ISSN 0208-7774 TRIBOLOGIA 6/2020 p. 71–75
DOI: 10.5604/01.3001.0014.8339

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TRIBOLOGICAL CHARACTERISTICS OF POLYURETHANES USED FOR THE SOLES OF FOOTWEAR

CHARAKTERYSTYKI TRIBOLOGICZNE POLIURETANÓW STOSOWANYCH NA SPODY OBUWIA

Key words: friction coefficient, wear, polyurethane, soles.

Summary: The inability to take into account the type of base material (floor, pavement, soil), as well as the inability to take into account the variable friction conditions – load, intermediary medium (water, loose abrasive, sand or other soil particles), sliding velocity, and ambient temperature – is a significant limitation the use of friction methods and devices used so far in the footwear industry to precisely anticipate the behavior of the bottom materials in the actual operating conditions of the footwear.
These limitations prompted the authors to adapt a tribological tester for this purpose, used in the area of construction and operation of machines and material engineering. A research methodology was developed and, in order to verify it, measurements of the coefficient of friction and wear of polyurethane used for shoe soles in combination with a raw and varnished wooden substrate were carried out.
The obtained test results are characterized by diversity, which proves the high research resolution of the developed method. It allows determining the coefficient of friction of associations influencing the slip of the footwear and the wear and tear that determines the length of use of the footwear.

Słowa kluczowe: współczynnik tarcia, zużycie, poliuretan, podeszwy.

Streszczenie: Brak możliwości uwzględnienia rodzaju materiału podłoża (posadzka, podłoga, nawierzchnia, grunt), jak też brak możliwości uwzględnienia zmiennych warunków tarcia – obciążenia, medium pośredniczącego (woda, luźne ścierniwo, piasek lub inne cząstki gruntu), prędkości poślizgu, temperatury otoczenia stanowi istotne ograniczenie wykorzystania metod i urządzeń tarciowych stosowanych dotychczas w przemyśle obuwniczym do precyzyjnego antycypowania zachowania się materiałów spodowych w rzeczywistych warunkach eksploatacji obuwia.
Ograniczenia te skłoniły autorów do przystosowania do tego celu testera tribologicznego, wykorzystywanego w obszarze budowy i eksploatacji maszyn oraz inżynierii materiałowej. Opracowano metodykę badawczą oraz w celu jej weryfikacji przeprowadzono pomiary współczynnika tarcia i zużycia poliuretanu stosowanego na podeszwy obuwia w skojarzeniu z podłożem drewnianym surowym i lakierowanym.
Otrzymane wyniki badań charakteryzują się zróżnicowaniem świadczącym o dużej rozdzielczości badawczej opracowanej metody. Pozwala ona określać współczynnik tarcia skojarzeń mający wpływ na poślizg obuwia oraz zużycie decydujące o długości eksploatacji obuwia.

INTRODUCTION

The processes taking place in the area of contact between two rubbing elements are significantly related to the properties of the materials used. The use of polymers as construction materials is steadily increasing, with most of them relating to the construction and operation of machines. They can replace metal, and they can even exceed them with their properties **[L. 1–4]**. Due to the modification, it is possible to improve certain properties

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of polymer materials, e.g., strength, friction coefficient, wear resistance, and heat resistance. For this reason, plastics are commonly used in the production of shoe soles, which are one of the most important elements responsible for the safety, durability, and comfort of footwear use.

The intended use of the footwear, and the resulting various types, as well as the systems of connecting the soles with the upper, set appropriate requirements when choosing materials for the soles. The selection of materials for the soles depends on many factors, including resistance to multiple bending, abrasion resistance, water absorption, elasticity, intended use, and the method of assembly **[L. 3–7]**. The soles should not deform with temperature changes, and they should exhibit appropriate thermal insulation properties and demonstrate adequate skid resistance, both on dry, wet, and dirty surfaces **[L. 7–12]**. Footwear skidding usually occurs on icy surfaces, moistened with water, oils, greases, mud, etc.

