Serbian Tribology Society

Faculty of Engineering
University of Kragujevac

SERBIATRIB '17

15th International Conference on Tribology

17 – 19 May 2017, Kragujevac, Serbia

PROCEEDINGS

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EDITOR: Slobodan Mitrović

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METHODS AND PRINCIPLES OF DETERMINING THE FOOTWEAR AND FLOOR TRIBOLOGICAL CHARACTERISTICS

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Abstract: 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.

Keywords: tribological characteristics, footwear, flooring, experimental methods, standards.

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.

Wetzel et al. [1] describe the requirements concerning the slip resistance and the state of art in slip resistance measurement standards in the European Union. 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 them for the producers of footwear and floors. 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 by the adhesion and hysteretic components.

There are different European standards that have adopted various test methods and rating systems [11-15]. 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 [8-9].

Basic factors influencing accidents and injuries in human walking can be divided in next groups: footwear, floor, human factors and environment (location) [10]. 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 surfaces, contaminants, etc.

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 Figure 1.

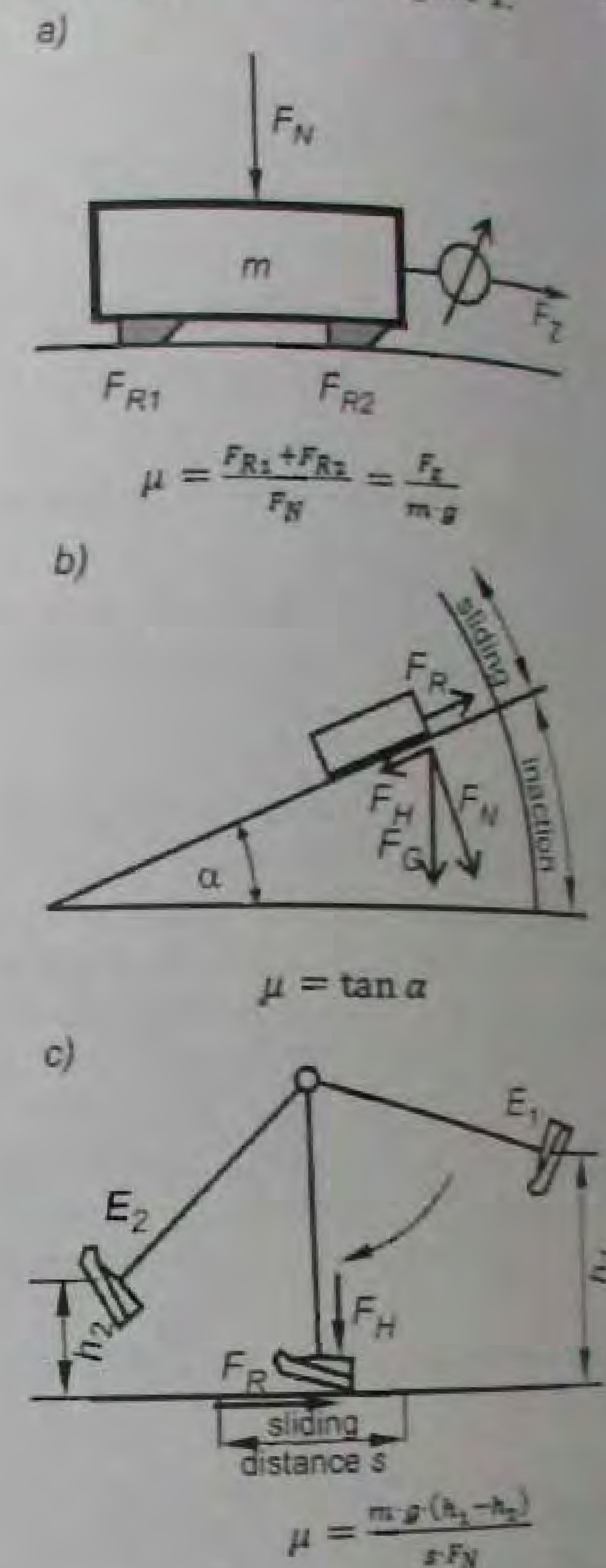

Figure 1. Friction coefficient determination by pulling force (a), friction angle (b) and energy loss (c)

