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Alumina-Ti(C,N) ceramics with TiB_2 additives

P. Putyra*, M. Podsiadło, B. Smuk
Institute of Advanced Manufacturing Technology, ul. Wrocławska 37a, 30-011 Kraków, Poland
* Corresponding author: E-mail address: piotr.putyra@ios.krakow.pl

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ABSTRACT

Purpose: The aim of the study presented in this article is to determine the effect of TiB_2 addition on the selected properties of ceramic tool materials. The effect of titanium diboride additives on the density, porosity, Young's modulus and Vickers hardness of Al_2O_3-Ti(C,N) matrix ceramics was determined.

Design/methodology/approach: Al_2O_3-Ti(C,N) ceramics with TiB_2 addition were sintered by SPS method. Materials for SPS sintering were pressed in graphite die with pressure of 35 MPa. The max. pressure was obtained after 10 minutes. Sinter process was operated in nitrogen atmosphere. Density, Vickers hardness and Young's modulus was determined for these materials. The materials were also subjected to tribological analysis. The results were compared with the properties of Al_2O_3-Ti(C,N) matrix material.

Findings: The use of SPS-method in the production of ceramic materials is possible reduce sintering temperature and sintering time. Depending on the TiB_2 additives used, the relative density values of individual materials were in the range of 94.4% to 97.7%. Young's modulus values for these materials were in the range of 392 GPa to 414 GPa, and Vickers hardness in the range of 1966 to 2225 HV1. The results of tribological analysis showed a friction coefficient value for the matrix material of 0.51. For the other materials, the friction coefficient values were in the range 0.31 to 0.49.

Practical implications: Ceramic materials with the addition of titanium diboride may be used in cutting tools. Study of the composition and production technology of such tools allows for the minimisation of the use of liquid cooling lubricants in the machining process and the achievement of higher cutting speeds.

Originality/value: Titanium diboride additives were added to the structure, resulting in a reduced coefficient of friction, which was measured at between 61% and 96% of the base material coefficient.

Keywords: Alumina; Titanium diboride; SPS-sintering; Mechanical properties

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MATERIALS

1. Introduction

Ceramic Al_2O_3-matrix composites with the addition of reinforcement phase Ti(C,N) are characterized by high physical and mechanical properties [1]. These materials are used in the manufacture of cutting tool with the use mainly for difficult cutting materials. Preliminary studies conducted at the Institute of Advanced Manufacturing Technology, shown that the Al_2O_3-Ti(C,N) multi-point cutting tools are characterized by relatively high friction coefficient (0.51). The steel ball with a diameter of 3.2 mm in the method of "ball-on-disc" was used. For the friction coefficient reduction the PVD and CVD coatings are applied on tool materials, quite accurately described in the literature [2-4]. Reducing the friction coefficient between the workpiece surface and the surface of the cutting tool could also be realized by introducing solid lubricants into the matrix tool [5]. Solid lubricants, also known as lubricating materials, are characterized by a layered crystal structure. It is important that in such a structure, there were weak bonds between the layers, which allow their shear [6,7].

Based on the results of mechanical and tribological properties presented in [8] assumed that the content of the lubricants in the ceramic tool should not exceed 10 vol.%. For the Al_2O_3-Ti(C,N) ceramic material with lubricant additives produced by free sintering, there is a reduction of friction coefficient (for the method of ball-on-disc with steel ball) to a value from 0.28 to 0.38 [9]. Because of high parameters for the free sintering process (high temperature, duration, high vacuum) part of the solid lubricants have been decomposed or melted. These materials were characterized by a rather low value of relative density, Young's modulus and hardness. In addition, these materials after process at high vacuum are characterized by a thick modified surface layer, which must be removed by grinding.

Compared to the conventional method of sintering substantial decreasing time and process temperature can be achieved using the SPS equipment (Spark Plasma Sintering). Ceramic materials with Al_2O_3-Ti(C,N)-matrix and lubricants additives sintered by SPS are characterized by slightly higher values of relative density, Young's modulus and hardness compared to the materials after the free sintering. For both cases (after SPS and free sintering), these values differ significantly from the hardness and Young's modulus of matrix material [10].

Addition of TiB_2 into the Al_2O_3-Ti(C,N) matrix resulted the friction coefficient reduction and the composite is characterized high values of relative density, Young's modulus and hardness [10]. Titanium diboride with high mechanical properties, is also characterized by good wear resistance and low friction coefficient [11,12]. High physical and mechanical properties of TiB_2 ceramic materials as well as oxide ceramics with the titanium diboride additives are confirmed by the results presented in papers [13-16].

