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METHODOLOGY FOR TESTING A JOINT CARTILAGE

METODYKA BADANIA CHRZĄSTEK STAWOWYCH

Key words: research methodology, friction tests, articular cartilage.

Abstract: A research method was developed to analyse the tribological properties of cartilage tissue. Based on the literature data and the possibility of obtaining samples of appropriate dimensions, the frequency and amplitude of friction tests were adopted. Based on the previously conducted preliminary tests, other test parameters were proposed, such as the frictional contact load and the number of test runs. It was assumed that the results of the research will be the friction coefficient and the wear intensity of the tribological system. According to the developed method, a series of verification tests was carried out in which the friction contact was lubricated in various ways with the selected lubricants. The results of tests of animal cartilage in non-lubricated contact were used as the reference basis for all the tested associations. The friction tests showed good method resolution and satisfactory repeatability. In the case of wear characteristics, a greater scatter of test results was observed. It is probably related to the varied geometrical structure of the cartilage surface as well as the elastic properties of the bone on which the tissue was placed.
The correctness of the obtained results and a relatively good resolution of the tribological test method were found.

Słowa kluczowe: metodyka badań, badania tarciowe, chrząstka stawowa.

Streszczenie: Opracowano metodę badań w zakresie analizy właściwości tribologicznych tkanki chrzęstnej. W oparciu o dane literaturowe i możliwości pozyskania próbek o odpowiednich wymiarach przyjęto częstotliwość i amplitudę badań tarciowych. Na podstawie wcześniej prowadzonych badań wstępnych zaproponowano pozostałe parametry badań, takie jak obciążenie styku tarciowego i liczbę cykli biegu badawczego. Przyjęto, że rezultatem badań będą współczynnik tarcia i intensywność zużywania systemu tribologicznego. Zgodnie z opracowaną metodą przeprowadzono serię badań weryfikacyjnych, w których styk tarciowy smarowany był w zróżnicowany sposób wytypowanymi do badań środkami. Jako bazę odniesienia dla wszystkich badanych skojarzeń przyjęto wyniki badań zwierzęcej tkanki chrzęstnej w styku niesmarowanym. Badania tarciowe wykazały dobrą rozdzielczość metody oraz satysfakcjonującą powtarzalność, biorąc pod uwagę charakterystyki tarciowe. W przypadku charakterystyk zużyciowych zaobserwowano większy rozrzut wyników badań. Prawdopodobnie związane jest to ze zróżnicowaną strukturą geometryczną powierzchni tkanki chrzęstnej, jak również z własnościami sprężystymi kości.
Stwierdzono poprawność uzyskanych wyników i stosunkowo dobrą rozdzielczość metody badań tribologicznych.

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INTRODUCTION

In order to ensure the proper functioning of human joints, in addition to synovial fluid, the proper condition of cartilage is also necessary; joint dysfunction as a result of degenerative changes may result in an inability to move and the necessity to implant an endoprosthesis.

Susceptibility to degenerative changes depends on many factors. The most important are the genetic system, diseases of internal organs, improper diet, insufficient physical activity, and age.

Tribological studies of materials used in the production of human joint endoprostheses, as well as the construction of endoprostheses, have brought many valuable scientific and practical results. There is a very rich and constantly growing literature on this subject, as well as the offer of endoprostheses manufacturers. The development of this area of knowledge and technology is favoured by the very intensive development of material engineering, especially the possibility of developing materials with structures and properties defined at the nano-dimensional level. An important factor of this development is also the development of research instrumentation allowing for the characterization of materials in terms of structure and properties, including tribological ones, in nano to macro scales.

It should be emphasized that tribological studies of natural human joints are rarely carried out. There are many reasons for this; the main ones include the inaccessibility of the friction zone, as well as very low friction forces occurring in the joint and equally low intensity in terms of the possibility of identification (and registration) of wear, even in cases defined from the medical point of view as drastic wear.

Not many works, for various reasons, have also been devoted to extracorporeal, model tribological studies of natural articular cartilage. The main reasons are the difficulties in obtaining it and keeping it in a state that does not cause rapid degradation, while ensuring that the tests (friction) conditions are similar to the working conditions of natural process. As a result, such research cannot provide sufficiently reliable information.

Of the two quantities characterizing the frictionally cooperating elements, which are

- resistance to motion (mainly determined by the coefficient of friction, friction force) and
- wear (or wear intensity),

it may be more satisfactory to determine the coefficient of friction.

The time-consuming determination of frictional wear resistance, since it is a very low intensity process from the point of view of identification and registration, does not guarantee sufficiently correct results. In addition, the material system studied – cartilages rubbing against each other, especially in the presence of a lubricating synovial fluid – outside the human body becomes, in contrast to the system under natural conditions, a system with increasing entropy, which results – it should be especially emphasized – in a change in the properties of the non-nourished it is a degradable material.

On the other hand, the literature containing theoretical considerations is relatively rich. This applies, in addition to medical, biomedical, biochemical, biomechanical studies, also tribological studies, mainly covering the issues of lubrication – from boundary, through hydrodynamic, to elastohydrodynamic, taking into account various rheological models of the lubricating fluid (Newtonian and non-Newtonian), models of the boundary layer (including mechanisms of its formation), shape and surface roughness, as well as mechanical properties of material systems. The results of these studies, describing the processes taking place in the work of joints more and more precisely, are so far useful primarily in the development of endoprostheses, and **only to a small extent contribute to the development of methods slowing down or removing** the effects of degradation of natural joints.