Main principles of friction coefficient determination are the tests with measuring of the pulling force (Fig. 1a), where friction coefficient is ratio of pulling force (F_z) and pulled weight (*mg*); tests with measuring the friction angle (Fig. 1b), where friction coefficient is in function of friction angle (α) and tests with measuring of energy loss due to friction (Fig. 1c), where friction coefficient is a function of difference of potential energies (E1 – potential energy at the start, E2 – potential energy at the end of measurement).

Static and dynamic coefficient of friction

There are static and dynamic (kinematic) friction force and according to 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 more important than the static coefficient for an evaluation of slip resistance.

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 exceed 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, but 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 the wheels and the ground. In the same way static friction between shoes sole and floor coverings is necessary for human motion.

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 [5] 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, so the contact between rubber and hard material should be studied. Rubber friction differs in many ways from frictional friction differs in many ways from frictional properties of most other solids due to very low elastic modulus of rubber 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.

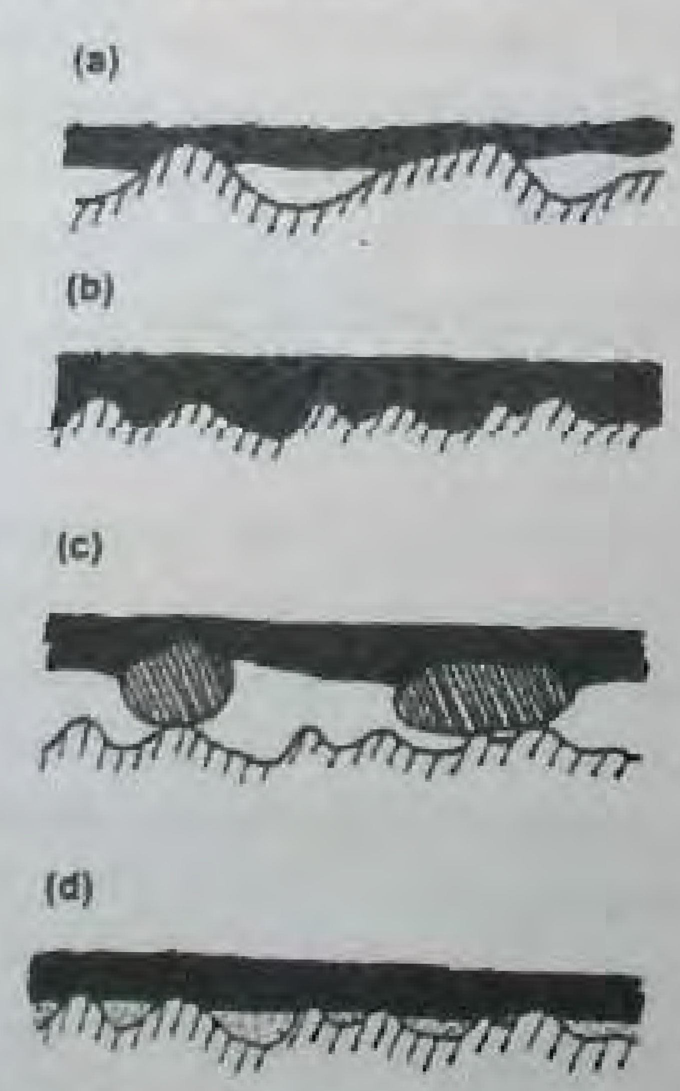

Figure 2. Rubber in contact with a hard substrate with a rough surface [7]

When a hard steel ball slides over a clean rubber surface 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 by the adhesion and hysteretic components [7].