When using the soles of footwear, the friction coefficient is important, which depends on many factors, including the type of polymer matrix, auxiliary agents, surface profiling and roughness, the hardness of the bottom, stiffness, wettability, and pressure **[L. 9, 10, 12]**. By reducing the hardness and increasing the flexibility of the soles, one can increase the friction coefficient on the dry surface. In the case of dirty or soft surfaces, reducing the hardness of the bottom may reduce the coefficient of friction **[L. 2]**.

Therefore, the criteria for selecting materials for the components of the shoe sole are very strict and take into account the fact that the components of the sole play a very important role during the use of footwear. In order to meet these requirements, the soles of footwear are primarily made of synthetic polymers, with polyurethanes having favorable mechanical properties, because they are friction-resistant, light, absorb vibrations, and have good adhesion to the upper parts of the footwear.

Polyurethanes (PU) are a group of polymers with the most versatile properties, and the scope of their application is constantly expanding. The greatest use of polyurethanes is as foams and adhesives, and this direction determines their application in the footwear industry. Semi-rigid foams used for the production of shoe soles ensure comfort and safety, and rigid foams ensure the lightness and durability of the structure and good insulation properties.

Despite such favorable properties of polyurethane soles, there are no reliable friction tests that would allow one to determine their resistance during operation on various surfaces. It is a parameter that determines, not only the strength of the footwear, but also the safety related to the phenomenon of slippage, which is particularly important in the case of elderly people and people with motor apparatus disorders **[L. 2, 6–8]**.

The presented research was aimed at verifying a new method of determining the tribological characteristics of the footwear bottom materials in combination with the surface being traversed.

SUBJECT AND METHODOLOGY OF RESEARCH

The research covered polyurethanes applied to the soles of footwear in frictional combination with a wooden substrate. The polyurethane samples were cut from a commercial raw material with a hardness of 70°

