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IRON AND BRONZE POWDERED BASED MATERIALS FOR BEARINGS WITH SURFACE MODIFIED WITH SOLID LUBRICANT NANOPARTICLES

MATERIAŁY O NISKIM WSPÓŁCZYNNIKU TARCIA NA OSNOWIE PROSZKU ŻELAZA I BRĄZU PRZEZNACZONE NA ŁOŻYSKA Z MODYFIKOWANĄ POWIERZCHNIĄ NANOCZĄSTECZKMI SMARU

In the recent years, a growth of demand for various types of self-lubricating elements of machines has been observed. A lot of parts are manufactured with the use of a powder metallurgy method. The Metal Forming Institute (INOP) in Poznan developed a modern technology, designed and made a tool for compaction of powdered parts with complex shapes and high density. The technology is being realised with a large scale equipment, which performs the forging and sizing of the sintered performs.

The present work describes development of manufacturing technology and determination of mechanical and tribological properties of nanocomposites for self-lubricating bearings with a very low friction coefficient. It is envisaged to use particulate materials which consist of nano-and microparticles of solid lubricant.

The study conducted aims at definition of a relationship between the microstructure and tribological properties of materials modified with solid lubricant MoS_2 nanoparticles dispersed in a technological oil. INOP's technology of nanoparticles manufacturing by RCT method (Rolling Cleavage Technology) results in that top layer of the porous bearing is modified with the nanoparticles. These layers are characterised by a low friction coefficient and considerably longer period of use. It should be noted that the stainless steel and bronze powders materials used have a good corrosion resistance. Production of the sintered bearings will disseminate the market especially in automotive and aircraft industries.

Keywords: self-lubricating bearings, BROMIX, metal powders, nanoparticles, grease

W ostatnich latach obserwuje się wzrost zapotrzebowania na różnego typu samosmarujące elementy maszyn. Wiele z tych detali jest wytwarzanych metodą metalurgii proszków. W INOP opracowano nowoczesną technologię i zbudowano stanowisko do kształtowania części dokładnych, o złożonych kształtach i wysokiej gęstości, z proszków metali na osnowie żelaza. Stanowisko to posiada specjalistyczną, zautomatyzowaną linię o dużej wydajności, w której realizowany jest proces dogęszczania i kalibrowania spiekanych wyprasek [1, 2].

Celem prowadzonych prac naukowo – badawczych jest opracowanie technologii wytwarzania oraz określenie właściwości mechanicznych i tribologicznych nanokompozytów przeznaczonych na łożyska samosmarujące o bardzo niskim współczynniku tarcia, z wykorzystaniem materiałów zdyspergowanych w postaci nano i mikrocząstek proszków smarnych oraz proszku żelaza i brązu [1, 3].

Prowadzone prace miały na celu określenie właściwości mechanicznych i tribologicznych materiałów modyfikowanych nanocząstkami smarów stałych (MoS_2) i olejem technologicznym. Opracowana w INOP metoda wytwarzania nanocząstek metodą RCT (Rolling Cleavage Technology) prowadzi do wniosków, że zmodyfikowane tymi cząstkami warstwy wierzchnie porowatych materiałów, cechują się niskim współczynnikiem tarcia oraz znacznie dłuższym okresem ich eksploatacji. Należy zaznaczyć, że wybrane materiały na osnowy, w postaci proszków stali nierdzewnej i brązu zapewniają odporność na korozję wyrobów. Wytworzenie przy opracowanych parametrach materiałów pozwoli rozszerzyć ofertę technologiczną wytwarzania wyrobów dla przemysłu (np.samochodowego czy lotniczego) [2, 3].

1. Introduction

The contemporary construction and use of machines is connected with a vital issue such as improvement of friction wear and properties of kinematic pairs. The continuous development of technology and issues connected with growing technological requirements leads, inter alia, to increase of excitations of the kinematic counterparts, that increases the probability of damage of twin the cooperating elements [1, 2].

The processes of wear, which are inherent elements of friction, depend on selection of structural materials, surface machining and selection of lubricant. Despite considerable achievements in the field of new materials and surface machining, there is still a vital issue of proper selection of a lubricating agent and methods of testing tribological prop-

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erties of the developed materials and technological solutions [1, 3].