Contact of rubber and hard substrate with a rough surface is presented in Figure 2 in different conditions [7]. Rubber on a hard substrate with long-wavelength surface roughness is shown in Figure 2a. Because of adhesion to the substrate, rubber in contact area deforms in to completely follow the short- wavelength surface roughness profile of the substrate (Figure 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 Figure 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 [8].

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 operating principle of ramp test is measuring of the friction angle; the principle of pendulum test is measuring the energy loses due 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 (Figure 3). The angle of the ramp is increased until the operator slips [11]. The acceptance angle obtained is used to assess the degree of slip resistance. In the ramp test (DIN 51097) the operator walks barefoot.

Figure 3. Ramp test

According the angle of ramp there are five classes 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 [12]. Pendulum friction tester is presented in Figure 4. It provides a standardized value of slip resistance. This is the pendulum test value (PTV).

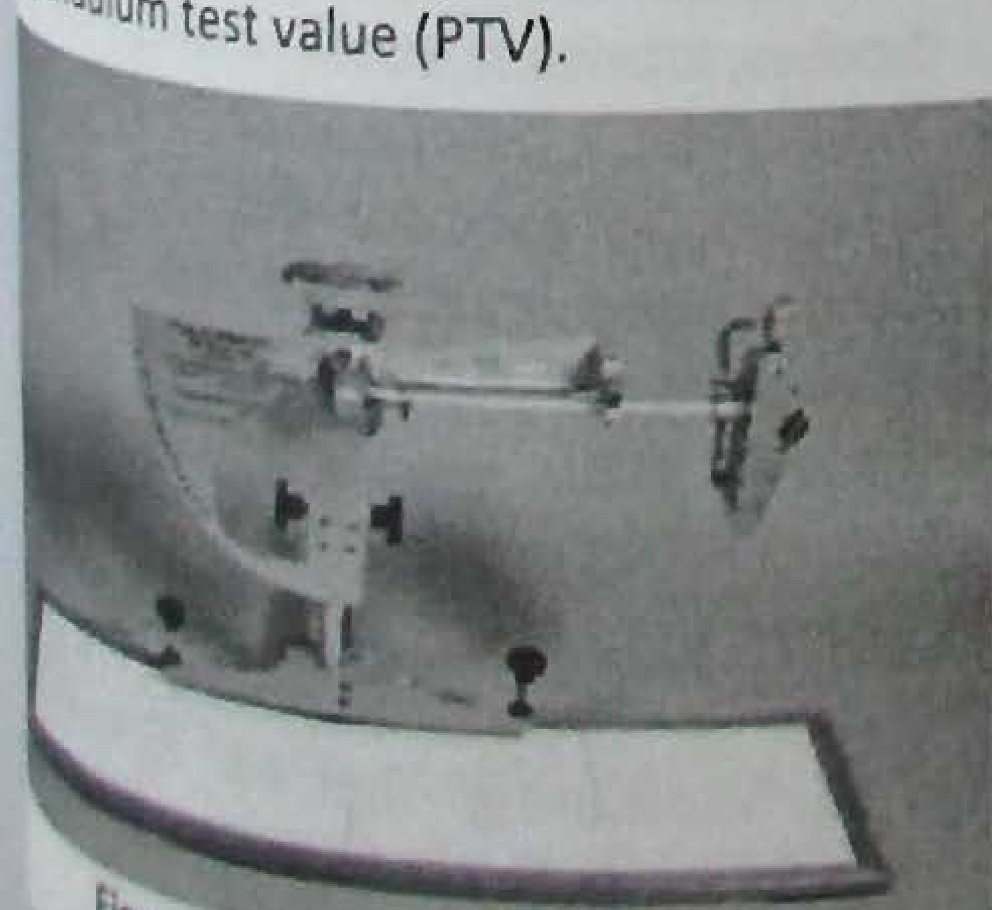

Figure 4. Pendulum friction tester

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. 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 is shown in Figure 5.