It should be emphasized that there are many reports on extracorporeal tribological tests of the properties of natural articular cartilage, but they limited to the measurement of friction in combination with counter samples made of other materials – ceramics, polymer, metal alloys, also mica **[L. 1, 2]**. In recent years, the most frequently used tool for this purpose is the AFM – atomic force microscope **[L. 3]**. However, determining the coefficients of friction in this way, although useful in preliminary studies, does not provide much valuable information for the operation of natural joints. This is because the research with the use of AFM does not allow one to take into account the fact that the tribological characteristics (which are the coefficient of friction and wear) do not characterize one material (such as hardness, Young's modulus) but are the features of the entire "tribological system," i.e. both friction materials additionally depend on the properties of the lubricant and the test conditions, including pressure, slip, temperature, and the type of the surrounding medium. In the case of precise measurements (e.g., very low resistance to motion, which occur when the cartilages rub against each other in natural joints), they also depend on the stiffness (natural frequency) of the measuring devices.

Despite the above-mentioned limitations, very helpful tests for the initial, relative selection of the suitability of endoprosthesis materials are performed on simple samples of rubbing cartilage tissues; they precede long-term, multi-millionth cycles, normative tests of finished prostheses.

There are few studies on the research on the mutual friction of natural cartilages against each other. The works of scientists from the Israel Institute of Technology in Haifa **[L. 4–6]** should be mentioned among them. They collected samples from natural joints from patients who had been implanted with endoprostheses. They were in the form of disks 4 and 8 mm in diameter and 1.5 to 2 mm thick. They were glued to the special grips of the tribometer. The friction tests were carried out at various loads, causing unit pressures from 0.4 to 2.4 MPa, and different slip from 0.5 to 2 mm/s, at room temperature (24°C) and body temperature (37°C) in the presence of lubricating fluids, which is an aqueous solution of sodium chloride, histidine, and synovial fluid from an inflamed joint. Among others, waveforms of changes in the static and dynamic friction coefficients in the presence of sodium chloride solution and histidine depending on the load and time (from 5 to 300 s). It was found that the values of both coefficients decreased (surprisingly intense, exponential) with increasing load.

Some of the above conclusions differ from the conclusions drawn from the research presented in **[L. 3]**. These studies show that the use of the polymers used in them allows for the fulfilment of all three laws of friction formulated by Amontons, including the proportionality of the friction force and load, denoting a constant value of the coefficient of friction, which completely differs from the results of the Israeli researchers' tests presented above using samples prepared from natural human joints (according to which the friction coefficient does not increase with load, but decreases significantly).

The values of the friction coefficient recorded in both works also differ significantly, i.e. they are lower by an order of magnitude in the latter case.

The preliminary tests of animal articular cartilage (commercially available material) carried out in 2018 at the Department of Tribology under the conditions of Ringer's lubrication confirm the increase in the friction coefficient with the increase in the frictional contact load.

The review of the frictional research conducted so far allowed us to state that, for the purposes of this study, it was possible to use, to some extent, the experience from research, an example of which are the experiments of Israeli scientists mentioned above.

This particularly applies to the following:

- The cartilage-cartilage friction junction used (**Fig. 1**), and
- Analysis of the influence of load on the coefficient of friction.

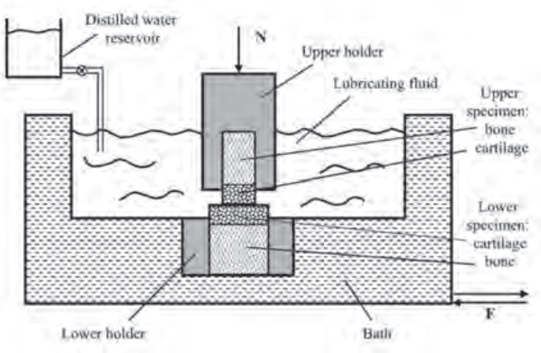

Fig. 1. Friction pair used by Israeli scientists [L. 4]; cartilage – cartilage

Rys. 1. Węzeł tarcia zastosowany przez izraelskich naukowców **[L. 4]**; chrząstka stawowa – chrząstka stawowa

In addition to the methodology of tribological tests, for the purposes of in vitro tests of frictional resistance of the articular cartilage, appropriate preparation of samples should be developed, as a result of which a flat test surface is obtained. It is also important to properly store biological samples to prevent them from perishing and to ensure proper sterility of the tests.

METHODOLOGY OF THE STUDY OF ARTICULAR CARTILAGE

The development of a method for testing the effect of the type of lubricant on the friction-wear characteristics of the mating cartilages involved the selection of a tribological device and the determination of the conditions that will enable obtaining sufficient resolution and repeatability of the results. This purpose was assigned to the appropriate handling of samples (preparation, storage, installation), as well as to characterizing their surface.

Based on the results of the analysis of the state of knowledge, as well as on the basis of own experience, it was decided to conduct a series of tribological research runs in reciprocating motion, with variant operating parameters of the friction contact (load and frequency, friction path/number of cycles), and the determination of the friction coefficient (friction force) and the intensity of wear of the tested cartilages.