Effectiveness of the lubricating agents is evaluated, inter alia, on the basis of durability of the lubricant film created on the top surface of the working element and its efficiency in seizure conditions. The tests are most often made with the use of tribological testers. Evaluation of the lubricant effectiveness requires several independent tests to be made. This decrease accuracy of comparison of various lubricating agents, because initial conditions of the tribology properties evaluation tend to vary. Therefore, it is difficult to establish a relation between durability of the lubricating film and resistance to seizure [3,4]. The works conducted aims at a particular focus on evaluation of effectiveness of lubricating agents intended for steel friction pairs, their impacts both on strength of the lubricate film and the resistance of the top payer to seizure. An important issue is an opportunity to identify transformations occurring in the top layer of the counterparts in the contact zone under the influence of the lubricating agent. The models of the interface layer formation during friction are not developed yet in detail. For this reason it is difficult to define the model of the friction process with the generation of a lubricating film and its destruction [5].

From the viewpoint of the non-compensated part of surface forces, the atom's clean layer of the solid body is very active both in physical and chemical terms. This leads to attachment of substances found in its vicinity. The process may be self-induced as a result of attachment of accidental substances which are artificially induced during a voluntary intervention. The top layer changed as a result of the process has different properties than the initial layer. It may constitute a new phase or phases differing from the basis with respect to energy. The phases may include additional components, or their composition may differ completely from that of the core material. Therefore, during manufacturing of components, the in top payer is being change changes due to various impacts in physical, chemical and structural terms. The obtained layer differs from the core of the object and is referred to as a top payer [4, 6].

Properties of top layers of metal elements as obtained in technological processes are subject to further changes during use. Considering changes in the top layer occurring in the friction pair, the friction pair should be treated as a kind of tribological system. The system is composed of several elements such as a friction counterparts, lubricating agent and surroundings. The initial condition of the tribological system is subject to change due to excitations during the friction process [2, 6].

Lubrication is a very significant issue relating to movement of the counterparts. It is determined by a lot of parameters such as friction forces, operating temperature of the system, possible vibrations or loss of energy. Lubrication is a process involving feeding of the lubrication agent in a sliding interface between the bearing and moving shaft in order to decrease resistance of friction, wear and to prevent seizure of the bearing. In the case of self-lubricating bearings, an oil lubricating agent, is fed onto slide surfaces through a system of pore channels. From the economical point of view, the use of self-lubricating bearings ensuring feeding of the lubricating agent automatically is a better alternative. Self-lubricating bearing application allows to simplify the entire structure of sliding pair. Self-lubricating parts are easily available and occur in a wide range of types and normalised sizes [2, 6, 7].

Since self-lubricating bearings were invented, they have been developed in two directions, namely shaping of a metal (porous) matrix of an appropriate material and finding an appropriate lubricating agent for saturation of the porous structure.

For a long time of porous bearing development an optimal porosity of the materials was established. It is approximately in the range of 20-30%. This optimal porosity is result of a compromise between a maximum volume of oil in the pores and the necessity to maintain possible high compression strength of the bearing. From the viewpoint of manufacturing and use porous bearings of various metals and bronze powders with addition of graphite are chosen [2, 6].

Powder metallurgy makes it possible to manufacture porous materials with a special microstructure – a metal matrix with evenly distributed solid lubricant particles, which leads to creation of a sliding film. Selection of a metal matrix and type and volume of solid lubricant is defined by conditions of operation of the bearing. The growing demand for unconventional materials with unique properties led to intensive development of their production methods. A perfect example of this includes metallurgy of powders making it possible to obtain untypical metal sinters with composition and properties, which cannot be obtained with the use of other traditional metallurgical methods.

2. Self-lubricating bearings

The industry distinguishes between the group of basic types of friction couplings including, but not limited, to rolling bearings and sliding bearings. There is a specific group of self-lubricating sliding bearings. In such bearings saturation with oil is realised by immersion in hot oil for a long period of time or with the use of a vacuum method, which involves impregnation of the oil at an appropriate temperature. The structure of the porous bearing resembles that of a sponge – there are pores in the sleeve wall, which constitute capillary channels. Obtaining of the porous structure is ensured by use of powder metallurgy [3, 6].