Figure 5. An example of a tribometer tester

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

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 [9].

The method for measurement of the slip resistance of shoes is described in EN 13287 [14]. The footwear to be tested is placed on the base of ceramic tile or steel floor, subjected to a given normal force (Figure 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. Dynamic (kinetic) coefficient of friction is the 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

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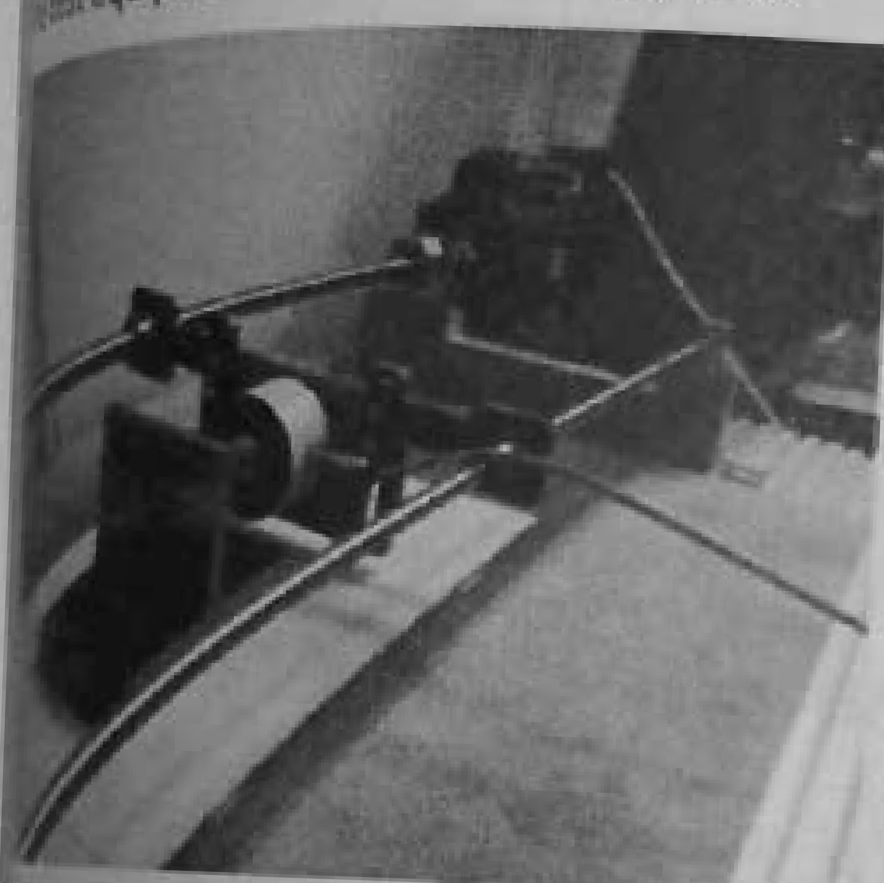
…rials of sliders were shoe sole made of … and leather (three pieces with …ions 10x40 mm) cut from the real … experimental samples of flooring covers … three different materials: laminate, … tiles and linoleum (vinyl). Contact … was 91 kPa.