Apparatus for tribological tests

The T-17 test device was used for tribological tests, meeting the requirements of the ASTM F 732 standard concerning the testing of materials for reciprocating hip joint endoprostheses.

The research association consisted of a stationary pin pressed by the force P against the plate making a reciprocating movement with a given frequency and amplitude.

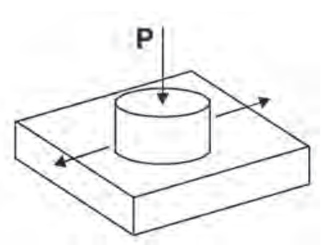

Fig. 2. Scheme of the friction pair of the T-17 pin-on-plate testing device for testing biomaterials in reciprocating motion

Rys. 2. Schemat węzła tarcia urządzenia badawczego T-17 typu trzpień–płytka do badania biomateriałów w ruchu posuwisto-zwrotnym

A photo of the T-17 testing device is shown in **Fig. 3**.

The tribological research device T-17 is equipped with a measurement and control system, which includes the following:

- A set of measuring transducers,
- A controller,

- A digital measuring amplifier, and
- A computer with a special measurement and recording program installed.

The following quantities are measured during the test run:

- Friction force,
- Total linear wear of the friction pair elements, and
- The ambient temperature of the friction pair.

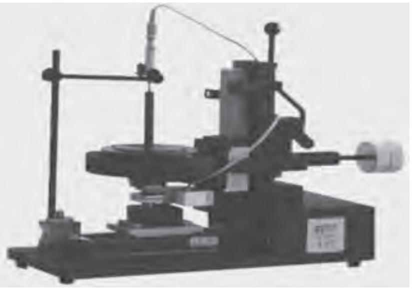

Fig. 3. View of the T-17 tribological test device of the pin-on-plate type for testing biomaterials in reciprocating motion

Rys. 3. Widok tribologicznego urządzenia badawczego T-17 typu trzpień–płytka do badania biomateriałów w ruchu posuwisto-zwrotnym

Before the test run, the frequency and amplitude of the reciprocating movement are set, as well as the number of test run cycles (friction path). The waveforms of the measured quantities and their values are displayed on the screen on an on-going basis and archived in the computer mass memory after the end of the test run. The drive motor of the device is automatically stopped after reaching the preset number of cycles (friction path). After the tests, it is possible to print a report with graphs of the measured values as a function of time.

Working parameters of the friction pair

Based on the literature data on the area of cartilage tribological tests and taking into account the possibility of obtaining samples of appropriate dimensions from the joints, the frequency and amplitude of friction tests were adopted. On the basis of the conducted preliminary tests, the remaining test parameters were proposed, i.e. the frictional contact load and the number of test run cycles.

In view of the above, the following parameters of tribological tests were adopted:

- Type of movement: reciprocating
- Movement amplitude 2 mm
- Oscillation frequency 1 Hz
- Contact load 10 N
- Number of test run cycles 9999
- Initial operating temperature of the contact 23 ±1°C.

The geometry of the friction pair

The friction node of the tested device, which is presented in the entire test system in **Fig. 4**, consists of the lower sample in the form of a disk and the upper sample in the form of a pin.

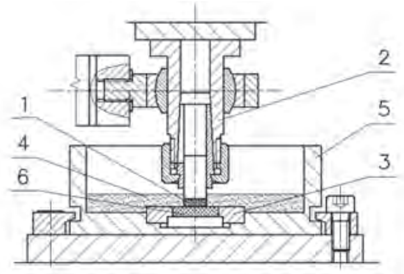

Fig. 4. Scheme of the T-17 tribological biosystem: 1 – stationary sample with cartilage, 2 – upper handle, 3 – lower handle, 4 – liquid, 5 – reservoir, 6 – lower sample with cartilage

Rys. 4. Schemat biosystemu tribologicznego T-17: 1 – próbka nieruchoma z chrząstką, 2 – uchwyt górny, 3 – uchwyt dolny, 4 – ciecz, 5 – zbiornik, 6 – próbka dolna z chrząstką

The dimensions of these samples as well as their appearance are shown in **Fig. 5**.

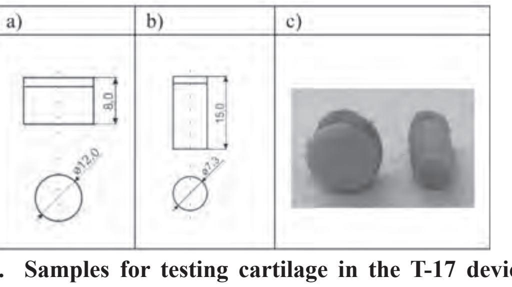

Fig. 5. Samples for testing cartilage in the T-17 device: a) dimensions of the lower sample (disk), b) dimensions of the upper sample (pin), c) view after cutting out

Rys. 5. Próbki do badań tkanki chrzęstnej na urządzeniu T-17: a) wymiary próbki dolnej (tarcza), b) wymiary próbki górnej (trzpień), c) widok próbki po wycięciu

Materials of friction pair elements (samples)

Elements of the friction pair (samples) were obtained from joints with different degrees of cartilage degradation. In order for the test results to be comparable, it is required that the geometrical structure of the cartilage (SGP) and the elastic properties are similar.

In order to carry out tribological tests using the T-17 device, special holders were made: the upper pin and the lower disk – **Fig. 6**.