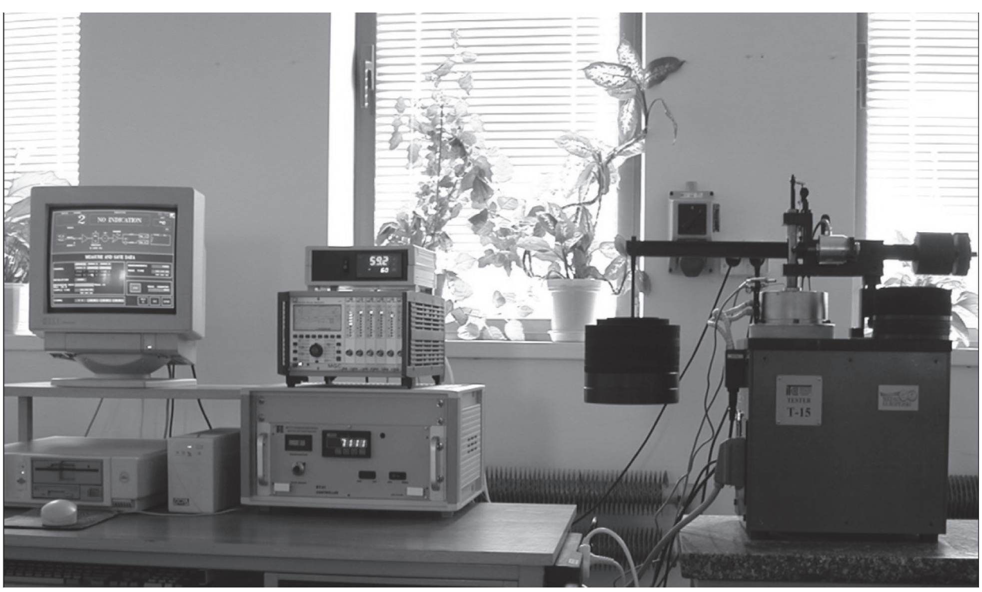

Fig. 1. View of the test stand
Rys. 1. Widok stanowiska badawczego

Sh A obtained by polymerizing a diisocyanate (TDI diisocyanate isomer mixture) with polyols (polyester). Wooden counter-samples with a moisture of 9% were cut from commercial parquet planks of a domestic producer. Commercial polyurethane varnish of Polish production was used for varnishing the wood. The tests were carried out on the T-15 test stand (**Fig. 1**) of the ring-disc type, produced by the Institute of Sustainable Technology – National Research Institute **[L. 13]**, enabling the use of test elements made in a simple way and conducting tests in a distributed contact at different sliding speeds. Three test runs were performed for each combination. Tribological tests were carried out at room temperature (approx. 22ºC) and humidity, which did not change by more than 5%.

The research carried out took into account the influence of the sliding speed on the friction coefficient and the wear intensity (determined by the weight method) of polyurethane materials in combination with a wooden substrate, taking into account typical varnish coatings. The tests were carried out at sliding speeds corresponding to slow walking, a standard human movement speed, and fast, vigorous walking.

The samples shown in **Fig. 2** were used for the study: polyurethane used for soles and two types of wood: deciduous – beech, and coniferous – pine, and varnished deciduous and coniferous wood.

For each combination, three runs were carried out at three different speeds: 0.2, 0.3, and 0.4 m/s, with a constant load of 0.03 MPa (corresponding to surface pressure exerted by a human on the ground) and a friction path of 250 m.

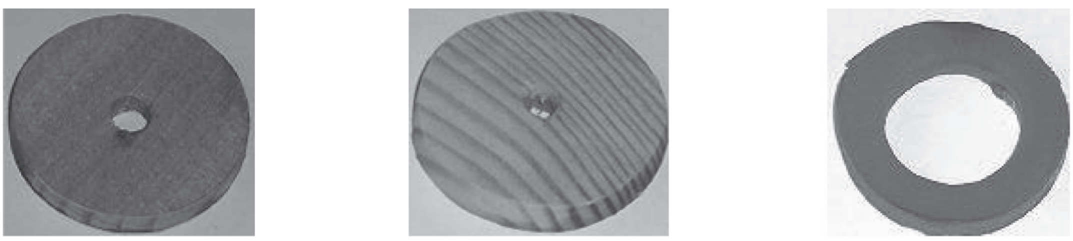

Fig. 2. Samples used for the investigation
Rys. 2. Próbki użyte do badań

The test result was the average of at least three test runs, the size of which did not contain the results requiring exclusion using the Dixon test.

The parameters of the main tests were selected on the basis of preliminary tests, so that they correspond to the actual conditions of footwear operation and that the obtained tribological characteristics were characterized by a stable course. **Figures 3** and **4** present selected runs of the frictional characteristics obtained for the lowest and highest sliding speed for the same friction path during preliminary tests.

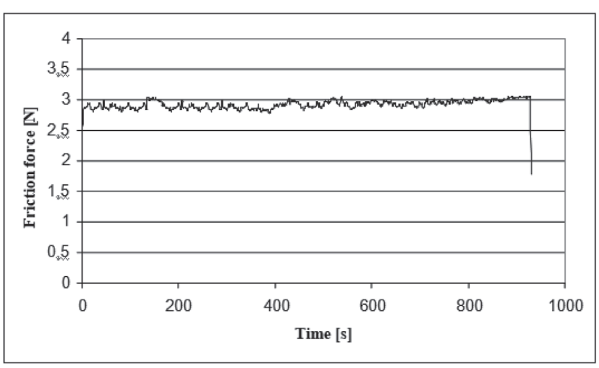

Fig. 3. Changes in the friction force for the polyurethane-varnished wood pair at the speed of 0.2 m/s
Rys. 3. Przebieg zmienności siły tarcia dla skojarzenia poliuretan–drewno lakierowane przy prędkości 0,2 m/s