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

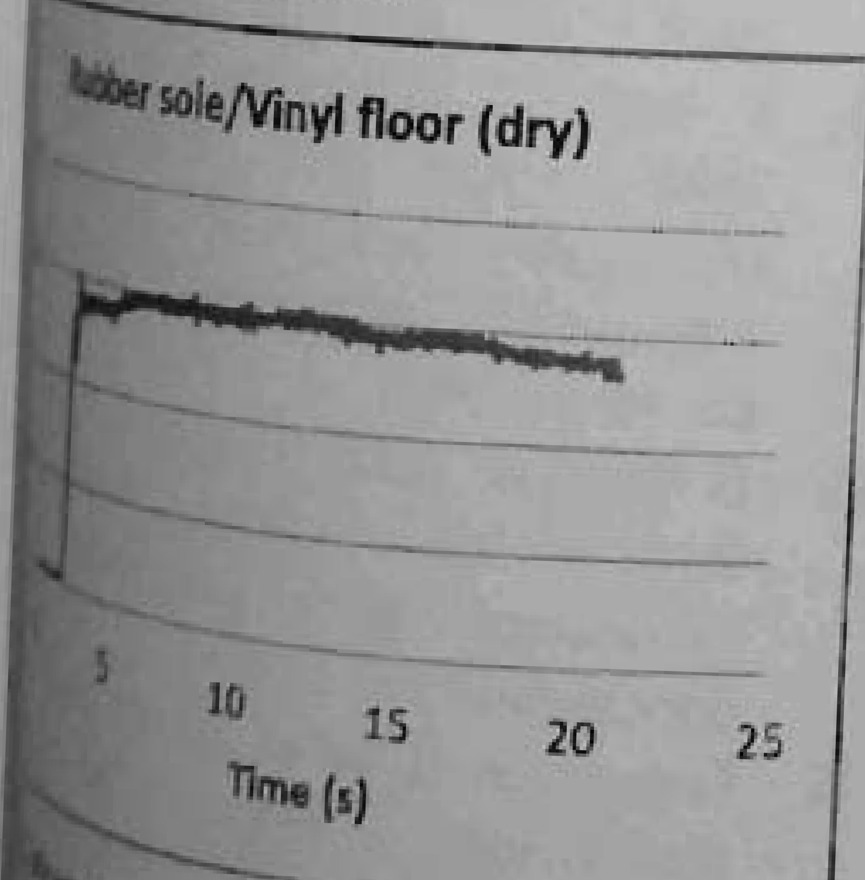
… force was measured and coefficient … was calculated in experimental …

… test equipment is shown in Figure 7.



…7. Test equipment in laboratory at Faculty of mechanical engineering in Nis

…ical example of measured friction … presented in Figure 8.