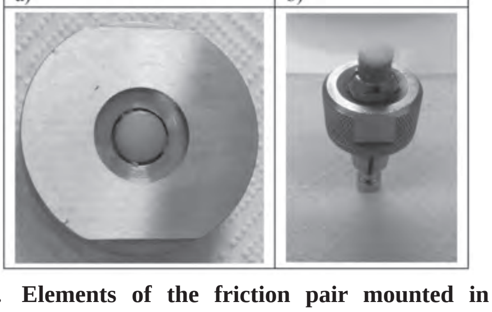

Fig. 6. Elements of the friction pair mounted in the holders: a) lower – disk, b) upper – pin

Rys. 6. Elementy węzła tarcia zamocowane w uchwytach: a) dolnym – tarcza, b) górnym – trzpień

Preparation of samples for testing

As emphasized in the summary of the literature review, proper storage of biological samples, preventing them from perishing and appropriate sterility of the research are very important. In order to maintain the appropriate sterility, the personnel performing the test should be equipped with personal protective equipment specified in the regulations. Samples should be transferred between rooms in desiccators until their disposal.

It was assumed that after cutting, the samples would be washed in a physiological saline solution, then dried, packed into special containers and stored in a refrigerator at 1°C. The samples were stored for a maximum of 5 days until they were prepared for tribological testing.

Before starting the study of the geometric structure, the samples were stabilized in a desiccator for 30 minutes, and then the working surfaces (SGP) were examined using an optical microscope and an interferometric microscope.

Before the beginning of each test run, the samples were mounted in the holders on the stand and stabilized for 2 hours.

A very important factor influencing the tribological properties of the tested system is the method of applying the polymer to cartilage samples in ex vivo conditions and determining the method and effectiveness of polymer anchoring on the tissue surface. The surface of the samples requires examination both before and after tribological tests in order to determine the effectiveness of the polymer as a lubricant and changes in the degree of coverage of the tissue with polymer due to friction.

Surrounding the friction pair

The tribological tests were carried out in an air-conditioned room with a relative humidity of 50 ± 5% and an ambient temperature of 23 ± 1°C. It is allowed to change the environmental conditions under the restriction that these conditions will be identical in all stages of tribological tests.

Measured tribological quantities

As mentioned in the introduction in the description of the T-17 device, during the test run, the friction force and the total linear wear of the friction junction elements are continuously measured and stored in the computer's mass memory.

The average coefficient of friction calculated for the interval in which the wear intensity was determined was adopted as the measure of resistance to motion.

Wear intensity, calculated from the trend line regression equation for each tested research run, was adopted as a measure of wear. The wear intensity was determined from the wear characteristics based on the wear trend line, on the stabilized part of this characteristic (after initial running in) recorded during the tests.

If a value significantly different from the others was found, the result had to be rejected. For this purpose, the Dixon Q test was used to identify and reject outliers.

In order to define the repeatability of the tests, and thus the resolution of the method, the test runs should be repeated at least for three sets of samples having similar parameters characterizing the cartilage. It is advisable to take them from one particular surface.

Equipment for testing the geometric structure (SGP)

The study of the geometrical structure of the surface and the mechanisms of wear of cartilage tissue elements was carried out using the Taylor Hobson Talysurf CCI interferometric microscope, which is a measuring system for measuring roughness, waviness, and shape, by an optical method. It works on the principle of white light interferometry with a microscopic objective increasing the vertical range.

Talysurf CCI uses two types of lenses: Michelson (2.5x and 5x magnification) and Mirau (10x, 20x, and 50x magnification). The interferometric microscope is equipped with Talysurf CCI and TalyMap Platinum software that enable 2D (profiles) and 3D (topography) analysis and allow for the determination of the following:

- Roughness parameters
- Waviness parameters
- Load curves
- Amplitude distributions
- Volumes
- Distances.

As part of the analytical research, the measuring optical microscope MM-40 by Nikon was also used, which is equipped with the MultiScanBase v.8.08 digital image acquisition and processing system.

Verification tribological tests

Verification tests were performed according to the proposed method. Animal cartilage tissue (commercially available material) which was prepared and processed as described above was used for the research. The cartilage tissues were lubricated with various lubricants. The obtained results were related to the results of friction tests of cartilage without lubrication.

It was assumed that the following lubricants will be used in these tests: hyaluronic acid and a copolymer solution marked with the B2 symbol, which is designed to rebuild degraded articular cartilage.

Hyaluronic acid is an organic chemical compound, a polysaccharide from the group of glycosamino-glycans. It occurs in all organisms and belongs to the compounds having an identical chemical structure in bacteria and mammals. It is a biopolymer that occurs in the synovial fluid.

The B2 polymer was used in the verification tests as a solution of various concentrations and dosed to the contact in different ways.

The cartilage tissue samples were prepared as follows:

- Soaked with 1% hyaluronic acid solution for 20 hours, and before the start of the test run, sprinkled with the same solution ("Hyaluronic acid 1%");

- Soaked with polymer B2 with a concentration of 3.14% for 20 hours, and sprinkled with polymer B2 with concentration of 1.72% before the run ("B2 instillation"); and,
- Soaked with polymer B2 at a concentration of 3.14% for 20 hours ("B2 soak").

The summary of the mean values of the results of the conducted research is presented in **Figs. 7** and **8**.

