Mechanical and Acoustical Properties of Bushings Made of Low-Alloyed Materials and Used in Brake Systems of Transport Vehicles

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Abstract. The increasing freight volumes and the speed of transport, as well as increasing demands with regard to safety have made the search and development of new anti-friction materials a topical task. The main requirements to the bearing assemblies include reliability, durability, simplicity and ease of maintenance. The paper considers the features of the manufacture of braking sliding sleeves/ bushings for transport vehicles made from sintered low-alloy powder materials based on Fe-C-Ni with Ni and Mo contents of 0.3%. The paper presents data on the microstructure of the sintered samples of the products and research of some physical and mechanical properties. Surface quality and friction coefficient were evaluated by surface profiling and tribological tests, correspondingly. Particular attention is paid to the use of ultrasonic testing for quality control of the products.

1. Introduction
Sliding sleeves and bushes made of sintered powder materials are widely used in the manufacturing of machinery, railway and various vehicles. Braking assemblies with the braking leverage transmission have specific operating conditions. It presents a system of levers that transmit forces arising from the pressure of the compressed air on the piston of the brake cylinder to the friction units of the brake system. The connection units of the brake system experience great dynamic and vibration loads. In addition, increased friction increases in the connection units during braking and brake release. In order to reduce friction, bearing bushes with heightened anti-friction properties are used. The use of metal powder
bushings (MPB) allows extension of the service life of bearing units several times at the same
time reducing operational, maintenance and repair costs [1, 2].

Given the importance of braking system assemblies, it is necessary to improve the quality
assurance of the components. By means of non-destructive testing, in particular, ultrasonic
testing (UT), it is possible to predict the mechanical properties of the braking elements, to
assess the presence of pores and defects. It was shown in [3] that the main feature of sintered
products distinguishing them from powder metals is the presence of free surface of the pores
as a major factor in the development of phase transformations. The free pore surface
manifests itself, on the one hand, as the stress relaxation space, and, on the other hand, as a
place where various defects emerge. In this case, it is advisable to use UT methods.

One of the main advantages of MPB is the presence of pores on their surface that facilitates
the formation of a stable oil film. As a result of the pre-dip of MPB in hot oil, the friction
surface is provided by the lubricating film for a long time. MPB are effective substitutes of
bearing products made of bronze and brass. The optimal physical and mechanical properties
were established to be the following: porosity in the range of 15 – 20%, oil absorption – not
less than 1.8%, the compression strength – 180 MPa. To improve the strength properties, alloy
powder materials containing nickel and manganese in the range from 1.5 to 2.5% are
commonly used [4]. This provides an increase in strength and hardness. However, it should be
emphasized that these additives significantly increase the cost of metal powder products [5].

The purpose of this paper was to examine the possibility of manufacturing of MPB for
leverage brake system in transport using low-alloy powder compositions [6] with the contents
of Ni and Mo up to 0.3% and to assess the impact of residual porosity on the mechanical and
tribological properties of MPB. It has been tasked to evaluate the use of UT to control the
degree of porosity and the presence of defects.

2. Experimental studies

2.1. Mechanical properties and microstructure

Powder mixtures containing the alloying elements Ni, Cu, and Mo were used to produce the
samples (table 1). Mixtures AHC100.29 + Cu + Ni + C produced by Hoganas AB (mixture 1)
and the same mixture with an increased Cu content (mixture 3) [7] were assumed as basic
materials. MPB samples were made also from the low-alloy experimental mixture with Ni and
Mo content less than 0.3% and reduced phosphorus content (mixture 2).
Table 1. Specification of materials for manufacturing of MPB samples.

| Mixture | Components [mass fraction by weight, %] | Powder properties |
|---------|----------------------------------------|-------------------|
|         | Fe, % | Ni, % | Cu, % | Mo, % | S, % | P, % | C, % | Kenologi  |
| Mixture 1 | 94 | 2.0 | 2.0 | 0.5 | 0.2 | 0.1 | 1.2 | 1.0 | 38 | 3.18 | 7.05 |
| Mixture 2 | 96.5 | 0.22 | 2.27 | 0.28 | 0.04 | 0.01 | 0.68 | 0.7 | 40 | 3.15 | 6.85 |
| Mixture 3 | 94 | 2.5 | 2.0 | 0.5 | 0.2 | 0.1 | 0.7 | 1.0 | 40 | 3.05 | 6.90 |

Pressing of MPB samples specified in table 2 was carried out in a rigid mold using a hydraulic press at a pressure of 600 MPa. Sintering was performed in a protective atmosphere during 40 minutes at a temperature of 1120°C.

