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Slide finishing burnishing of metal alloys and metal matrix composites

Gładkościowe nagniatanie ślizgowe stopów metali i kompozytów na osnowie metalowej

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Results of the research performed at the Institute of Advanced Manufacturing Technology (IAMT) regarding the possibility of slide burnishing of metal alloys and metal matrix composites are presented. Results include among others, analysis of surface geometry, microstructure and microhardness changes of the surface layer for selected materials.
KEYWORDS: slide burnishing, surface geometrical structure, metal alloys, metal matrix composites

The main characteristics of the technological quality of machine parts are the wear resistance, which is determined by properties of the surface layer (SL), including: surface geometry (SG), hardness distribution and stress state. An effective method of shaping the favorable properties of SL is burnishing, which improves the resistance of machine parts to abrasive wear and improves their fatigue strength – this applies in particular to co-operating elements in moving connections and subject to surface loads.

Compared to other finishing methods such as grinding, honing, lapping or polishing, burnishing has many technical and economic advantages. It allows to obtain surfaces with very small roughness (even with *Ra* = 0.05÷0.10 µm), large radius of rounding of vertices and recesses of the profile (much larger than after grinding) and large material share of the unevenness profile, and also produce SL crush (gaining hardness which decomposes with small gradients) and compressive stresses while maintaining the internal metal fibers [1, 2].

Slide finishing burnishing, especially with a diamond (natural or polycrystalline), is used in the finishing work of both higher hardness components (e.g. hardened surfaces and hard diffusible and electroplated coatings) and low or medium hardness components when small crushing force is required (e.g. during thinning of thin-walled components). An important advantage of sliding burnishing is the ability to use it for finishing work on complex shapes or areas where tooling is difficult to access, since the workpiece for sliding burnishing has a simple construction and a small working part [3, 4].

Methodology of research

The research includes the following:

- EN AW-AlCu4MgSi(A) aluminum alloy in the form of rolls with a diameter of approx. Ø75 mm, chemical composition [5]: 3.8÷4.8% Cu; 0.4÷1.1 Mg; 0.4÷1.0 Mn; the rest – Al;
- two types of composites, in the form of rollers with a diameter of Ø35 mm, on a matrix of aluminum alloys with a chemical composition [6]:

- A6061 + 15% Al2O3 (17 µm particles); chemical composition of the matrix: 0.4÷0.8% Si; 0.7% Fe; 0.15÷0.4% Cu; 0.8÷1.2% Mg; 0.15% Mn; the rest – Al;
- A390 + 2.5% SiC (particles with a diameter of 10 µm); chemical composition of the matrix: 4÷5% Cu; 0.45÷0.65% Mg; 16÷18% Si; 0.5% Fe; 0.1% Mn; the rest – al.

The sliding burnishing process was carried out using a chisel with working element made of polycrystalline diamond-tipped, Ti_3SiC_2 bonded, round-shaped, 3.5 mm radius bowl (fig. 1) [7]. Turning and burnishing was performed at Mori Seiki's NL2000SY turning and milling center. A small amount of Hysol R oil from Castrol was used in the burnishing process.

Burnishing parameters were as follows:

- for aluminum alloy: feedrates *f* = 0.04; 0.07 and 0.10 mm/rev; speed *v* = 40 m/min; *F* = 50; 80; 120; 160 and 200 N;
- in the case of composite aluminum alloy matrix A6061 with Al_2O_3 hard particles: feedrates *f* = 0.02; 0.05 and 0.07 mm/rev; speed *v* = 30 m/min; *F* = 50 and 70 N;

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- in the case of composite on aluminum alloy A390 matrix with SiC hard particles: feedrates *f* = 0.02; 0.05 and 0.07 mm/rev; speed *v* = 30 m/min; force *F* = 40; 60 and 80 N.

Fig. 1. Slide burnisher with working element of diamond composite

Prior to the burnishing process, the surface of rollers was turned, providing a surface roughness parameter *Ra* in the range of 0.75 to 1.25 µm.

The 2D measurements of SG parameters were made using the HOMMEL TESTER T1000 profilometer. Various parameters of surface roughness were determined – the paper shows the parameter *Ra*.

In addition to the measured values, the K_{Ra} roughness coefficient is also directly determined:

$$K_{Ra} = \frac{Ra'}{Ra}$$

where: *Ra'* – arithmetic average deviation of the profile from the midline before burnishing, *Ra* – arithmetic mean deviation of the profile from the midline after burnishing.

Metallographic studies were performed on JEOL's JSM-6460LV scanning electron microscope (SEM), equipped with a set of X-ray spectrometers: EDS, WDS, EBSD. In addition, the Precision Etching Coating System, model 682 PECS, from Gatan, was used for precision etching and surface coating, with an angle-setting device.

Micro-hardness measurements were made by Vickers on the Future Tech. Corp. digital FM-7 digital micro-hardness-meter.

