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Wear resistance of the diamond-impregnated specimens fabricated using the SPS process

Badania odporności na zużycie ścierne segmentów metaliczno-diamentowych otrzymanych metodą SPS

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This paper presents the tribological properties of the diamond-impregnated specimens in the grinding process of sandstone materials. Obtained metallic-diamond composites were homogenized in Speed Mixer and sintered by SPS (spark plasma sintering). The matrix was prepared from: Cu-Sn (NAM-40 80/20 containing 20% wt. Sn) and Fe-Cu-Sn powders. After consolidation the diamond-impregnated specimens were tested for density using the hydrostatic method, Rockwell's hardness using B scale and for wear rate on abrasive sandstone using a testing rig specially designed to simulate the tool application conditions.

KEYWORDS: metallic-diamond tools, matrix, SPS, wear resistance

Metallic-diamond tools are widely used in the process of shaping cavity materials in various industrial sectors. Diamond tools for cutting and grinding natural stone are a group of products whose application dynamically grows. Their main component is abrasive (diamond) and metal matrix. Authors of professional literature underline the importance of proper selection of matrix material and the technology of manufacturing these tools.

The basic technology of making metal-diamond tools is free sintering and hot pressing. The metal-diamond segments can also be manufactured by: detonation molding [1], powder injection molding [2] or SPS (spark plasma sintering) [3, 4].

The heating process in the SPS method is realized by the flow of current through the sintered material. Around the contact areas of the particles are the „necks" [5], which gradually grow. This phenomenon is accompanied by plastic deformation [6]. In the SPS method the oxide surfaces of the powder particles are much easier to reduce (mainly by the point-at-high temperature that causes them to evaporate). Also faster (i.e. at lower temperatures) compared to traditional sintering processes is the phenomenon of sinter activation. This allows to conduct the process at a temperature lower than 200÷500 °C than in conventional methods and in a much shorter time. The heating time of the material together with its isothermal sintering in this method is usually in the range of 5 ÷ 20 min. This allows sintering of nano-crystalline powders without grain growth. In comparison with the isostatic hot pressing method, the demand for electricity in the SPS process is about 20÷30% lower, which is very important for economic reasons [7].

The research was conducted in response to the growing demand for diamond tools for cutting and grinding stone materials. The main aim of the work was to determine the mechanisms of wear and the properties of matrix materials in conditions reflecting their actual functioning. The developed materials can be an alternative to materials commonly used for the production of professional metal-diamond tools (Co, Ni).

Methodology and research results

Test specimens were made of elemental tin bronze powders, reduced iron and synthetic diamond. SEM images show the shape of the particles used (fig. 1).

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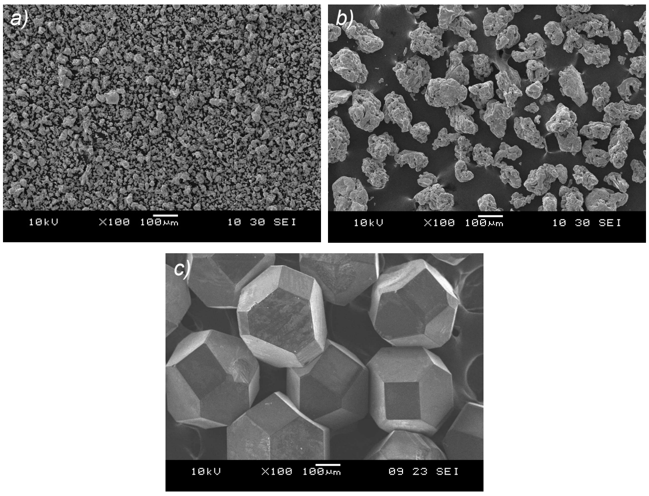

Fig. 1. Electron image of powder: a) Bronze Cu-Sn NAM-40 80/20 with content of 20% Sn; b) iron of grade NC100.24; c) 40/50 US mesh grade synthetic LS4820 + diamond

Metal powders prepared from two matrix materials: Cu-Sn (blend A1), Fe-Cu-Sn (blend A2) and synthetic LS4820 + grade 40/50 mesh and 20% (5% by mixing in a Speed-Mixer DAC 400.1 FVZ homogenizer. The prepared blends were sintered using the SPS method in a specially designed die (fig. 2a), which allowed simultaneous sintering of six samples of nominal size ⌀7 × 7 mm (fig. 2b). Regardless of the composition of the mixture to be consolidated, the powder was held for 2 min at maximum temperature and under 35 MPa. For each material, the ironing temperature was chosen in such a way as to obtain sintering with a porosity of no more than 5%. SPS sintering was performed under argon atmosphere using FCS SPS HP 5.