…ured friction force in sliding rubber …sample on vinyl floor covering

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

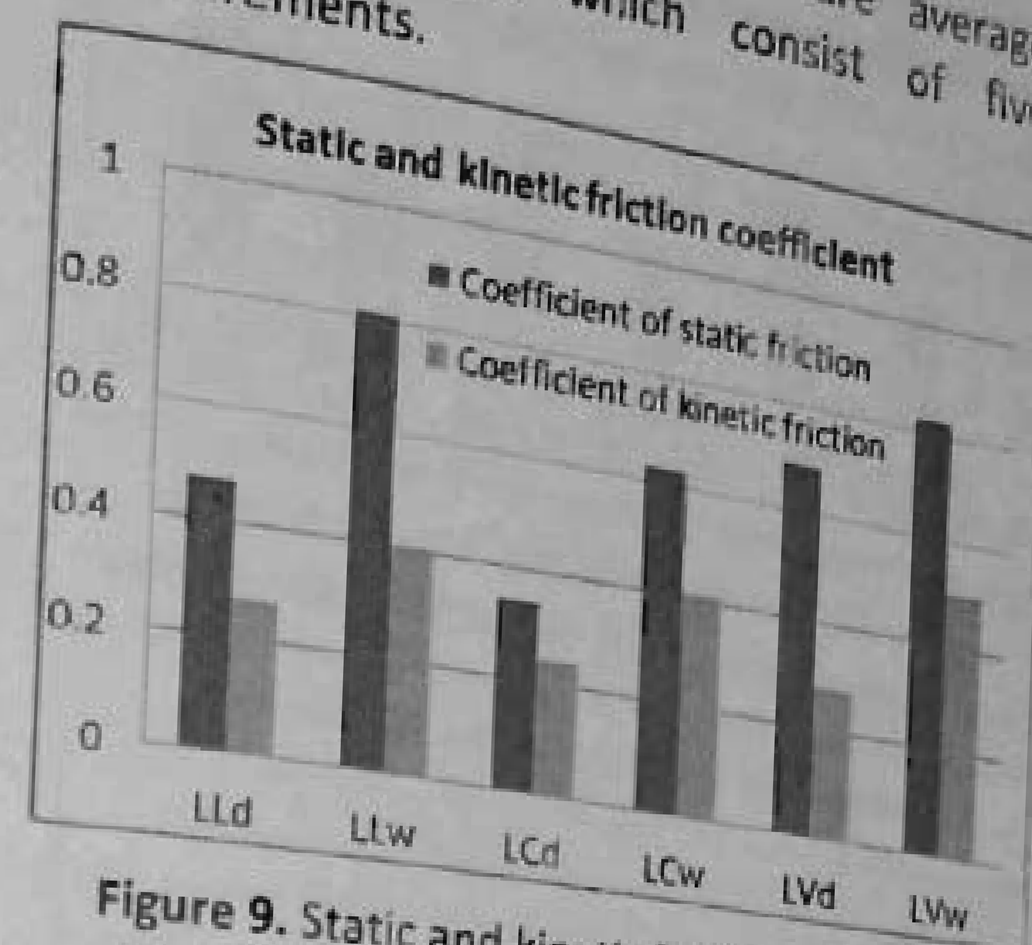


Figure 9. Static and kinetic friction coefficient values (LL-leather-laminate; LC- leather-ceramic tile; LV-leather-vinyl; d-dry contact; w-wet contact)

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.

