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FOOTWEAR SAFETY IN THE LIGHT OF SCIENTIFIC RESEARCH

BEZPIECZEŃSTWO UŻYTKOWANIA OBUWIA W ŚWIETLE BADAŃ NAUKOWYCH

Key words: friction, slippage, shoe soles.

Abstract: Improving living conditions and developing medical care contributes to increasing human life expectancy. Because motor skills decrease with age, older people need comfortable shoes that provide a high level of safety. The soles should not deform during temperature changes, they should have appropriate thermal insulation properties and a good grip to dry, wet, and dirty floor surfaces, as slips usually occur on surfaces covered with ice, water, oil, grease, mud, etc.

During the use of footwear, the friction coefficient is important. It depends on various factors, including: the type of a polymer matrix, auxiliary agents, the shape of the tread, the hardness of the sole, stiffness, wettability, and pressure. From the point of view of the footwear safety, the type of the sole material, its construction, especially the profile of the sole, the shape of the heel, and the thickness of the sole, as well as the method of use, are important.

The types of rubbing surfaces (their structures, physical properties), the temperature of the contacting bodies, and the type of the substrate have a significant impact on friction. The assumption and purpose of the article was to compare the methods for determining the coefficient of friction between the shoe soles and walking surfaces used in scientific research around the world in relation to the methodology developed in Poland.

Słowa kluczowe: tarcie, poślizg, spody obuwnicze.

Streszczenie: Poprawa warunków życia oraz rozwój opieki medycznej przyczyniają się do zwiększenia długości życia człowieka. Ponieważ sprawność motoryczna zmniejsza się wraz z długością życia, osoby w wieku dojrzałym potrzebują obuwia wygodnego i zapewniającego wysoki poziom bezpieczeństwa. Podeszwy nie powinny odkształcać się przy zmianach temperatury, powinny wykazywać odpowiednie właściwości termoizolacyjne oraz odporność na poślizg zarówno w warunkach suchych, jak i na powierzchniach mokrych i zabrudzonych. Poślizg obuwia występuje zwykle na podłożach oblodzonych, zwilżonych wodą, olejami, smarami, błotem itp.

Podczas użytkowania spodów obuwia istotne znaczenie ma współczynnik tarcia, który zależy od wielu czynników między innymi od: rodzaju matrycy polimerowej, środków pomocniczych, kształtu bieżnika, twardości spodu, sztywności, zwilżalności oraz nacisku. Z punktu widzenia bezpieczeństwa użytkowania obuwia istotne znaczenie ma rodzaj materiału spodu, jego konstrukcja, a szczególnie profil podeszwy, kształt obcasa i grubość podeszwy, a także sposób użytkowania. Znaczny wpływ na tarcie wywierają rodzaje trących powierzchni (ich struktura, właściwości fizyczne), temperatura oraz rodzaj podłoża.

Założeniem i celem artykułu było porównania metod określania współczynnika tarcia pomiędzy spodem obuwia a podłożem stosowanych w badaniach naukowych na świecie w odniesieniu do metodyki opracowanej w Polsce.

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INTRODUCTION

The concept of footwear safety should be understood as walking stability improved as a result of a higher coefficient of friction between the shoe sole and the walking surface, which protects shoes from slipping and guarantees higher footwear safety.

The phenomenon of slipping is related to different values of the coefficient of static and kinetic friction, with materials characterized by a higher coefficient of static than kinetic friction in combination with walking surface materials. Slipping typically results in falls, frequently culminating in injuries, particularly when unfavorable factors, such as the presence of water, lubricants, or solid impurities (such as sand or stones), impact the tribological characteristics of the sole-ground system. Wet pedestrian pathways often lead to severe accidents, particularly involving seniors and individuals with lower limb disorders. This is due to a sudden and unexpected decrease in the adhesion of footwear to the ground. Ensuring a high coefficient of friction between the sole and the walking surface on a variety of ground types and conditions (e.g. wet surfaces) determines the footwear safety **[L. 1–5]**.