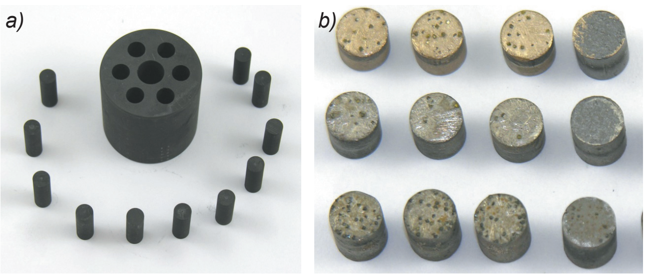

Fig. 2. Graphite matrix for sintering of metal-diamond segments with a diameter of ⌀7 mm (a); segments obtained by SPS (b)

Composition of sinter and parameters of sintering process are presented in Table I.

All sinters were subjected to density measurements (by air and water weighing), hardness and abrasion resistance, using Struer's RotoPol-21 grinder. Measurement of the resistance of metallic-diamond segments to abrasive wear consisted in simultaneous movement of three cylindrical specimens with respect to the abrasive wheel made of sandstone Abrasive, using water as a coolant and washing sanding abrasive products. The segments were placed in steel clamps, which were fastened in the standard sample holder provided with the RotoForce-4 head. Selected physical and mechanical properties are presented in Table II. The abrasive wear resistance of the metallic-diamond segments is shown in fig. 3.

TABLE I. Composition of blends and sintering conditions by SPS method

Marking of blendi	Composition of blend,% vol.	Parameters of the sintering process			
		Heating speed, °C/min	Tempe-rature, °C	Time, min	Pressure, MPa
Cu-Sn	95% Cu-Sn 5% synthetic diamond	100	550	2	35
Fe-Cu-Sn	95% Fe-Cu-Sn 5% synthetic diamond		750		

TABLE II. Results of density and hardness measurements of sinter*

Marking of blend	Composition of blend, % vol.	Average density value, g/cm^3	Average hardness value, HRB
Cu-Sn	95% Cu-Sn 5% synthetic diamond	8,69 ±0,04	99 ±1,04
Fe-Cu-Sn	95% Fe+Cu-Sn 5% synthetic diamond	7,76 ±0,04	82 ±0,82

* The uncertainty ranges were estimated for the confidence level 1 – α = 0,9

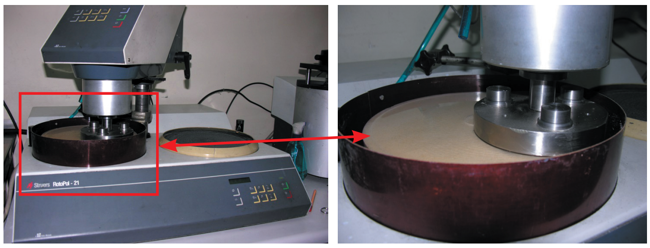

Fig. 3. Test stand for abrasion wear of metallic-diamond segments together with a stone abrasive wheel

During each twenty-second measurement cycle, the segments were individually pressed into a stone abrasive wheel with a force of F = 20 N. The rotational speed of the disc was 150 rpm. Under the test conditions, the average linear velocity of the sample was 1.72 m/s. After each twenty-second measurement cycle, the segments were thoroughly washed in ethanol (in ultrasonic scrubber), dried and weighed to within 0.1 mg. After calculating the loss of volume, they were subjected to observation using the Dino Lite Digital Microscope Dremler, a 40× magnification, to determine the number of diamond crystals on the working surface of the segment. The results of the study are presented in Table III and fig. 4.

TABLE III. Loss of segment volume and number of diamond crystals on its working surface after consecutive measurement cycles and average number of diamond crystals on segment surface

Matrix material and segment number		Volume change (mm^3) and number of diamond crystals - in parentheses - as a function of the friction path (m)							Średnia liczba kryształów diamentu $\bar{D}$
		29,13	58,25	87,38	116,51	145,64	174,76	203,89	
Cu-Sn	s1	0,90 (18)	1,60 (17)	2,43 (19)	3,08 (21)	4,69 (23)	5,48 (24)	6,10 (25)	21,0
	s2	1,09 (14)	1,76 (16)	4,59 (15)	6,92 (14)	8,32 (18)	12,95 (16)	15,09 (14)	15,3
	s3	1,94 (11)	4,93 (11)	6,33 (8)	9,40 (12)	14,43 (13)	18,69 (14)	24,18 (15)	12,0
Fe-Cu-Sn	s4	2,90 (7)	8,73 (9)	13,72 (6)	25,48 (9)	30,46 (8)	39,92 (7)	43,92 (6)	7,4
	s5	4,21 (11)	10,68 (10)	15,81 (10)	22,47 (9)	25,98 (8)	37,42 (5)	43,32 (2)	7,9
	s6	3,24 (9)	6,71 (8)	14,15 (9)	20,74 (10)	22,34 (11)	29,29 (12)	31,42 (12)	10,1

