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Influence of tribotesting on microhardness of polymers

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Abstract

This study investigates the microhardness of the polymeric material Zedex zx-100k and other polymers following tribological testing at different sliding speeds. The primary objective of this research is to select polymers for potential use in composite materials. Microhardness was determined using a ПМТ-3 microhardness tester by indenting diamond indenters into samples in various zones – on the initial surface of the material and in the wear area. The results obtained allow evaluating the influence of sliding speed on the change in microhardness of the polymeric material and its behavior under wear conditions. Additionally, the results enable comparison of different polymers tested on a tribometric setup with subsequent assessment of their physical characteristics.

The research highlights the importance of understanding the tribological properties of polymers, as these materials are increasingly being used in various industrial applications due to their favorable characteristics, such as low weight, cost-effectiveness, and chemical resistance. The selection of suitable polymers for composite materials is crucial for enhancing the performance and durability of products in which these materials are used.

Moreover, the study provides insights into the mechanisms of wear and the role of microhardness in the wear resistance of polymers. By analyzing the behavior of polymers under different sliding speeds, the research contributes to the development of more effective materials for engineering applications where high wear resistance is required. The findings suggest that optimizing the sliding speed can significantly impact the wear resistance and longevity of polymer-based components.

In conclusion, this study offers a comprehensive analysis of the microhardness of polymers subjected to tribological testing, providing valuable data for the selection and optimization of materials in composite applications. The methodology and results discussed in the paper can serve as a basis for further research aimed at improving the performance of polymeric materials in demanding operational environments.

Key words: polymers, microhardness, wear resistance, tribological properties, composite materials.

Introduction and statement of the research problem

This study examines the hardness of polymeric materials, which is defined as the ability of a material to resist localized surface deformation under indentation [1]. The hardness of a material can be interpreted in different ways depending on its properties. For example, if hardness is viewed as resistance to touch, steel is harder than rubber. However, if hardness is understood as the ability of a material to resist permanent deformation, then rubber can be considered harder than most metals because its range of elastic deformation is much wider.

Metals, despite having high elastic moduli, have a limited elastic range [2]. Therefore, during hardness testing, the deformation of metals mostly goes beyond the elastic range and turns into plastic deformation. In the case of polymers, the situation is even more complicated. Polymers can exhibit both elastic and plastic properties depending on their composition, operating conditions, and temperature [3]. For example, some polymers can change their hardness in the area of contact with other materials, which can be considered a surface hardening effect similar to the scaling in metals. This feature is important for assessing the wear resistance of polymers under different sliding conditions.

The study of microhardness of polymers has been of interest due to the need for a deeper understanding of their behavior under load, as the viscoelastic properties of plastics significantly affect test results. Since plastics exhibit both elastic and viscoelastic properties, testing their hardness requires taking into account phenomena such as creep under load and time-dependent recovery after load removal. It is known that the term "hardness" covers many different aspects: scratch hardness, rebound, deformation, etc. In the case of viscoelastic materials, such as polymers, hardness properties can change depending on the time of loading, which necessitates the selection of a well-defined test method for accurate comparisons [4].

From a practical point of view, microhardness testing of polymeric materials has significant potential as a non-destructive method for assessing the quality of polymeric products [5]. For example, microhardness results can correlate with parameters such as polymer morphology, density, orientation effects, and even mechanical properties during molding. In addition, microhardness results can help in the study of stress, polymerization, water dissipation, and durability parameters of polymer coatings, which is particularly valuable for understanding the long-term stability of polymers in service [6].

Materials and methods of research

In this study, the following polymeric materials produced by the Röchling Group were selected: Sustamid 6G OL yellow, Sustamid 66 gray, Sustadur PET white, Sustapeek GF30, Sustamid 6 black, Sustapei transparent, Sustadur GLD white, Zedex zx-100k.

All samples were subjected to standard preparation prior to testing, including dirt removal and degreasing to prevent the influence of foreign substances on the results of microhardness measurements.

The Sustamid 6, Sustapei, Sustamid 6G OL, Sustapeek GF30, Sustadur GLD, Sustamid 66 and Sustadur PET materials were tested at a sliding speed of 2.8 m/s, which provided standardized conditions for evaluating their characteristics.

After the initial series of tests on a tribometric machine [7] under the same conditions, it was determined that the Zedex zx-100k material showed the best results and was selected for further experiments. This material was additionally tested at three sliding speeds: 1.4, 2.8, and 5.5 m/s.