Data published in the United States show that over 16% of workplace accidents were caused by falls and dislocations of lower limbs, with half of them occurring on a straight road. This resulted in insurance companies paying out over $2.5 billion in workers' compensation **[L. 6]**. In addition to these costs, slip accidents resulted in employees being on sick leave and hospitalized, leading to additional problems in the workplace and contributing to the increase in the costs of such injuries. In 2019, slip accidents were the leading cause of workplace fatalities in the United States.

Tests of the coefficient of friction between the sole of the footwear and the walking surface are usually carried out using methods that do not consider the basic factors affecting the obtained results. Most testers allow testing of shoe soles in combination with a standard surface, and do not analyze the presence of contaminants or tread structure **[L. 7–11]**. The occurrence of the skin phenomenon on the elastomer surface following the injection process significantly influences the results obtained during the boiling test of base material samples. Therefore, the best way to conduct research is to obtain samples from ready-made shoe soles or to conduct research on a commercial product, i.e. generally available ready-made footwear combined with real substrate materials.

RESEARCH CONDUCTED WORLDWIDE

The available literature on footwear safety shows that the tests are based on laboratory methods, most often taking into account the preparation of samples from sole materials and sometimes taking into consideration the structure of the tread, in combination with the selected floor material. The research described by Indian researchers **[L. 1]** involved making test samples on their own in silicone molds obtained by 3D printing and then casting polyurethane samples in them. When obtaining silicone molds, the tread shapes of selected shoe soles were considered. The samples prepared in this way were tested on a British pendulum tester for determining the coefficient of friction shown in **Figure 1**. Smooth and matte ceramic tiles were used as a counter-sample; the tests were carried out without the use of a lubricant and by introducing lysol (a chemical agent used to disinfect ceramic surfaces) and oil.

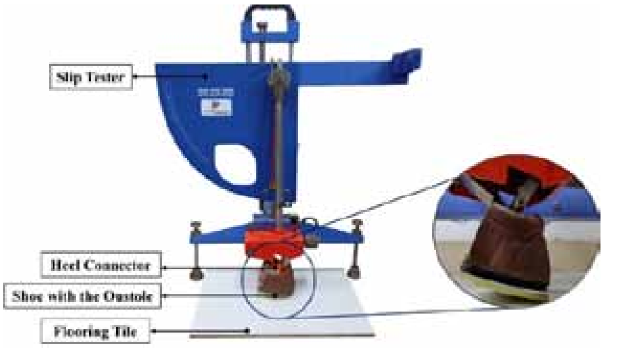

Fig. 1. British pendulum skid resistance tester
Fig. 1. Tester wahadłowy do badania współczynnika tarcia produkcji angielskiej

It should be noted that the obtained results only approximately determine the dependence of the coefficient of friction on the structure of the tread of polyurethane soles in combination with a ceramic substrate. The oscillating movement of the arm of the testing machine in no way reflects the actual operating conditions of the footwear, and determining the coefficient of friction based on the angle of inclination of the machine arm is also an approximate result and subject to error. An additional unfavorable factor influencing the discrepancy between the obtained results and the actual operating conditions is the independent production of test samples. Although the way the tread structure is reflected deserves recognition, casting polyurethane in laboratory conditions gives a product with completely different operating parameters than industrially obtained shoe soles. Therefore, the results obtained using this methodology can be used to verify the structure and shape of the tread in relation to the coefficient of friction in combination with a ceramic substrate. Another drawback of this method is the very high labor intensity and cost of preparing and producing test samples. Additionally, this method will make it difficult to perform tests on other sole materials, such as rubber soles, natural leather, or thermoplastics.

RESEARCH METHODS DEVELOPED IN POLAND

Research on the friction and wear characteristics of shoe soles in combination with typical substrate materials has been carried out in Poland for many years. As a result, laboratory research methods, considering actual materials used for shoe soles cooperating with typical substrates and technologically advanced research devices enabling the determination of wear and coefficient of friction of finished footwear in combination with any substrate under real operating conditions, were developed.