Test results

Figs. 2 and 3 show the microstructures of the examined composites on the metal matrix observed on transverse cuts. Fig. 2 shows irregular longitudinal Al_2O_3 reinforcing phase particles (average size 17 µm), which are grouped into composite clusters of alloy A6061. Fig. 3 shows, however, the irregular SiC reinforcing phase particles (average size 10 µm) in the composite matrix of the A390 alloy.

Fig. 4 illustrates the measurement results (in the form of a contour plot) of the *Ra* surface roughness parameter after burnishing the EN AW-AlCu4MgSi(A) alloy, depending on the feedrate and burnishing force. The *Ra* = 0.10÷0.34 µm (*Ra'* output parameter after turning was 0.76÷1.08 µm), with the smallest values obtained for feedrate *f* = 0.04 mm/rev. and burnishing power *F* = 120 N. The value of K_{Ra} in this case exceeded 10.

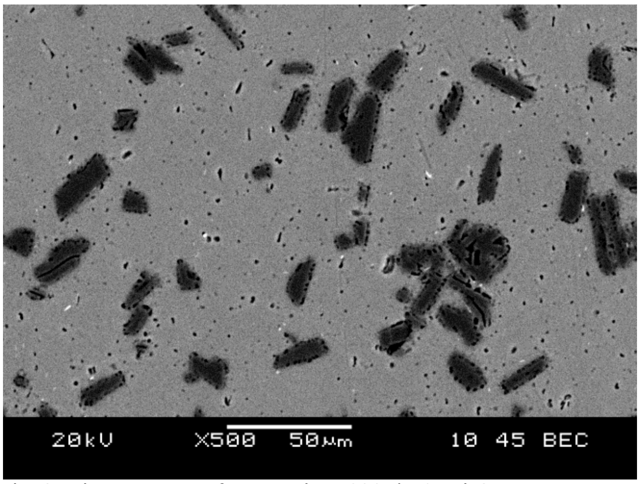

Fig. 2. Microstructure of composite A6061/15% Al_2O_3

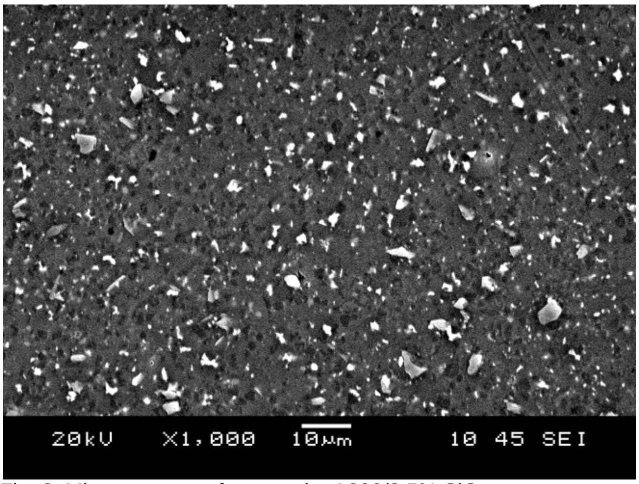

Fig. 3. Microstructure of composite A390/2.5% SiC

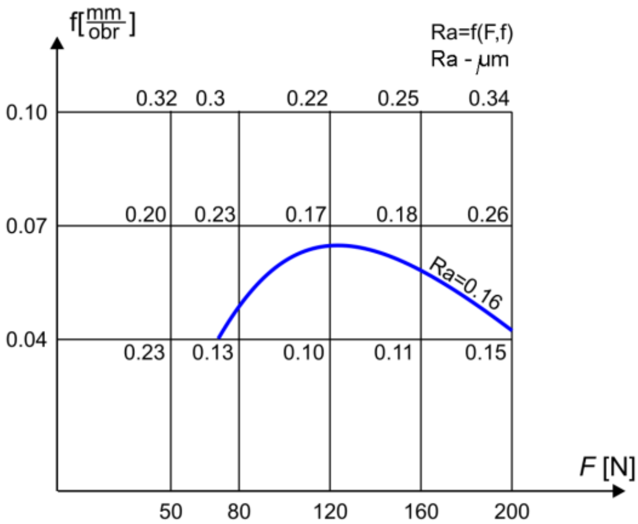

Fig. 4. Relation of surface roughness parameter *Ra* from feedrate *f* and burnishing force *F* for EN AW-AlCu4MgSi(A) alloy after slide burnishing at speed *v* = 40 m/min using a diamond composite tip with a radius of 3.5 mm

As a result of burnishing composites on aluminum alloy matrix – A6061 + 15% Al_2O_3 and A390 + 2.5% SiC – values of the surface roughness *Ra* = 0.13÷0.31 µm (*Ra'* = 0.85÷1.15 µm), with the smallest values obtained for the feedrate f = 0.02 mm/rev and the burnishing force F = 60÷70 N (fig. 5). In this case, the K_{Ra} value was 6÷8.