2. Experimental

2.1. Materials and procedure

Investigations presented in this paper are related to the Al_2O_3-Ti(C,N) material with titanium diboride additives. The influence of TiB_2 on the Al_2O_3-Ti(C,N) matrix mechanical and tribological properties was studied.

Matrix material was prepared from the following powders: 68 mass.% Al_2O_3 (A16SG, ALCOA) with the addition of 2 mass.% ZrO_2 and 30 mass.% Ti(C,N) (H.C.STARCK). For these powders, size of grains was less than 1 µm. This material application is for the manufacture of multi-point cutting tool. Its density is 4.2 g/cm^3, hardness HV0.5 of 1900 and flexural strength equal to 600 MPa. Information about the recommended cutting parameters for the multi-point cutting tools based on Al_2O_3-Ti(C,N) are shown in the Table 1.

TiB_2 powder (H.C. Starck; 2.5-3.5 µm) was added for the matrix material in an amount of 5, 10, 30 and 50 vol.%. Al_2O_3-Ti(C,N) ceramics with additives were prepared using the SPS apparatus for sintering. Spark Plasma Sintering furnace with graphite die is shown in Fig. 1.

Materials are compacted in a graphite die using a maximum pressure of 35 MPa at vacuum. Maximum pressure was obtained after duration of 10 min. Vacuum and pressing time 10 min. was to vent the mixture. After that, protective gas was introduced to the chamber of SPS apparatus. Because of Ti(C,N) and TiB_2 good electrical conductivity the passage of current through graphite elements and pressed powder grains is possible. Chamber and graphite die with ceramic powder before sintering process are shown in Fig. 2. Mechanism of SPS sintering process and pulsed current flow through powder particles are shown in Fig. 3.

Table 1.
Recommended cutting parameters in turning for Al_2O_3-Ti(C,N) cutting tools [17]

Workpiece material	Type of machining	Cutting parameters		
		v_c [m/min]	f [mm/obr]	a_p [mm]
Cast iron	Moderately accurate, finishing	350-600	≤ 0.3	≤ 3.0
Normalized carbon steel, < 300 HB	Moderately accurate	150-200	≤ 0.3	≤ 3.0
	Finishing	250-300	0.05-0.15	≤ 0.3
Alloy tool steel < HRC	Moderately accurate, finishing	80-100	≤ 0.2	≤ 1.0
v_c - cutting speed, f - feed, a_p - depth of cut				

In the Fig. 4 is shown the sintering parameters for Al_2O_3 ceramics with TiB_2 additives. The shrinkage of various materials during the sintering process is shown in Fig. 5.

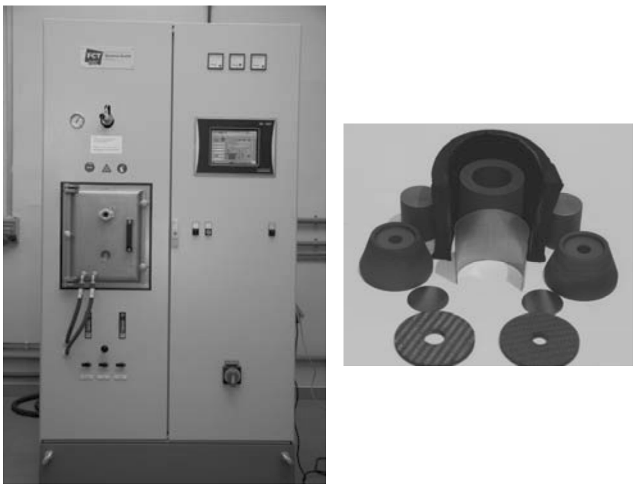

Fig. 1. SPS apparatus with graphite die

For the Al_2O_3-Ti(C,N) matrix material a significant shrinkage is observed in the first stage of heating (a temperature of 1250°C). Similar shrinkage were found for materials with the 5 vol.% and 10 vol.% TiB_2 addition.

In the case of materials containing 30 vol.% and 50 vol.% TiB_2 shrinkage was observed also in the first and the second heating stage (at 1250°C and at 1650°C).

Irrespectively of TiB_2 content the shrinkage all investigated materials is from 40% to 42%.

Fig. 2. Graphite die with ceramic powder before sintering process

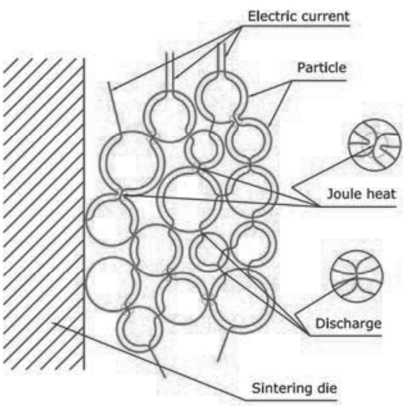

Fig. 3. Pulsed current flow through powder particles

2.2. Methodology

After sintering, the materials were subjected to a study of their physical and mechanical properties.