This method becomes even more important in connection with the growing demand for unconventional materials with unique properties, which cannot be ensured by the use of traditional materials. The powder metallurgy also makes it possible to manufacture sintered materials in which solid lubricant particles are distributed evenly [2].

3. Research methods and materials

The tested samples have been made of 316L steel based mixture of powders. At the same time, a technology of production of the sleeves with the use of BROMIX bronze powder has been developed. Additionally, we developed a process of production of a porous materials based on iron alloy and bronze powder, which was saturated with the solid lubricant MoS_2 particles and oil (NT-100) with the use of a vacuum method. The technology of production of the sleeve involved compaction and sintering and, subsequently, introduction of lubricant composed of MoS_2 micro- and nanoparticles under pressure. The relevant process of sintering was conducted in the atmosphere of dissociated ammonia in a PSF-12/75 electrical furnace suitable for sintering in temperatures of up to 1200°C. The samples were subject to additional forging connected with calibration to a desired size.

The device for pressure modification was designed and manufactured in INOP. Presently, the device is patent pending (PC-2 pressure device – Fig. 1.). The previous prototype version of PC-1 was subject to patent in 2009 as No. PCT/PL 2010/000091: "The method of increase of bearings and a complex for increase of strength properties of bearing sleeves". The idea of modification was not changed, but the device was modified in order to improve characteristics of the sleeve working surface.

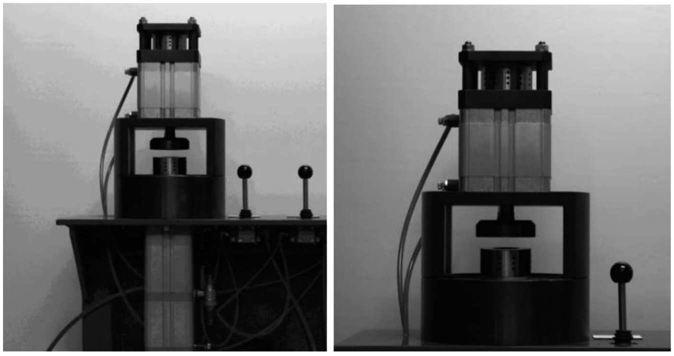

Fig. 1. The device for top layer modification: a) PC-2 pressure device, b) head

The layer was modified on sleeves delivered with the use of a modification fluid composed of FC111 technological fluid with specified content of MoS_2 powder nanocomposite particles. The strong point of this agent is that it is highly capable of evaporation from the modified parts. The obtained structure is characterised by a homogenous particulate solid lubricant layer.

The further stage of work is connected with sleeve-shaft type tribological tests. They will be made in the Laboratory of Surface Engineering and Tribology of the Metal Forming Institute in Poznan with the use of TWT-500 N modernised tester (Fig. 2.). The tester is suitable for friction and wear tests in the ambient temperature of up to 600°C, with the load of up to 500 N with the possibility of adjustment of the shaft revolutions up to 110 rev/min.

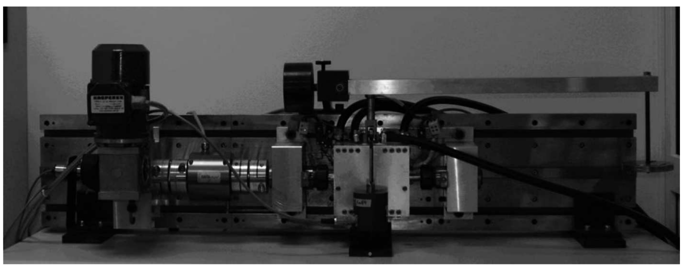

Fig. 2. TWT-500 N tester used for friction and wear tests

The structure of obtained samples was studied in the Metal Testing Laboratory of the Metal Forming Institute. Longitudinal sections were made and microscopic observations were carried out with the use of Nikon Eclipse L150 following etching in a hot two-component reagent (for 316L), whereas bronze samples were etched in a solution of 5 g of $FeCl_3$, 100 ml of H_2O and 50 ml of HCl.

The measurement of porosity was made with the use of Nikon Eclipse L150 and appropriate digital processing using special software.