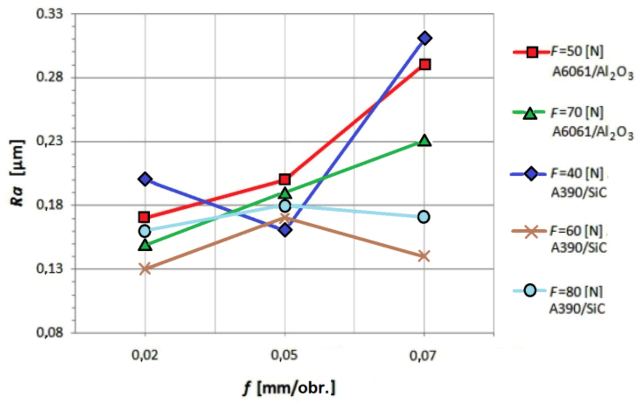

Fig. 5. Relation of surface roughness parameter *Ra* from feedrate *f* and burnishing force *F* for composites made of aluminum alloy after slide burnishing at speed v = 30 m/min using a diamond composite tip with a radius of 3.5 mm

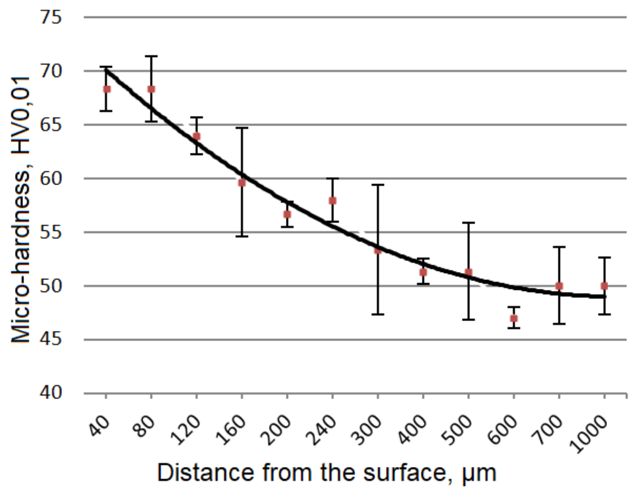

Fig. 6. Micro-hardness changes depending on the distance from the surface for composite A6061/15% Al_2O_3

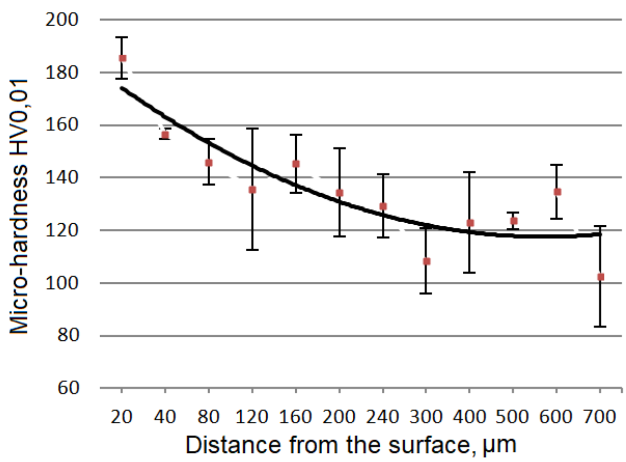

Fig. 7. Micro-hardness changes depending on the distance from the surface for composite A390/2.5% SiC

Fig. 6 and 7 show the results of micro-hardness measurements on lateral wrinkles from the edge of the burnished surface to the sample core. These graphs show an increase in the hardness of the outer layer of both composites. After burnishing composite A6061 + 15% Al_2O_3, over 30% increase in hardness of the topcoat was obtained, and after burnishing composite A390 + 2.5% SiC, this increase was even greater and amounted to about 50%.

Conclusions

The presented results indicate the possibility of using sliding burnishing treatment to achieve a significant improvement of the surface topography – not only for metal alloy but also metallic composites.

For EN AW-AlCu4MgSi(A) alloy, value of the K_{Ra} index was greater than 10, while for composites with an aluminum alloy matrix, it was in the range of 6÷8.

Achieving a significant improvement in topography of composite metal surfaces (used in automotive and aerospace industry, for example) is very important for applications requiring good tribological properties.

It should also be noted that slide finishing burnishing with a diamond composite allows the micro-hardness of the SL to be increased by approximately 30÷50% relative to the core of the composite on the metal matrix.

In the case of metal-based composites with hard Al_2O_3 or SiC particles, the impact of burnishing on fatigue strength can be very different due to the possibility of the formation of moles on the surface of the void instead of hard particles (especially when they have larger dimensions).

In IZTW, the effect of burnishing on the fatigue strength of composite components is determined by the bending method. Both comparative tests of the sample with the surface and obtained by other finishing methods (for the assumed value of the periodic stress) and full tests to determine the limit value of the extreme periodic stress can be performed here, which may be repeated a number of times up to Element destruction (with Wöhler curve plot – according to ISO 1143:2010 (E)).

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