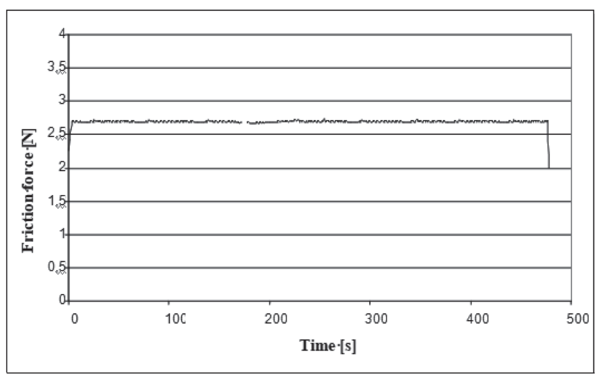

Fig. 4. Changes in the friction force for the polyurethane-beech pair at a speed of 0.4 m/s
Rys.4. Przebieg zmienności siły tarcia dla skojarzenia poliuretan–buk przy prędkości 0,4 m/s

The relationships shown in the figures are characterized by a stable course, which proves that there are no factors that would interfere with the cooperation of the studied associations.

RESULTS AND DISCUSSION

The results of the measurements of the friction force of the tested material systems in relation to the slip velocity are presented in the diagrams (**Figs. 5** and **6**), while the results of the wear measurements are presented in the diagrams in **Figs. 7** and **8**.

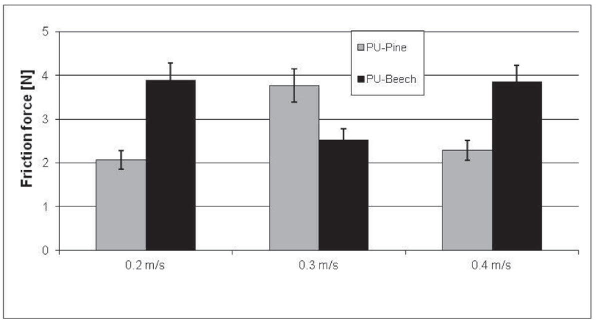

Fig. 5. The magnitude of the friction force of the PU–pine and PU–beech at different speeds

Rys. 5 Wielkość siły tarcia skojarzenia PU – sosna i PU–buk przy różnych prędkościach

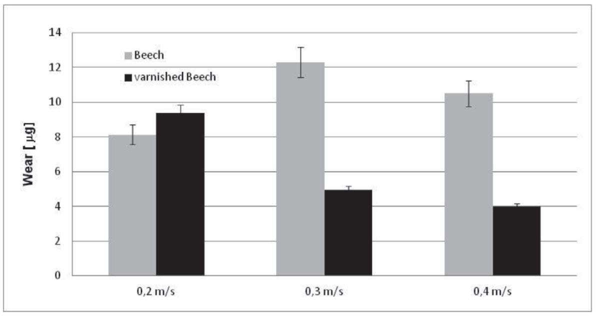

Fig. 7. Comparison of wear results for PU–beech and PU–varnished beech combinations

Rys. 7. Porównanie wyników zużycia wagowego skojarzeń PU–buk i PU–buk lakierowany

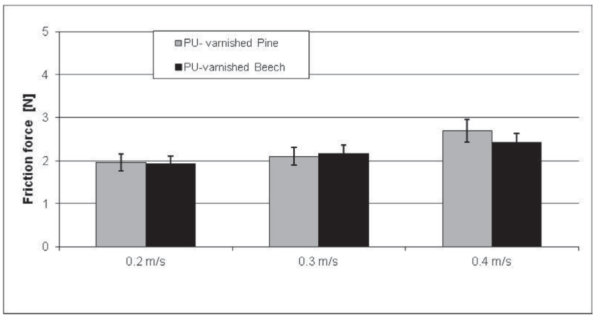

Fig. 6. The magnitude of the friction force of the PU – varnished pine and PU – varnished beech at different speeds

Rys. 6 Wielkość siły tarcia skojarzenia PU–sosna lakierowana i PU–buk lakierowany przy różnych prędkościach