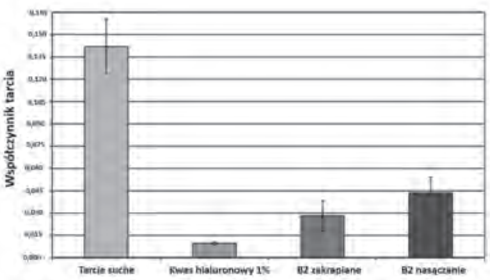

Fig. 7. The average values of the friction coefficient of the tested materials

Rys. 7. Zestawienie średnich wartości współczynnika tarcia badanych skojarzeń

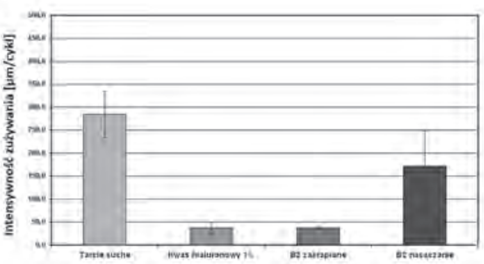

Fig. 8. The average values of the intensity of wear of the tested materials

Rys. 8. Zestawienie średnich wartości intensywności zużywania badanych skojarzeń

Analysing the obtained results in the form of both frictional and wear characteristics, it can be stated that, after the initial period of cooperation of about 2,000 cycles, the friction coefficient and the wear intensity of the tested associations are stabilized.

The results presented in **Fig. 7** show that the type of the lubricant used and the way it is applied to the joint significantly affect the value of the friction coefficient during friction tests. It is obvious that the highest friction coefficient was recorded for the non-lubricated combination. The lowest coefficient of friction was obtained for the combination lubricated with hyaluronic acid solution.

In the case of average wear intensity (**Fig. 8**), a greater dispersion of test results was noted. It should be assumed that this was related to the varied geometrical structure of the cartilage tissue surface, as well as the elastic properties of the bone and the tissue itself. In the summary of the tribological research, it should be stated that the method of "friction contact lubrication" had a very significant impact on the test results, and taking this into account, the most appropriate seems to be soaking cartilage tissues with B2 polymer for 20 hours and sprinkling with this polymer before starting the tests.

SGP ANALYTICAL RESEARCH

As already mentioned, analytical tests of the geometric structure of friction surfaces (SGP) were performed before and after the tribological tests. These studies were performed using an optical microscope and an interferometric microscope.

Images of the surface of selected cartilage tissues before and after tribological tests made with an optical microscope are shown in **Figs. 9** to **12**.

In all cases, these images show clear differences in the topography of the cartilage surfaces before and after the tests. There are also clear differences between the individual cartilage tissues before the tests, which is due to the fact that they were collected from different articular cartilages.

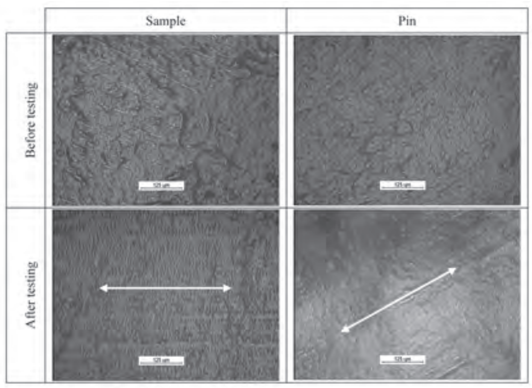

Fig. 9. Topography of the surface of the sample and counter-sample (pin) before and after tribological tests of the non-lubricated contact

Rys. 9. Topografia powierzchni próbki i przeciwpróbki (trzpienia) przed i po badaniach tribologicznych styku niesmarowanego

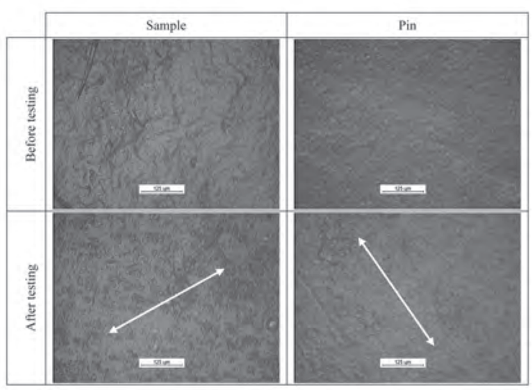

Fig. 10. Topography of the sample and counter-sample (pin) before and after tribological tests of the contact soaked and sprinkled with hyaluronic acid solution

Rys. 10. Topografia powierzchni próbki i przeciwpróbki (trzpienia) przed i po badaniach tribologicznych styku nasączanego i zakrapianego roztworem kwasu hialuronowego

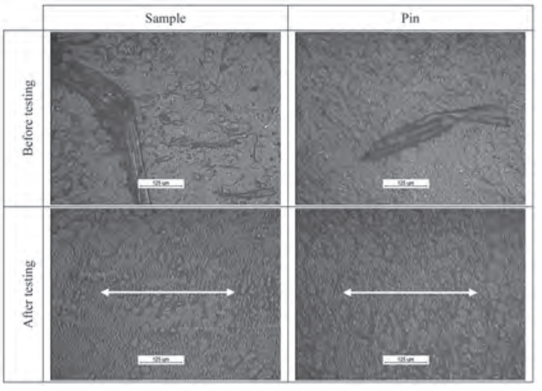

Fig. 11. Topography of the surface of the sample and counter-sample (pin) before and after tribological tests of the contact sprinkled with B2 polymer