Table 2. Main geometrical parameters and some physical and mechanical properties of MPB.

| Outer diameter [mm] | Wall thickness [mm] | Height [mm] | Porosity [%] | Hardness [HB] |
|---------------------|--------------------|-------------|--------------|-------------|
| 40                  | 4                  | 30          | 15           | 120         |
| 80                  | 6                  | 80          | 18           | 90          |

The results of the study of physical and mechanical properties of the MPB samples made of mixtures specified in table 1 are shown in figure 1. The compression strength of the samples was determined according to ISO2739: 2012 [8].
Figure 1. Compression strength of MPB samples vs. density.

The sintered material of low-alloy powder (mixture 2) has a strength somewhat lower than the control material (mixture 1). However, given the significantly lower content of costly components in mixture 2, it can be recommended for the MPB production.

The microstructure of a sample from mixture 2 reflects the uniformly distributed porosity (figure 2).

Figure 2. Microstructure of MPB of low-alloy powder (Mixture 2): A -x50; B – x500.

Studies have shown that when mixtures 1 and 3 are used for MPB production, the problems with obtaining homogeneous samples by their chemical composition and structure appear, since the mixtures are produced by mixing the starting powders. Mixture 2 is made by spraying a steel melt with the predetermined chemical composition followed by the addition of solid lubricant. Therefore, to obtain MPB for brake systems designed to operate in the conditions of impact loading and complex stress, it is advisable to use a low alloy powder composition, such as mixture 2. However, the final conclusion can be drawn based on the tribological properties.
2.2. Surface quality and tribological properties

Surface quality of the low-alloyed MPB was investigated by using “Taylor Hobson Ltd” 3D measurement system. 2D and 3D measurements with stylus instrument were achieved by basic “stepping” method (figure 3, figure 4). Main roughness and surface texture parameters according to ISO 4287 “Surface texture: Profile method - Terms, definitions and surface texture parameters” and EN ISO 25178-2 “Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters” respectively are given in table 3.

![Figure 3. Surface profilogram of a low-alloyed powder part.](image)

![Figure 4. View of 3D surface image and photo simulation of the low-alloyed powder part.](image)

| 2D amplitude roughness parameters | Ra, [µm] | 2.37 |
|-----------------------------------|----------|------|
|                                   | Rz, [µm] | 11.2 |
| 3D amplitude texture parameters   | Sa, [µm] | 2.65 |
|                                   | Ssk      | -1.56|
| 3D spatial parameter              | Str      | 0.766|
| 3D functional parameter           | Vmc, [mm³/mm²] | 0.0187|
| 3D functional parameter           | Sfd      | 2.56 |

Table 3. Roughness and surface texture parameters of the low-alloyed powder parts.
The results of the measurement confirm that powder part of the new low-alloyed powder material has a relatively high surface quality. It should be mentioned that the surface is sufficiently close to isotropic since the value of parameter $\text{Str}$ (texture aspect ratio of the surface, measures the isotropy of the surface) is close to 1 (maximal value of $\text{Str}$). The highest value of functional parameter $\text{Vmce}$ (core material volume of the scale-limited surface, indicates a measure of the material forming the surface between various heights) proves a good bearing ability of the surface due to great core material volume in contact during normal exploitation time (after wear-in). The negative value of amplitude parameter $\text{Ssk}$ (skewness of the scale-limited surface, represents the degree of symmetry of the surface heights about the mean plane) confirms good lubricant retention ability.