Comprehensive tests of shoe sole materials are conducted in multiple stages, encompassing the initial selection of material combinations for both the shoe sole and the base material. The chosen material systems undergo rigorous laboratory testing using tribological testers. The final stage involves verifying the test results on a device that replicates actual operating conditions. The results of laboratory tests and measurements under real conditions of tribological characteristics of sole-ground associations have been described by the authors **[L. 12–14]**.

The first stage is carried out based on the developed methodology of preliminary verification of material associations before their friction tests **[L. 12]**, based on the energy state of the interacting surfaces. Thanks to this approach, one can quickly and cheaply select a large number of material combinations and, after selecting the most advantageous systems, proceed to time-consuming and expensive laboratory tests on tribological testers. In this way, the best sole materials for selected substrates (appropriate composition of the mixture for the soles of work shoes for employees of a metal processing factory, concrete substrate) can be chosen.

The next stage is laboratory testing on specially adapted tribological testers such as T-07, T-15; verification of the test results on these devices was carried out and described in the literature **[L. 13]**, and based on the obtained results, a database of tribological characteristics of typical materials used for shoe soles in combination with typical substrates under dry and wet friction conditions was created. Examples of test results for friction and wear characteristics are presented in **Figures 2–7**. The tests were conducted with the following parameters:

- linear speed (rotational) 0.27; 0.40; 0.53 m/s (200, 300, 400 rpm);
- load 0.06 MPa;
- friction distance 250 m;
- temperature up to 22 ^{O}C.

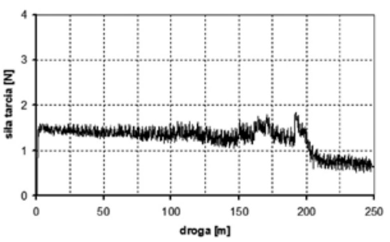

Fig. 2. Course of the friction force from the road for the skin-concrete connection, load 0.06 MPa, sliding speed 0.27 m/s

Fig. 2. Przebieg siły tarcia od drogi dla skojarzenia skóra – beton, obciążenie 0,06 MPa, prędkość poślizgu 0,27 m/s

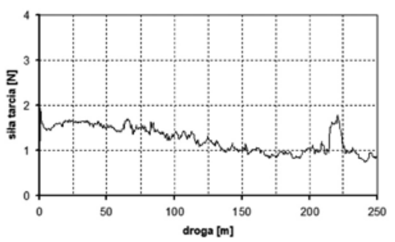

Fig. 3. Course of the friction force from the road for the skin-concrete connection, load 0.06 MPa, sliding speed 0.40 m/s

Fig. 3. Przebieg siły tarcia od drogi dla skojarzenia skóra – beton, obciążenie 0,06 MPa, prędkość poślizgu 0,40 m/s

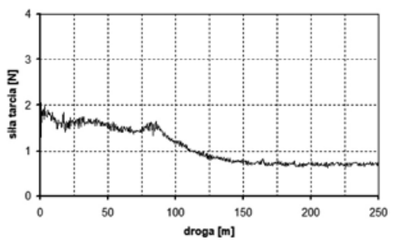

Fig. 4. Course of the friction force from the road for the skin-concrete connection, load 0.06 MPa, sliding speed 0.53 m/s

Fig. 4. Przebieg siły tarcia od drogi dla skojarzenia skóra – beton, obciążenie 0,06 MPa, prędkość poślizgu 0,53 m/s