Rys. 11. Topografia powierzchni próbki i przeciwpróbki (trzpienia) przed i po badaniach tribologicznych styku zakrapianego polimerem B2

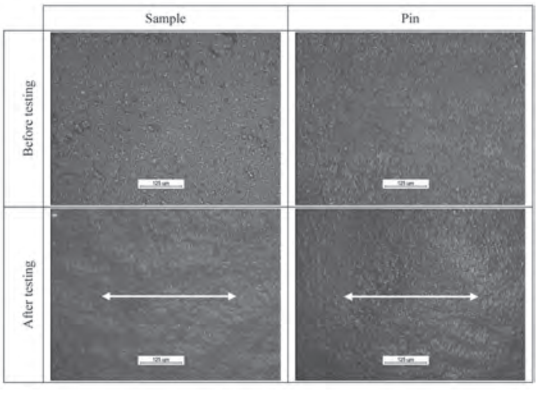

Fig. 12. Topography of the sample and counter-sample (pin) surface before and after tribological tests of the contact soaked with B2 polymer

Rys. 12. Topografia powierzchni próbki i przeciwpróbki (trzpienia) przed i po badaniach tribologicznych styku nasączanego polimerem B2

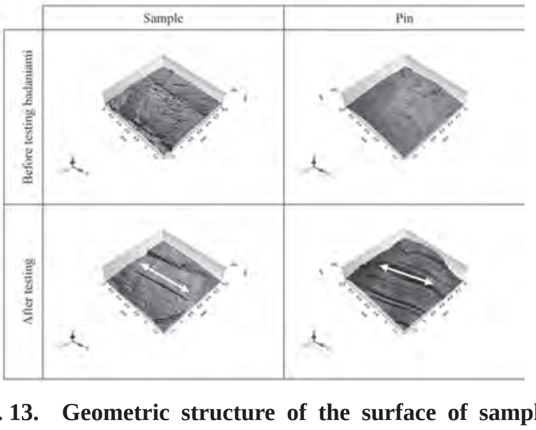

Fig. 13. Geometric structure of the surface of samples subjected to dry friction testing

Rys. 13. Struktura geometryczna powierzchni próbek poddanych badaniu przy tarciu suchym

Very clear differences in the geometric structure of the sample surfaces, both before and after tribological tests, are confirmed by the tests carried out with the interferometric profilograph – **Figs. 13** to **17**.

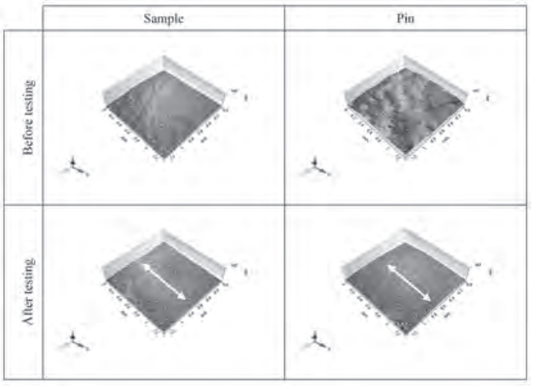

Fig. 14. Geometric structure of the surface of the samples subjected to testing with lubrication of the contact with hyaluronic acid

Rys. 14. Struktura geometryczna powierzchni próbek poddanych badaniu przy smarowaniu styku kwasem hialuronowym

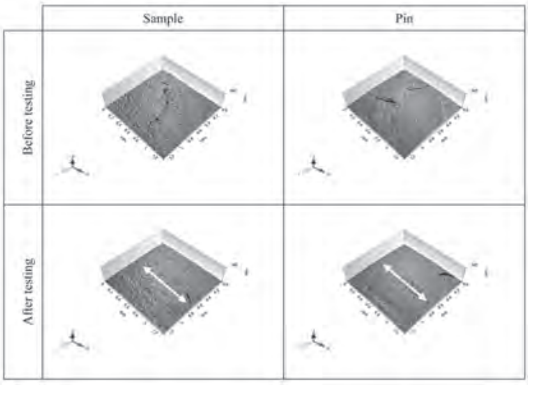

Fig. 15. Geometric structure of the surface of the samples tested during lubrication of the contact with B2 polymer

Rys. 15. Struktura geometryczna powierzchni próbek poddanych badaniu przy smarowaniu styku zakrapianego polimerem B2

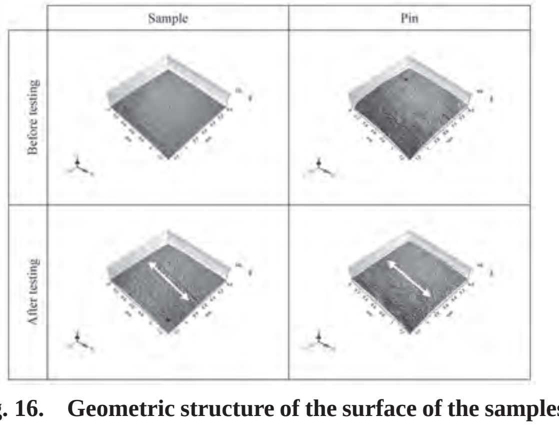

Fig. 16. Geometric structure of the surface of the samples tested for lubrication of the contact soaked with B2 polymer

Rys. 16. Struktura geometryczna powierzchni próbek poddanych badaniu przy smarowaniu styku nasączanego polimerem B2

In all tested cases, the traces of cooperation between these elements are clearly visible on the samples and pins. The smallest traces were recorded for the combination lubricated with the hyaluronic acid solution, while the largest, as expected, for the dry contact.