Tribological study was done using tribometer of “CSM Instruments” (Switzerland). The friction coefficient was evaluated using “ball-on-disk” testing without lubrication, when the tested example was used as a disc, but a high-strength steel ball with the contact radius 3 mm was used as a counter-body. The main parameters of testing were: force – 3 N; measurement period – 20 s, linear velocity – 0.05 m/s.

The friction coefficient as a function of time, laps (number of rotation cycles) and length of friction path for compacted and sintered powder parts are shown in figure 5. The stable curve of friction coefficient with a relatively small fluctuation along the length of friction is observed. The visual examination after testing in order to reveal any traces of wear or plastic deformation of the surface revealed that the standard friction process occurred during testing. The average value of friction coefficient for low-alloyed MPB was $\mu = 0.22$.

![Figure 5. The friction coefficient as a function of time, laps and length of friction path for sintered powder part.](image)
2.3. Ultrasonic testing of MPB

To assess the degree of homogeneity of MPB and the possibility of determining the possible cracks by means of ultrasound, the TOF (time-of-flight) method was used. Traditionally, the method demonstrates its efficacy in the detection of cracks in welds and metal products [8]. The method is based on sounding the zone between the transmitter and the receiver, and the analysis of signals generated by direct propagation of ultrasound, bottom reflections and diffraction reflections from the cracks if they appear. The purpose of our measurements was simultaneous estimation of heterogeneity of material properties of the PMB products and locations of cracks. For comparative examination, PMB samples with longitudinal cracks by height and PMB without visible defects were chosen.

Measurements were carried out in the surface transmission mode at a fixed acoustic base between the transmitter and the receiver of 20 mm (figure 6). The base was oriented perpendicular to the longitudinal axis of MPB to be perpendicular to the direction of the crack. To perform the measurements on the cylindrical surface, transducers with point contact were used requiring a small amount of liquid lubricant. Ultrasound excitation signals were sinusoidal pulses with duration of 2 periods at a carrier frequency of 1 MHz. The samples were measured in 4 sectors around the circumference and in 3 zones by height.

Figure 6. Illustration of ultrasonic measurements: on the left – a sample with a crack; on the right – the application of the sensors.

The results of ultrasonic measurements on the MPB surface showed that the samples were heterogeneous. The ultrasound velocity related to the longitudinal wave varied in different zones of the samples from 3.75 to 5.00 km/s, showing this heterogeneity related to the composition and porosity distribution and caused by the technological process. The distribution of ultrasound velocity of in the samples (figure 7) indicates a greater variability of properties by height than in the zones of perimeter. There was a sharp increase of ultrasound velocity in one of the end zones caused by the non-uniform powder compaction during manufacturing.
Figure 7. Distribution of ultrasound velocity $C$ (km/s) in the perimeter (zones 1-4 by axis X) and by height (zones S1-S3 by axis Y) in two MPB samples.

Figure 8. Plots of ultrasonic signals by samples’ height (see description in the text): in the left–the sample without defects, in the right–the sample with a longitudinal crack. Brace marks the height of the crack.

In the area of the crack, ultrasonic signals were recorded in 10 zones by the sample’s height, in order to observe the changes of ultrasonic signals related to the development of cracks. Figure 8 shows the two-dimensional plotting of plurality of ultrasonic signals obtained by height, where the abscissa axis is time of ultrasound propagation, the axis of ordinates is the zone of the sample’s height, and the brightness corresponds to the signal amplitude. The two-dimensional plot of the ultrasonic signals shows a clear detection of the cracks by the lack of the direct propagation signal and the relative gain of delayed echoes from the opposite end of the sample. Thus, a simple analysis of signal plots can indicate the appearance of cracks very illustratively.

3. Conclusions
1. The use low-alloyed iron-based powders can improve strength characteristics of products without increasing their cost.
2. The achieved 2D surface roughness parameters, 3D texture parameters and the friction coefficient (average value 0.22) confirmed the appropriateness of the new low-alloy metal powder material on the iron base for producing bushing for braking systems.
3. TOF method of ultrasonic testing is able to detect cracks in the PMB, and also is promising to control the spatial deviations of the material properties in the PMB products.
4. References

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