4. Tests results and discussion

The results of the pressure-density relationship determination after compaction and sintering are shown in the Table 1 and 2. The samples made of BROMIX powder show greater homogeneity of material structure for lower values of pressure as compared to the details made of 316L steel powder. Following sintering, the sample of 316L powder is characterised by greater density as compared to the samples subject to measurements directly after pressing. A similar tendency may be observed for samples made of bronze powder. Porosity of the materials was also tested. The results are presented in the Table 1 and 2 and Fig. 3.

TABLE 1

Relation of density and porosity to pressures for samples made of 316L powder

Pressing pressure [MPa]	Density [g/cm^3]	Porosity [%]
After pressing		
500	6,21	24,8
600	6,39	23,9
700	6,55	22,64
800	6,68	21,98
850	6,86	21,14
After sintering		
500	6,38	22,11
600	6,56	21,43
700	6,7	21,13
800	6,89	20,16
850	6,96	19,74

TABLE 2

Relation of density and porosity to pressures for samples made of BROMIX powder

Pressing pressure [Mpa]	Density [g/cm^3]	Porosity [%]
After pressing		
400	6,84	22,7
450	7,31	17,5
500	7,55	14,8
570	7,53	15
640	7,76	12,38
After sintering		
400	7,23	18,39
450	7,45	15,91
500	7,59	14,33
570	7,67	13,43
640	7,76	12,41

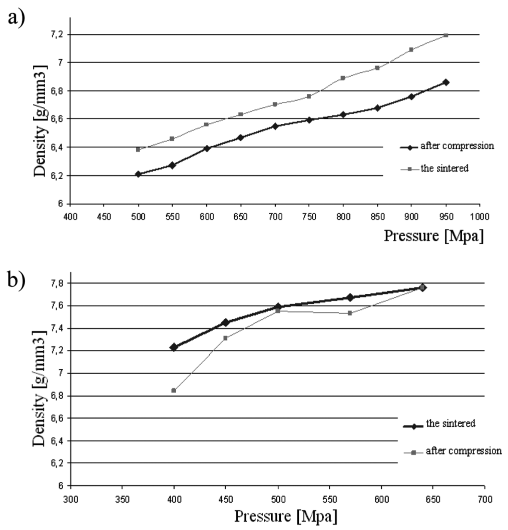

Fig. 3. Comparison of density of materials made of: a) 316L powder, b) BROMIX powder

SEM images of the structure of the mouldings made of stainless steel powders with addition of Cr and Ni and made of BROMIX powders as well as the images of MoS_2 powder are shown in Fig. 4.

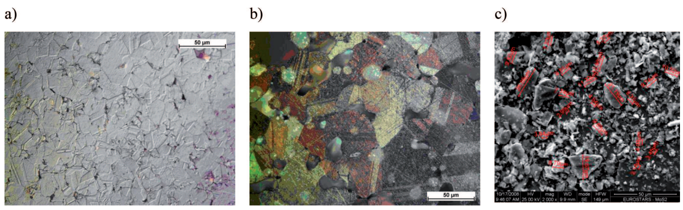

Fig. 4. An example of structure of the mouldings made of: a) 316L austenite steel powder with addition of Cr and Ni, b) BROMIX powder, c) SEM photograph of MoS_2 powder

Results of measurements of hardness depending on pressures are shown in the Table 3.

TABLE 3

Relation of hardness to force of pressure of bronze and 316L steel mouldings

Pressure [MPa]	Hardness HV 0,05
BROMIX	
400	87
450	82
500	84
500	86
570	84
640	88
316L	
500	85
600	109
700	118
800	132
850	128

Strength tests were carried out for samples made with the use of variouscompaction stresses. Fig. 5 and 6 show examples of results obtained from the tensile strength test of the tested materials.