Changes in the surface roughness of the rubbing surfaces of the samples, made across the friction marks, are best characterized by the profilograms presented in **Figs. 18** to **25**. When analysing them, attention should be paid to the roughness of these surfaces, expressed as the total height of the P_t profile.

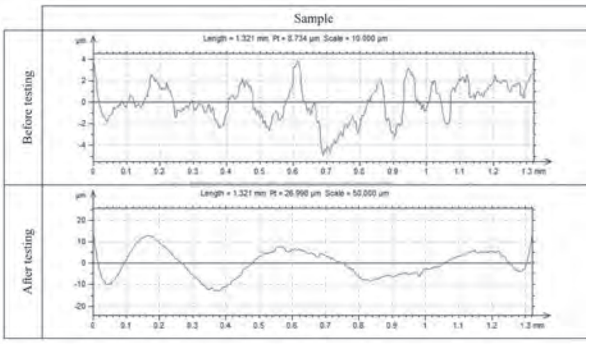

Fig. 17. Roughness profile of the sample surface with cartilage tested with dry friction

Rys. 17. Profil chropowatości powierzchni próbki z tkanką chrzęstną badaną przy tarciu suchym

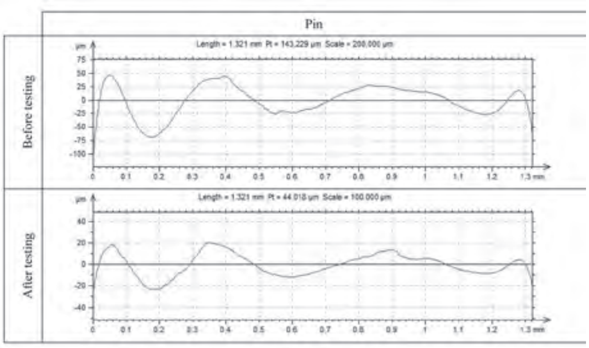

Fig. 18. Roughness profile of the surface of the pin with the cartilage tissue tested with dry friction

Rys. 18. Profil chropowatości powierzchni trzpienia z tkanką chrzęstną badaną przy tarciu suchym

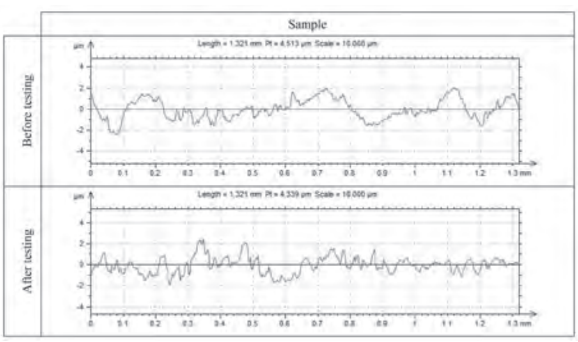

Fig. 19. Roughness profile of the sample surface with cartilage when lubricating the contact area by soaking with hyaluronic acid

Rys. 19. Profil chropowatości powierzchni próbki z tkanką chrzęstną przy smarowaniu styku przez nasączanie kwasem hialuronowym

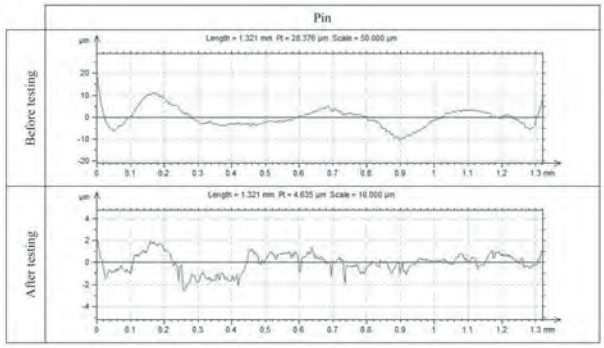

Fig. 20. Profile of the roughness of the surface of the pin with the cartilage tissue tested during the lubrication of the contact by soaking with hyaluronic acid

Rys. 20. Profil chropowatości powierzchni trzpienia z tkanką chrzęstną badanej przy smarowaniu styku przez nasączanie kwasem hialuronowym

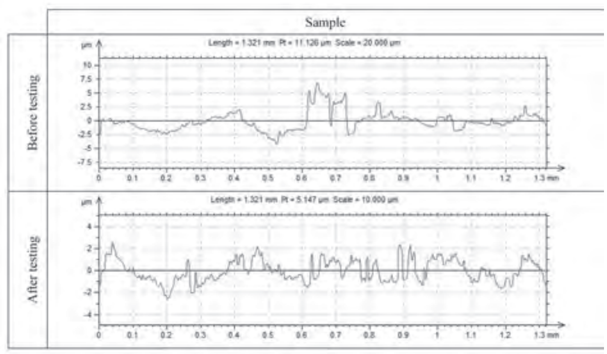

Fig. 21. Roughness profile of the sample surface with cartilage when lubricating the contact sprinkled with B2 polymer