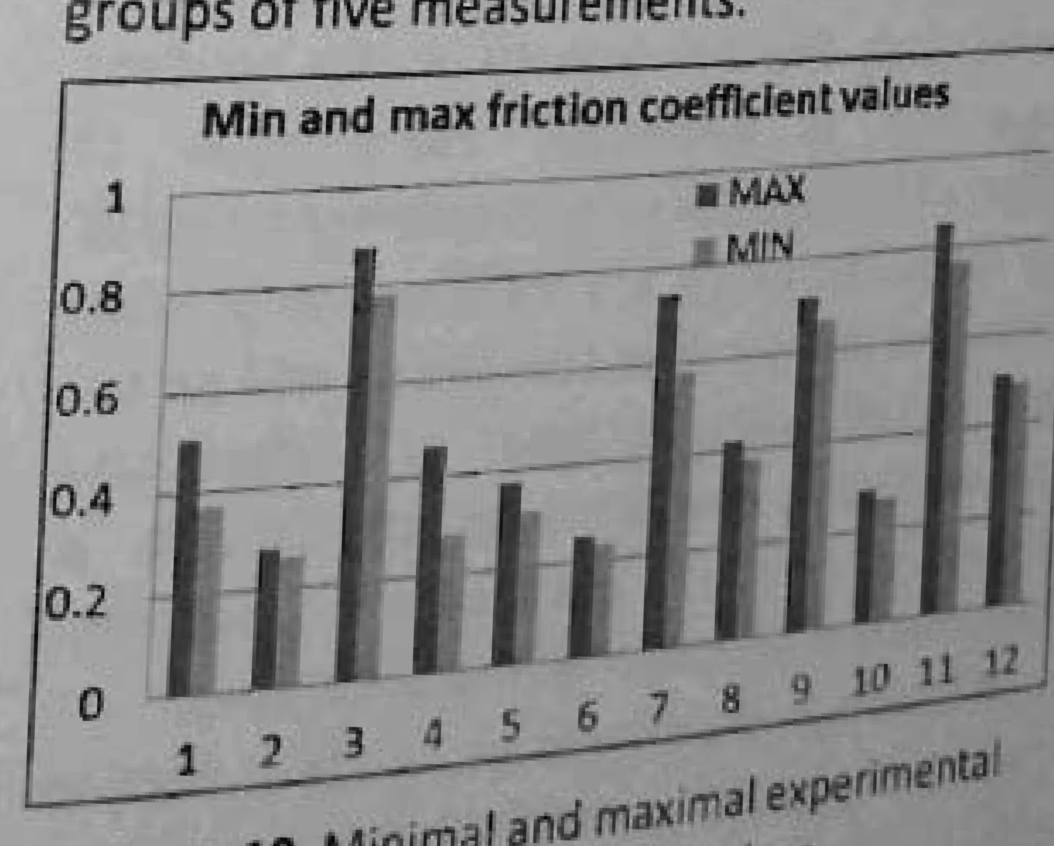


Figure 10. Minimal and maximal experimental friction coefficient values

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 (Figure 11).

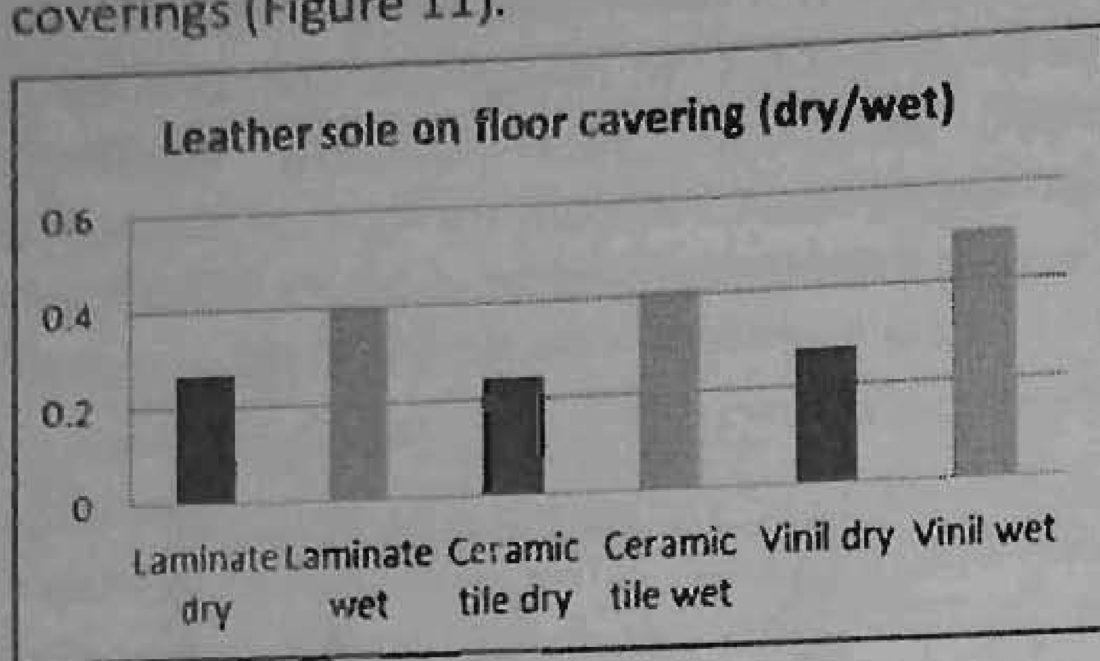


Figure 11. Average values of kinetic friction coefficient values in case of leather sole samples