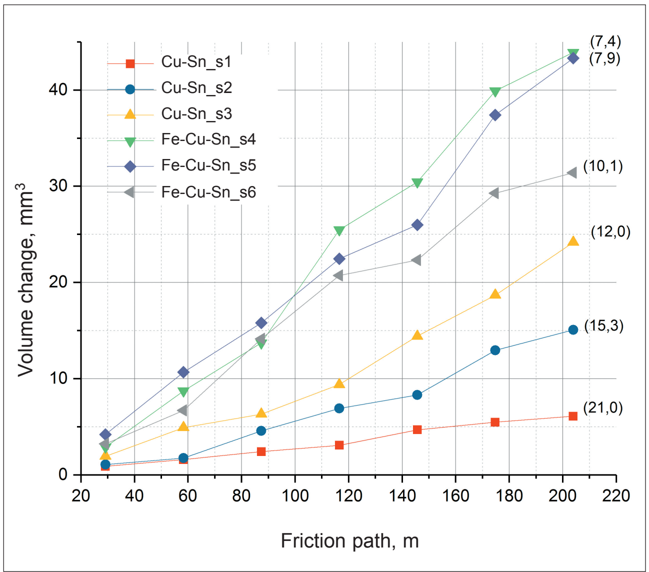

Fig. 4. Changing the volume of segments as a function of the friction path (in brackets the average number of diamond crystals on the working surface of the segment is given)

Analysis of results

The accepted parameters of the sintering process enabled obtaining high density sintering, similar to the theoretical density (Table II). The hardness of the obtained sinter was in the range of 82÷99 HRB. Lower hardness values were noted for iron based sinter.

Tribological studies have compared the abrasion resistance of Cu-Sn and Fe-Cu-Sn metal abrasives. Copper-based sinters are characterized by higher resistance to abrasion from iron-based friction. The study of the wear and tear of the metallic-diamond segments indicated the importance of the concentration and size of diamond crystals and their distribution in the volume of the segment, which indirectly resulted from the effect of the homogenization of the mixture.

The measurements show that the momentum of wear of the segment during processing of abrasive materials is most strongly influenced by the number of diamond crystals per unit working area of the segment. Less segments were used in which more diamond crystals were involved in sandstone processing (Table III, fig. 4).

The results of the study confirm the benefits of using the SPS method to obtain metal-diamond tools for cutting and grinding stone materials. It is possible to obtain material with better physico-mechanical properties at lower sintering temperature (200÷500 °C) and in a much shorter time (5÷20 min) [8].

Conclusions

Based on the results of the study, it was found that:

- Using the SPS method, it was possible to obtain materials with a density close to the theoretical and high hardness.
- Tribological studies have shown the effect of diamond grain concentration on the degree of wear of the segments.
- The best combination of physical and mechanical properties was made with materials based on tin bronze.
- The materials used meet the criteria for their use in the production of diamond tools for stone materials.

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REFERENCES

1. Novikov N.V., Maistrenko A.L., Trefilov V.I., Kovtun V. "Structure and properties of shock-wave sintered diamond composites". *Industrial Diamond Review*. 51, 1 (1991): s. 20–23.
2. Risso L., Vicenzi B., Bernieri S. "Improved cutting performance of diamond beads by means of innovative shape". *Industrial Diamond Review*. 67, 4 (2007): s. 28–30.
3. Tillmann W., Kronholz C., Ferreira M. "Novel current induced short--time sintering processes for the production of diamond tools". *Proceedings of Euro PM2009 Congress & Exhibition*. Copenhagen, Denmark, 2009, s. 796–803.
4. Schmidt J., Knote A., Armbrüster M., Weißgärber Th., Kieback B. "Spark Plasma Sintering of diamond impregnated wire saw beads". *Applicazioni & Tecnologia*. 64 (2011): s. 35–40.
5. Jaworska L., Putyra P., Wyżga P., Figiel P. „Nowoczesne metody spiekania". *Annales Universitatis Paedagogicae Cracoviensis*. 6 (2013): s. 35–40.
6. Michalski A., Siemaszko D. „Impulsowo plazmowe spiekanie nanokrystalicznych węglików WC-12Co". *Inżynieria Materiałowa*. 3 (2006): s. 629.
7. Hebda M. „Spark Plasma Sintering – nowa technologia konsolidacji materiałów proszkowych". *Mechanika. Czasopismo Techniczne*. 6-M, 11 (2012).
8. Sprawozdanie IZTW DS.14-3.1 – praca niepublikowana. ■