The hardness of the tested samples was evaluated using a PMT-3 microhardness tester with a diamond indenter. The indenter has the shape of a tetrahedral diamond pyramid with an angle of 136 degrees at the top, which ensures high accuracy of indentation and measurement of the microhardness of polymers.

The microhardness tests were performed both for the original surface that was not subjected to friction and for the surface in the friction track zone, which allowed comparing the effect of the tribological experiment on changes in microhardness. The load applied during indentation was 0.39 N for all samples.

The main indentation hardness tests can be divided into two categories:

1.Tests that evaluate the residual strain after application and removal of the indenter (such tests are typically used for metals, as they measure the hysteresis or elastic function).

2.Tests that evaluate the load and strain characteristics, which are used for polymers because they measure the elastic modulus function.

The method of the second category was used to test polymers, since it allows taking into account the peculiarities of viscoelastic deformation of polymers, ensuring the accuracy of the assessment of their microhardness under loading conditions. [8].

The friction tests were performed using a counterpart made of 30KhGSA steel, which had the following characteristics: HRC = 43 and Ra = 0.37 μm. The contact surface of the polymers interacted with the steel counterbody during friction, which allowed for standardized loading conditions for each sample and ensured comparability of results.

The process of assessing the microhardness of polymers requires taking into account their viscoelastic properties, as polymers tend to deform significantly under load. To reduce the influence of viscoelastic deformation and ensure the stability of the results, the measurements were performed a short time after the indenter was inserted. The experiments took into account the change in microhardness of the samples in the friction zone, which may be due to the phenomenon of sticking, characteristic of polymers under specific loading conditions. This allows for a deeper understanding of the mechanism of behavior of polymeric materials under friction and wear.

Purpose

The aim of the study is to analyze in detail the changes in the microhardness of polymeric materials under different sliding speed conditions, using Zedex zx-100k as a base material for testing. In the course of the study, the microhardness of polymer samples is evaluated before and after tribometric loading, which allows establishing the regularities of changes in the physical and mechanical properties of the material under the influence of various operating conditions. Particular attention is paid to the change in microhardness in the contact zone, which is an important indicator for assessing the wear resistance and durability of polymeric materials.

Results

The study evaluated the changes in the microhardness of various polymeric materials after testing on a tribometric setup. An important aspect was the comparison of the microhardness values on the original surface and on the friction track, which made it possible to assess the trend of changes in the microhardness of the material after the experiment. The Sustapeek GF30 material (Fig. 1), like other samples, was measured on the PMT-3 installation using a diamond indenter, which allows obtaining accurate hardness results that are important for understanding the wear resistance and mechanical stability of polymers.

Table 1 shows the results of changes in the microhardness of polymeric materials. The deviation values show the difference between the original surface and the contact zone where friction was observed. Negative values (weakening) indicate a loss of hardness after friction, which may indicate a decrease in the material's strength under load. For example, the Sustamid 6 material has a significant weakening, with a deviation of -1296.8, which may indicate a decrease in its resistance to prolonged friction.

Particular attention was paid to the Zedex material, which was tested in three sliding speed regimes to investigate the effect of different operating conditions. Samples Zedex No. 1 (5.5 m/s), Zedex No. 2 (2.8 m/s) and Zedex No. 3 (1.4 m/s), conventionally numbered to simplify the analysis, show different hardening rates with increasing sliding speed, which may be useful for further optimization of the material depending on the conditions of use.

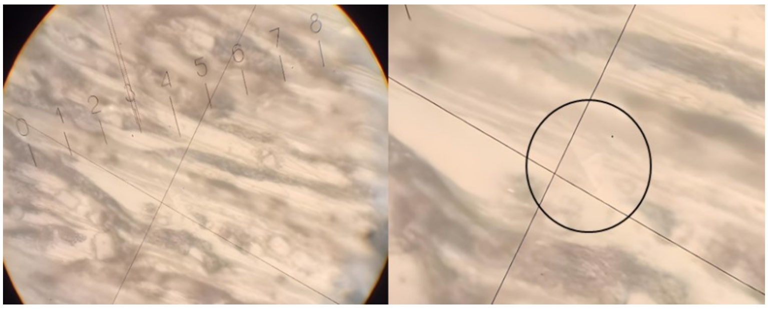


Fig. 1. Image of the microhardness tester imprint on the surface of Sustapeek GF30 material.