Rys. 21. Profil chropowatości powierzchni próbki z tkanką chrzęstną przy smarowaniu styku zakrapianego polimerem B2

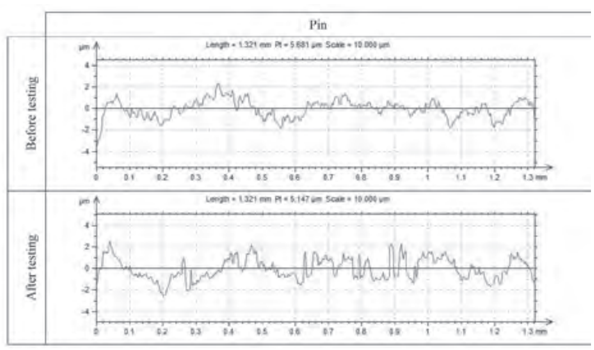

Fig. 22. Roughness profile of the pin surface with cartilage during lubrication of the contact sprinkled with B2 polymer

Rys. 22. Profil chropowatości powierzchni trzpienia z tkanką chrzęstną przy smarowaniu styku zakrapianego polimerem B2

Considering the first case of testing with dry friction, the friction surface of the sample (**Fig. 18**) increases the friction roughness expressed by the P_t parameter, while the surface of the pin (**Fig. 19**) reduces its roughness by more than 4 times.

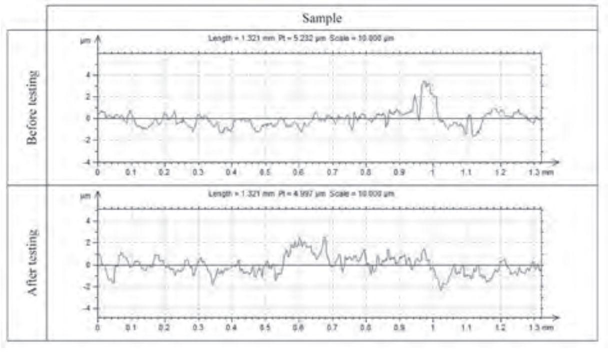

Fig. 23. Roughness profile of the sample surface with cartilage when lubricating the contact by soaking with B2 polymer

Rys. 23. Profil chropowatości powierzchni próbki z tkanką chrzęstną przy smarowaniu styku przez nasączanie polimerem B2

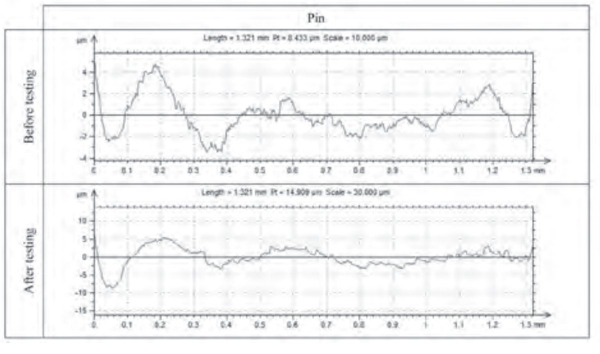

Fig. 24. Roughness profile of the pin surface with cartilage when lubricating the contact by soaking with B2 polymer

Rys. 24. Profil chropowatości powierzchni trzpienia z tkanką chrzęstną przy smarowaniu styku przez nasączanie polimerem B2

Interesting are the changes in roughness, expressed by the P_t parameter, in the case of a contact lubricated by soaking with hyaluronic acid (**Fig. 20** and **Fig. 21**). The friction surface of the sample before and after friction hardly changes its roughness, while the working surface of the pin after friction is characterized by a reduced coefficient of P_t almost 7 times and confirms the observed geometric structure of the surface of the friction elements shown in **Fig. 14**. Soaking the contact with polymer (**Fig. 24** and **Fig. 25**) resulted in a reduction of the sample roughness by half after the friction run, with almost unchanged, after friction, the roughness of the friction surface of the pin.

A different phenomenon was observed in the case of the contact in which the test elements were additionally sprinkled with polymer (**Fig. 22** and **Fig. 23**). The roughness of the working surface of the sample after friction hardly changed, while the roughness of the pin surface almost doubled; therefore, when planning tribological tests of cartilage, particular attention should be paid to the method of lubricating the contact.

In the conducted tests, the most appropriate method of lubricating the contact was soaking with polymer B2 at a concentration of 3.14% for 20 hours and sprinkling with it at a concentration of 1.72% before the run.

SUMMARY

As a result of the performed works, a good resolution of the developed method of identifying friction characteristics and a satisfactory repeatability of the test results were found. The method allows one to evaluate the influence of the type of the lubricant and the method of lubrication (delivery to the friction zone) on the friction-wear characteristics of the cartilages.

In the case of wear characteristics, a greater dispersion of test results was observed, which was related to the different geometrical structure of the surface (SGP) of the tested cartilage tissues. Therefore, conducting research on the geometric structure of the surface is necessary to select cartilage tissue for tribological tests with similar surface stereometric features. This will reduce the scatter of test results and will allow, in addition to assessing wear, one to identify wear mechanisms. It seems justified to develop a scale for the degradation of cartilage tissue, which may also contribute to a better assessment of the measures being developed to reduce the intensity of cartilage wear or its reduction.

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