The apparent density ρ_p, was measured using the hydrostatic method. Young's modulus measurements of the sintered samples were also taken, using the ultrasonic method of measuring the transition speed of transverse and longitudinal waves, using a Panametrics Epoch III flaw detector. The hardness was determined by the Vickers method at a load of 9807 mN using a digital hardness tester (Future Tech. Corp. FM-7).

The tribological studies were performed using a UMT-T2 universal testing machine. Analysis of the tribological properties of the individual materials was performed at a temperature of 22°C and the wear track radius was in the range of 3 mm to 5 mm. The force in wear investigation on the material was 10 N, the speed of the sample was 0.100 m/s and the friction track was 100 m.

The physical, mechanical and tribological investigations were performed on the samples with a grounded and polished surface.

For materials after sintering and after tribological tests SEM observation at JEOL JSM-60LV were carried out. Analysis of chemical composition in micro-areas for individual samples were carried out using EDS microanalysis by INCA ENERGY-350 spectrometer.

3. Results of investigations

3.1. Mechanical investigations

The results of measurements of the relative density, Young's modulus and hardness of the ceramics obtained by SPS are collected in Table 2. SPS-sintered materials were characterized by the relative density values of 94.4% to 97.9%. Materials with higher content of titanium diboride, sintered at these same conditions were characterized by slightly lower values of relative densities. Material with 5 vol.% TiB_2 was characterized by a density equal to the relative density of the Al_2O_3-Ti(C,N) matrix material. A lower value of the relative density of materials with high TiB_2 content confirm that these materials should be sintered at a higher temperature than 1650°C. The investigated materials were characterized by similar Young's modulus of 392 to 414 GPa. Increasing of titanium diboride participation characterized by higher hardness. The highest hardness HV1 was 2225 and was measured for the material containing 50 vol.% TiB_2. In Fig. 6 is shown the microstructure of the material with the 30 vol.% TiB_2 addition. Analyses of chemical composition in micro-areas for this material are shown in Table 3.

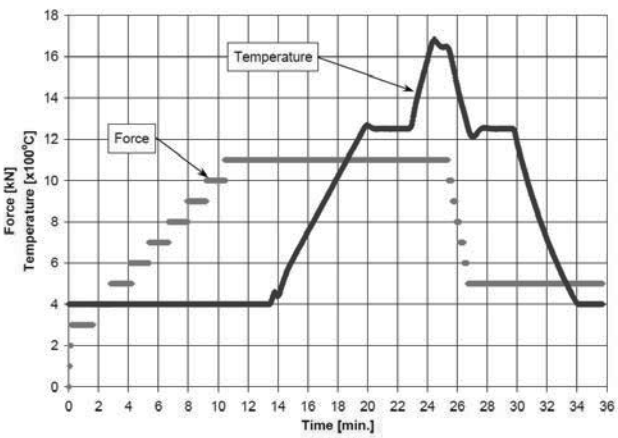

Fig. 4. Sintering parameters of Al_2O_3-Ti(C,N) ceramics with TiB_2 additives

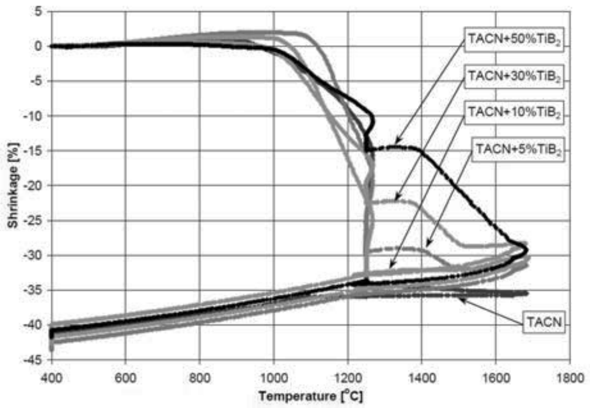

Fig. 5. Shrinkage of materials sintered by SPS-method (TACN: Al_2O_3-Ti(C,N) ceramic)