In the process of studying the microhardness of polymers after friction with a metal counterbody, one can observe the phenomena of mechanical destruction and thermal destruction of polymeric materials, which have a key impact on the parameters of the contact zone. Mechanodegradation occurs due to the influence of mechanical load, which leads to the destruction of molecular bonds and a decrease in the integrity of the polymer structure. This destruction is associated with microscopic deformations and cracks that gradually accumulate on the polymer surface, especially in areas of high pressure, such as the contact zone with a metal counterbody. Mechanodestruction is an important wear factor because it leads to degradation of physical properties such as hardness and, ultimately, to a reduction in material life.

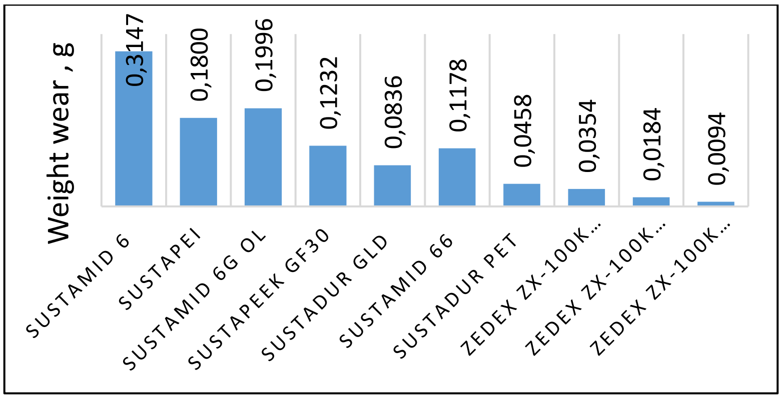
In addition to mechanical degradation, thermal degradation of polymeric materials occurs under friction at high speeds. It is caused by a significant increase in the temperature in the contact zone, when it sometimes exceeds the operating range of the material. When critical temperature values are reached, some polymers begin to lose structural stability, which can lead to softening, loss of stiffness, or even chemical degradation. Thermal degradation can lead to partial melting or oxidation of the surface layers of the polymer, which reduces its mechanical strength. It is this fracture mechanism that explains the microhardness deviation value for Zedex #1, which showed the least tendency to harden after testing at the highest quench rate.

Table 1

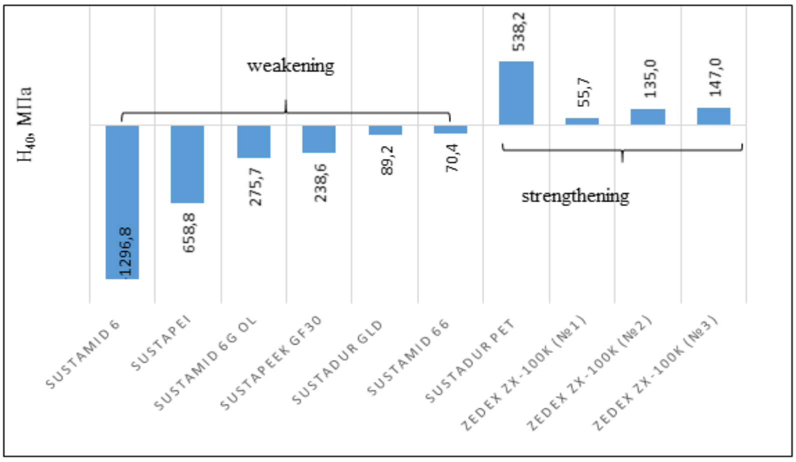
Results of Changes in Microhardness of Polymeric Materials

Material	**Microhardness H_{40}, МПa**				**Weight wear, g**
	The original surface	The friction track	ΔH		Δm
Sustamid 6	1830.1	533.3	1296.8	weakening	0.3147
Sustapei	996.5	337.7	658.8	weakening	0.1800
Sustamid 6G OL	1313.6	1037.9	275.7	weakening	0.1996
Sustapeek GF30	738.9	500.3	238.6	weakening	0.1232
Sustadur GLD	658.8	569.7	89.2	weakening	0.0836
Sustamid 66	398.9	328.4	70.4	weakening	0.1178
Sustadur PET	260.6	798.8	538.2	strengthening	0.0458
Zedex zx-100k (№1)	158.4	214.1	55.7	strengthening	0.0354
Zedex zx-100k (№2)	158.4	293.5	135.0	strengthening	0.0184
Zedex zx-100k (№3)	158.4	305.4	147.0	strengthening	0.0094

The increase in the microhardness of polymers under tribotechnical loading can be explained by both mechanical and morphological factors. First, the mechanical strengthening of the surface layer due to local deformation from friction leads to its compaction and orientation of molecules in the direction of the load. This contributes to the creation of a denser and more stable structure, which has a positive effect on microhardness. This effect often occurs as a result of slander, which, although typical for metals, can also occur in polymeric materials under certain conditions. The results of the studies of weight wear and microhardness of materials are shown in Figure 2. The graphs demonstrate the relationship between the mechanical properties of materials and their resistance to wear.



a)



b)

Fig. 2. Comparison of weight wear (a) and microhardness (b) of materials: results of experimental studies.