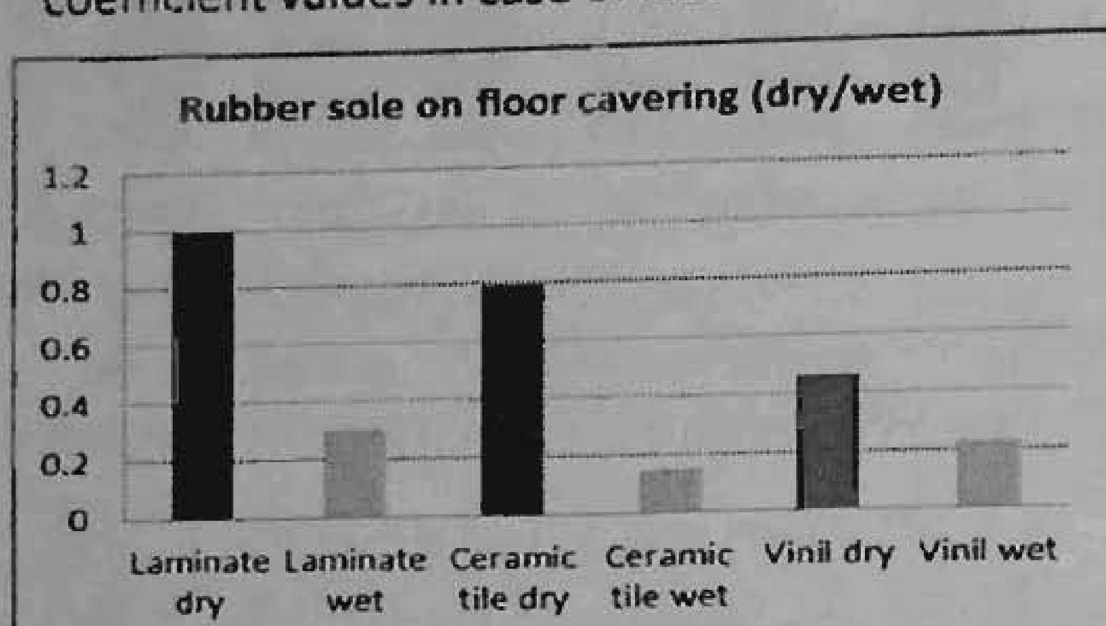


Figure 12. Average values of kinetic friction coefficient values in case of rubber sole samples

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 than for the dry condition (Figure 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 implementation of 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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A GRAPHIC ANALYTICAL MODELING LINEAR CONTACT BETWEEN STEEL AND COMPOSITE MATERIALS REINFORCED WITH GLASS FIBERS AT HIGH PRESSURES AND TEMPERATURES

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Abstract: *Issues of wear occur in the thermoplastic injection molds at high temperature and high speed injection so they can achieve a pressure of 100 MPa and temperatures of 210 ⁰C Steels used have been C120 which is used to make steel screws injectors and Rp 3 is a tool steel. In this article we are showing a graphical analytical modeling linear contact, between steel and composite materials reinforced with glass fibers (SGF) at high pressures and high temperatures, based on experimental determinations of the worn surface depending on the metal friction coefficient and the evolution of the temperature. The purpose is the evaluation of the dependence of the sliding speed and the load loading of the specimen, the amount of wear evaluated and measured depth of wear. The thermoplastic composite material transfer processes due to metal abrasion and corrosion, adhesion to the contact determined with Archard relationship by measuring the length of all using three points were determined graphically. A wear volume and depth of wear depending on load and contact pressure for different composite materials reinforced with glass fiber.*

Keywords: *contact temperature, friction coefficient, plastic material transfer, hardness of steel, steel surface wear, plastics with glass fibers, dry friction, linear contact.*

1. INTRODUCTION

The process of injecting thermoplastic materials for injection molding machines with auger is highly complex, including numerous factors which influence the wear of metal surfaces in permanent contact with the material at melting temperature. In the technical literature, the following wear factors for injection molding machines are known: the processing conditions (auger geometry, working temperature, working pressure), the steels used for fabricating the cylinder and the auger, the geometrical conditions between the cylinder and the auger.

In the injection process two conditions must be observed: the composite materials have different lubrication properties in molten state which, if not strictly observed, lead to an interruption of material feed in the cylinder and therefore to the increase of adhesion wear. The second condition for the process of filling the cylinder is that there should be no ares with molten material present or areas with partially molten material, as they will lead directly to an increase in the wear of metal surfaces coming into contact with the injected material.

Composite materials containing corrosive volatile elements are a special case. These

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