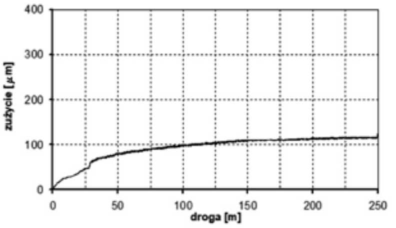

Fig. 5. Wear course from the road for the skin-concrete combination, load 0.06 MPa, sliding speed 0.27 m/s
Fig. 5. Przebieg zużycia od drogi dla skojarzenia skóra – beton, obciążenie 0,06 MPa, prędkość poślizgu 0,27 m/s

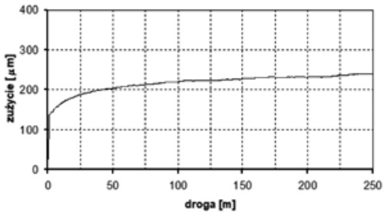

Fig. 6. Wear course from the road for the skin-concrete combination, load 0.06 MPa, sliding speed 0.40 m/s
Fig. 6. Przebieg zużycia od drogi dla skojarzenia skóra – beton, obciążenie 0,06 MPa, prędkość poślizgu 0,40 m/s

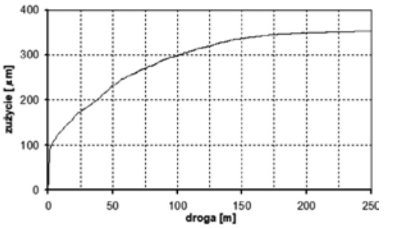

Fig. 7. Wear course from the road for the skin-concrete combination, load 0.06 MPa, sliding speed 0.53 m/s
Fig. 7. Przebieg zużycia od drogi dla skojarzenia skóra – beton, obciążenie 0,06 MPa, prędkość poślizgu 0,53 m/s

The presented friction and wear characteristics are stable for the entire speed range in which the tests were carried out. Similarly stable curves were recorded for various surface pressures of the friction node.

The last stage of the comprehensive tribological tests of soles in combination with the substrate material are tests carried out using commercially available ready-made footwear, in combination with the actual substrate, on the modern T-31 research stand developed at the Łukasiewicz Research Network – Institute for Sustainable Technologies (formerly: Institute for Sustainable Technologies – National Research Institute) in Radom **[L. 14]**. The research device presented in **Figure 8** allows determining the tribological characteristics of footwear in combination with any surface. In the full range of walking speeds, sliding speed and surface pressures can be forced. Various walking styles can be simulated (e.g. "Indian

Fig. 8. Photograph of the T-31 Simulator for friction and wear testing of materials intended for shoe soles [L. 14]
Rys. 8. Zdjęcie symulatora T-31 do badania tarcia i zużycia materiałów na podeszwy obuwia **[L. 14]**

walk", increased pressure on the heel or toes) and any impurities can be introduced into the friction zone. All parameters are program-controlled, and the forces are measured using digital sensors installed in the device.

The tests carried out on the T-31 simulator are based on the developed method for testing friction and durability of footwear. They are characterized by good repeatability and resolution, allowing the identification and distinction of friction properties and abrasion resistance of different types of footwear soles working with different surfaces. Additionally, the device is devoid of the disadvantages of other testing methods such as: ASTM D 1630, ASTM G 195, or ASTM D 1894.

SUMMARY

The presented research methodologies and devices developed at the Łukasiewicz Research Network – Institute for Sustainable Technologies (formerly: Institute for Sustainable Technologies – National Research Institute in Radom) allow for the determination of friction characteristics of base materials that are almost to obtain using methods previously used. They enable the measurement of the friction of various materials used for shoe soles in combination with various flooring materials. They also make it possible to change friction conditions, i.e. pressure, sliding speed, temperature, and the type of medium in which the materials are tested. The different results obtained using them for various combinations of the sole material-floor material system indicate the need to select appropriate shoe materials depending on the type of the floor, as well as the purpose of the footwear, which determines the parameters of the friction process (user's weight, conditions of use). The developed devices can be used by manufacturers of shoe soles to increase the footwear safety by selecting the most advantageous sole material ensuring the best friction properties, depending on the type of the base material and environmental conditions.

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