Second, morphological changes that occur in the surface layers of polymers during friction play an important role. Increased temperature and mechanical loading can promote partial crystallization of the polymer, which leads to the formation of a more structured, oriented microstructure. This is especially true for partially crystalline polymers [9], which are capable of changing their morphology under heating conditions. Such structural changes increase the material's resistance to external influences and contribute to the growth of microhardness.

Conclusions

The study has shown that the polymeric material Zedex zx-100k (No. 1) has a positive tendency to strengthen even at high sliding speeds. Despite the recorded destruction of the surface in the contact zone, a slight strengthening of the material was observed after the test was completed. This indicates the ability of Zedex zx-100k to withstand significant loads and maintain its structural integrity, which is an important factor for its use in composite materials operating in harsh environments.

Comparison of the microhardness of polymers allows us to determine the optimal operating conditions for each material. In particular, an increase in hardness in the friction zone indicates the ability of polymeric materials to adapt structurally in response to mechanical loading, which is a promising factor for their selection as matrices in composite materials. The decision to choose Zedex zx-100k for a more in-depth analysis was justified, as this material proved to be resistant to deformation and showed a tendency to increase microhardness after testing on a tribometric machine.

In addition, it was noted that the processes of mechanical degradation and thermal degradation play a key role in the behavior of polymers during operation. The temperature rise in the contact zone sometimes exceeded the operating range of the materials, which caused structural changes in the surface layers of polymers. Accordingly, the selection of polymeric materials based on their temperature and mechanical characteristics is important to increase their durability and stability. Careful selection of materials can help to minimize the negative impact of destructive processes on polymer parts operating in harsh environments.

Thus, the results of the study confirm the prospects of using polymeric materials, in particular Zedex zx-100k, in composites subjected to significant loads. This opens up new opportunities for improving polymer composites that can adapt to operating conditions and demonstrate increased wear resistance and strength.

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Марчук Р. М., Мнацаканов Р.Г., Ящук О П., Кущ О. І., Нищук Д. В. Вплив триботестування на мікротвердість полімерів

У цьому дослідженні вивчається мікротвердість полімерного матеріалу Zedex zx-100k та інших полімерів після триботестування за різних швидкостей ковзання. Основна мета цього дослідження – відібрати полімери для потенційного використання в складі композиційних матеріалів. Мікротвердість визначали за допомогою мікротвердоміра ПМТ-3. Отримані результати дозволяють оцінити вплив швидкості ковзання на зміну мікротвердості полімерного матеріалу та його поведінку в умовах зносу. Крім того, результати дозволяють порівняти різні полімери, що тестувалися на трибометричній установці, із подальшою оцінкою їх фізичних характеристик.

Дослідження підкреслює важливість розуміння трибологічних властивостей полімерів, оскільки ці матеріали дедалі більше використовуються у різних промислових галузях завдяки їхнім сприятливим характеристикам, таким як низька вага, економічна ефективність та хімічна стійкість. Вибір відповідних полімерів для композитних матеріалів є ключовим для покращення продуктивності та довговічності виробів, у яких ці матеріали використовуються. Крім того, дослідження надає розуміння механізмів зношування та ролі мікротвердості у зносостійкості полімерів. Аналізуючи поведінку полімерів за різних швидкостей ковзання, дослідження сприяє розробці більш ефективних матеріалів для інженерних застосувань, де вимагається висока зносостійкість. Результати показують, що оптимізація швидкості ковзання може суттєво вплинути на зносостійкість та тривалість служби полімерних компонентів.

У підсумку, це дослідження пропонує комплексний аналіз мікротвердості полімерів після триботестування, надаючи цінні дані для вибору та оптимізації матеріалів у композитних застосуваннях. Методологія та результати, обговорені у статті, можуть слугувати основою для подальших досліджень, спрямованих на покращення характеристик полімерних матеріалів у складних експлуатаційних умовах.

Ключові слова: полімери, мікротвердість, зносостійкість, трибологічні властивості, композиційні матеріали