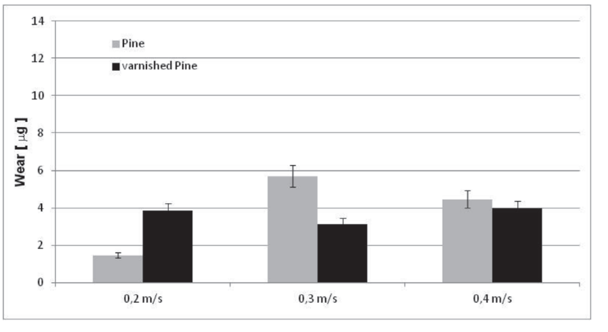

Fig. 8. Comparison of wear results for combinations PU–Pine and PU–Varnished pine

Rys. 8. Porównanie wyników zużycia wagowego skojarzeń PU–sosna i PU–sosna lakierowana

When analyzing the obtained results, it should be stated that the friction force of the polyurethane-wood associations, apart from the sliding speed, is also influenced by the type of wood, and strictly – by its hardness. In the case of beech, the highest friction force was recorded for extreme speeds; an inverse relationship was observed for pine, and the highest friction force was measured for the speed of 0.3 m/s **Fig. 5**.

For hardwood with a varnish coating, a slight increase in the friction force was noted with an increase in the sliding speed, while the application of the varnish coating contributed to the reduction of the friction force in relation to raw wood (**Figs 5** and **6**). In the case of pine wood, the application of the varnish layer had a small effect on the increase of the friction force along with the increase of the sliding speed. Regarding raw wood, at the lowest speed, varnishing does not affect the friction force. A slight increase in the friction force was recorded for the highest speed, and a significant decrease was recorded for the speed of 0.3 m/s, after applying the varnish coat.

Interesting relationships were noted for the tested material combinations when determining the consumption of polyurethane in combination with a wooden substrate. In the case of hard wood (beech), the lowest wear was recorded for the speed of 0.2 m/s. However, a further increase in speed resulted in an increase in polyurethane consumption, and then a slight decrease for the highest speed. After the paint coating was applied, the PU wear decreased with the increase of the sliding speed. For the material system of polyurethane softwood (pine), similarly to the combination polyurethane–beech, the lowest wear was recorded for 0.2 m/s, then an increase was recorded at a speed of 0.3 m/s and a slight decrease was recorded for the highest speed. The application of the varnish coating contributed to the unification of the wear volume of the tested material combinations for extreme speeds, and a slight decrease was noticed for the speed of 0.3 m/s.

SUMMARY

The conducted research allow us to conclude that the use of modern tribological devices to determine the friction and wear characteristics of sole materials in combination with various base materials allows one to conduct tests in conditions similar to the actual conditions of footwear operation. The obtained research results are characterized by diversity, which proves the high resolution of the developed research methodology. Based on the obtained friction characteristics, it is possible to assess the safety of using the tested combinations in terms of the occurrence of shoe slip, which is currently one of the main aspects of the development of footwear soles in the world.

The highest friction coefficient was recorded for the combination of polyurethane with raw beech up to extreme sliding velocities and for the combination with pine wood for the speed of 0.3 m/s. The application of a varnish layer contributes to the reduction of the friction force of polyurethane in combination with the tested types of wood for all tested speeds. A slight deviation was noted for the combination of polyurethane pine, for which the application of the varnish coat to the pine surface caused a slight increase in the friction force.

For both types of wood, the application of the varnish coating resulted in an increase in polyurethane consumption for the lowest speed and a significant reduction in wear for the remaining sliding velocities, with the differences being greater for the beech substrate than for pine.

Measurements of friction, according to the methodology proposed by the authors of various materials used for the soles of footwear in combination with various flooring materials, under various friction conditions, i.e. pressures, sliding velocity, temperature and the type of medium surrounding the tested materials, enable the selection of materials for the soles of footwear, thus limiting the possibility of creating slip, which provides the highest possible level of safety and the longest possible service life of the footwear.

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