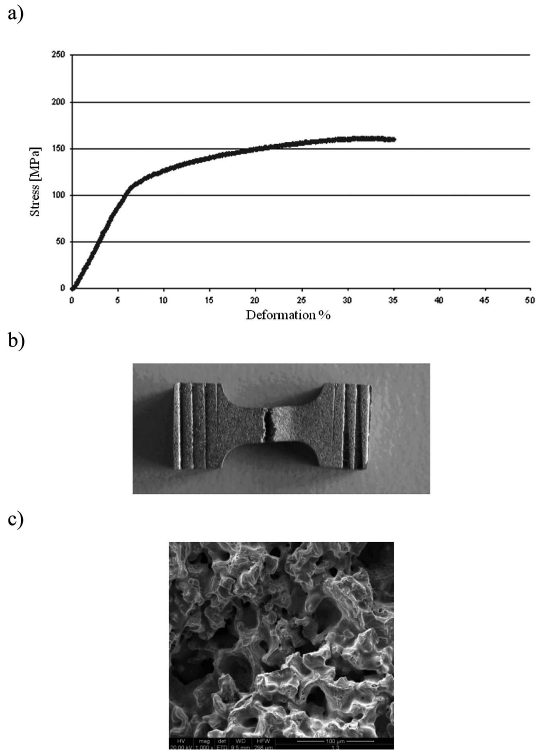

Fig. 5. Tensile testing of mouldings made of BROMIX powder for pressing under the pressure of 500 MPa: a) relation of tension in the function of deformation, b) photographs of the macro sample after ripping, c) SEM photographs of the sample structure

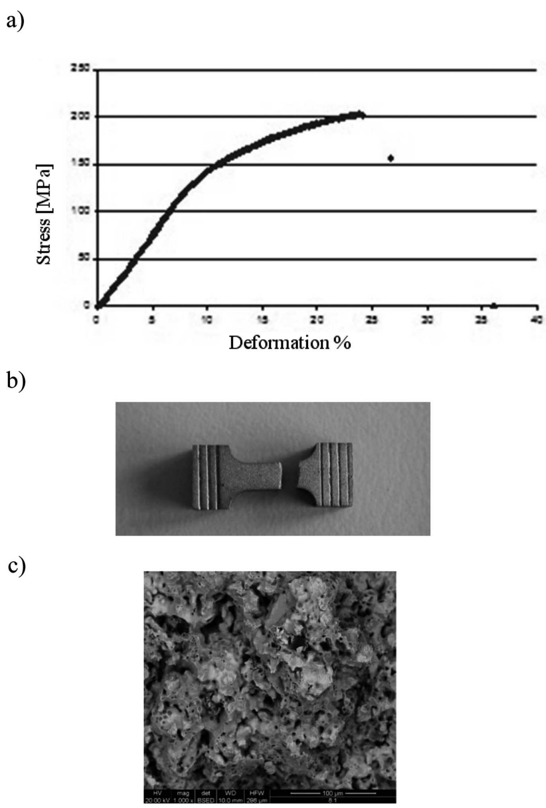

Fig. 6. Tensile testing of mouldings made of 316L steel powder under the pressure of 500 MPa: a) relation of tension in the function of deformation, b) photographs of the macro sample after ripping, c) SEM photographs of the sample structure

On the base of the obtained results, tensile strength of the samples was determined. The tensile strength increased with the increase of sample pressing force. This result can be observed both in the case of 316L steel and bronze samples. The structure of the samples is presented in Fig. 5 c and 6 c.

The analysed samples were subject to compression strength tests. On the base of the measurements made, Young's modulus was determined (Tab. 4). The obtained results made it possible to determine the average value of Young's modulus (E), which was 4,75 GPa for samples made of BROMIX powder and 3.91 GPa for samples made of 316L steel powders.

TABLE 4

Relation of Young's modulus for specified values of pressures in the process of forming of mouldings

Pressure [MPa]	Young's modulus GPa
BROMIX	
400	**4,80**
450	**4,61**
500	**4,29**
500	**4,80**
570	**5,13**
640	**4,87**
Average	**4,75**
316L	
500	**4,01**
600	**3,76**
700	**3,84**
800	**3,78**
850	**4,37**
Average	**3,91**

5. Conclusions

The tests results allow to choose the most favourable parameters of samples manufacturing. The samples are to be used as self-lubricating sliding bearings for heavy-duty operation. The parts are characterised with the high strength, resistance to corrosion and will constitute self-lubricating elements owing modification of the top layer with nano- and microparticles and NT-100 oil. Particles of solid lubricant were implemented in the internal structure of the samples and generate the lubricant film on the surface cooperating with the counter-sample. The tests make it possible to develop the technology of production of iron and copper powder based powder components, in which the top layer will be subject to modification.

The tribological tests make it possible to determine most optimum materials and means used for modification of the top layer of self-lubricating sleeves. The analysed friction pair with the use of the above-mentioned method of modification is characterised by low friction and wear and stable range of operation of the friction pair.

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