering.

Static and kinetic coefficients of friction were estimated during the experiment. There are significant differences between static and kinetic friction coefficient values in different type of contact and different conditions (Fig. 9). Static and kinetic friction coefficient values presented in Fig. 9 are average values of groups which consist of five measurements.

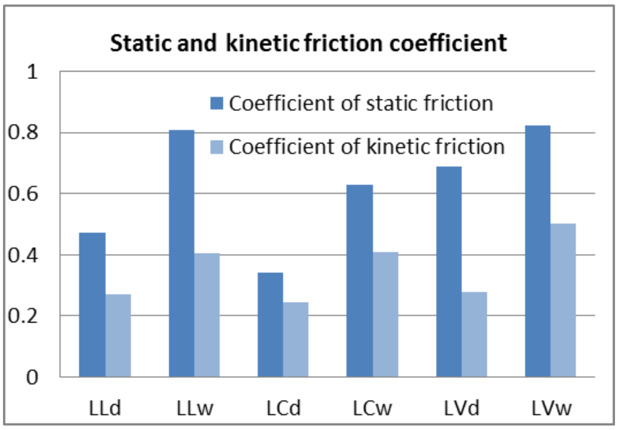

Fig. 9. Static and kinetic friction coefficient values (LL-leather-laminate; LC- leather-ceramic tile; LV-leather-vinyl; d-dry contact; w-wet contact).

In most cases the values of static friction coefficient is higher than kinetic friction coefficient. But in some situations static friction coefficient is equal or smaller than kinetic friction coefficient.

Investigation of different contact conditions and different material samples required numerous tests (measurements). Each contact case was tested five times. Deviations of friction coefficient values within the group of measurement were not so big. Figure 10 presents the maximum and minimum values of friction coefficients in testing the leader sole samples on floor coverings within the twelve groups of five measurements.

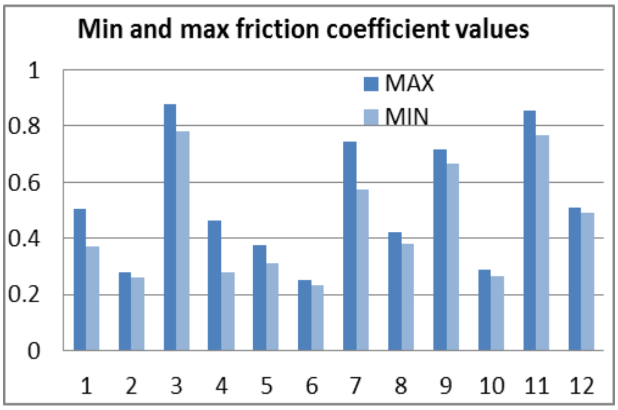

Fig. 10. Minimal and maximal experimental friction coefficient values.

Comparing the kinetic friction coefficient values in dry and wet condition it can be seen that values in wet condition are bigger in case of leader sole sliding on all types of flooring coverings (Fig. 11).

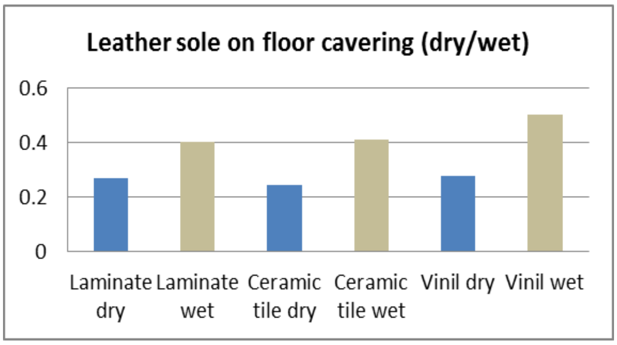

Fig. 11. Average values of kinetic friction coefficient values in case of leather sole samples.

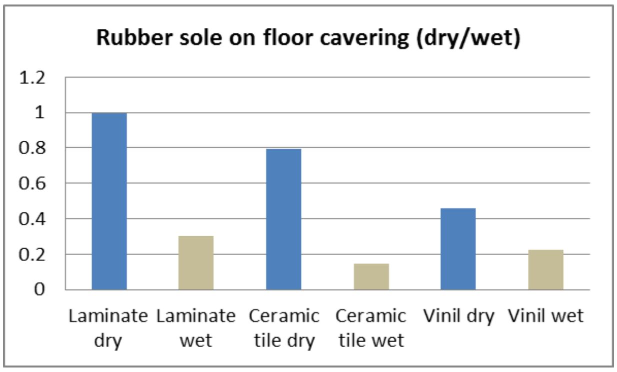

Fig. 12. Average values of kinetic friction coefficient values in case of rubber sole samples.

In contrast to the case of leather sole samples kinetic coefficient of friction in case rubber sole sliding is two to three times lower in wet condition according the dry condition (Fig. 12).

5. CONCLUSION

There are numerous causes of slip accident in human walking and they are mostly stochastical. The key activity in slip accident prevention is systematic examination of influential parameters and according that implementation the measures which are sufficient to prevent harm. But no one shoe sole design will be the best on all different types of surface and contaminants, and because of that it is necessary to investigate different combinations of materials and conditions.

Measuring (determining) of the friction coefficient should be conducted in conditions which are identical with real conditions. Measuring with different types of shoe sole (soft and hard; smooth and rough) should be conducted in cases where the substrate material is known. In order to provide environmental conditions that may occur in real conditions (sunny, very hot, cool, dry, wet-rain, wet-snow, etc.) on-site testing is preferably. If shoe material is known, flooring materials should vary with different properties of hardness, macro and micro texture, etc.

Evaluation of floor and footwear slip resistance should be based on recognition of the basic tribological parameters and their testing.

Assessment of the floor and shoe slip resistance should be based on the recognition of the basic tribological parameters for specific friction contact and their testing in application conditions.

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