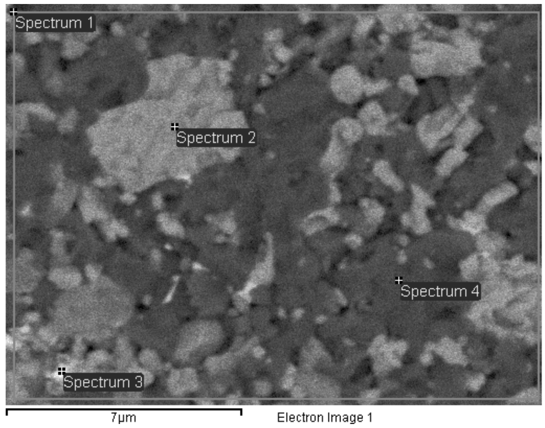

Fig. 6. Microstructure of the Al_2O_3-Ti(C,N) material with 30 vol.% TiB_2 additive, EDS-analysis

Table 2.
The results of measurements of density, Young's modulus, hardness of ceramic Al_2O_3-Ti(C,N) with additives after SPS-sintering

Materials	ρ_w [%]	E [GPa]	HV1	σ-HV1
Al_2O_3-Ti(C,N)	97.9	401	2042	56
Al_2O_3-Ti(C,N) +5 vol.%TiB_2	97.9	407	1966	139
Al_2O_3-Ti(C,N) +10 vol.%TiB_2	97.7	392	1996	55
Al_2O_3-Ti(C,N) +30 vol.%TiB_2	96.6	402	2106	54
Al_2O_3-Ti(C,N) +50 vol.%TiB_2	94.4	414	2225	247

T_s - sintering temperature; ρ_w - relative density; E - Young modulus; HV - Vickers hardness

Table 3.
Chemical composition analysis of the Al_2O_3-Ti(C,N) material with 30 vol.% TiB_2 additive.

Spectrum	B	C	N	O	Al	Ti	Zr
1	19.75	8.66	-	35.89	16.15	19.56	-
2	-	15.39	8.24	-	-	76.37	-
3	25.41	20.53	-	13.37	0.42	26.03	14.24
4	-	8.46	-	47.84	41.49	2.21	-

Al_2O_3-Ti(C,N) matrix material after SPS-sintering achieved higher Young's modulus and hardness compared to the free sintered materials. Ceramics of Al_2O_3 matrix with reinforcing phase Ti(C,N) after free sintering is characterized by Young's modulus of 380 GPa and hardness HV1 of 1750.

3.2. Tribological investigation

The friction coefficients measured for ceramics Al_2O_3-Ti(C,N) with TiB_2 additions are presented in Table 4. Tribological test results were compared with the wear results of the matrix material.

Table 4.
The results of tribological tests on Al_2O_3-Ti(C,N) ceramics with TiB_2 additives after SPS-sintering.

Materials	Radius of wear track	Friction coefficient	
	[mm]	COF	σ-COF
Al_2O_3-Ti(C,N)	3	0.51	0.06
Al_2O_3-Ti(C,N) +5 vol.% TiB_2	3	0.49	0.09
	4	0.49	0.13
Al_2O_3-Ti(C,N) +10 vol.% TiB_2	3	0.33	0.06
	4	0.35	0.04
Al_2O_3-Ti(C,N) +30 vol.% TiB_2	4	0.35	0.05
	5	0.39	0.08
Al_2O_3-Ti(C,N) +50 vol.% TiB_2	3	0.31	0.04
	4	0.32	0.04

Table 5.
Chemical composition analysis of the wear layer formed on Al_2O_3-Ti(C,N) ceramic +30 vol.% TiB_2 additive.

Spectrum	B	C	O	Al	Ti	Fe
1	22.81	5.79	41.38	27.98	2.04	-
2	17.08	7.91	24.41	0.83	3.13	46.65
3	28.72	-	16.38	1.48	53.41	-
4	21.80	6.28	33.09	11.97	3.56	23.30
5	20.37	7.42	37.14	11.68	15.20	8.19

Friction coefficient for Al_2O_3-Ti(C,N) matrix material is 0.51. Materials with titanium diboride are characterized by lower friction coefficients. Wear of couples in these studies were a ceramics and hardened steel balls. With the increase of TiB_2 participation reduction in friction coefficient was observed. For the material with 5 vol.% TiB_2 additive friction coefficient was 0.49 and for the Al_2O_3-Ti(C,N) with 50 vol.% TiB_2 material this coefficient was 0.31.

The wear tracks is mainly formed on the surface of the ceramics specimen disc. In Figures 7 to 10 are shown wear traces for various materials. With the increase of TiB_2 participation in the investigated materials, this layer was less uniform and more frayed. For example, Fig. 11 presents the layer formed on ceramic containing 30 vol.% TiB_2. In Table 5 were shown the results of the chemical composition analysis.

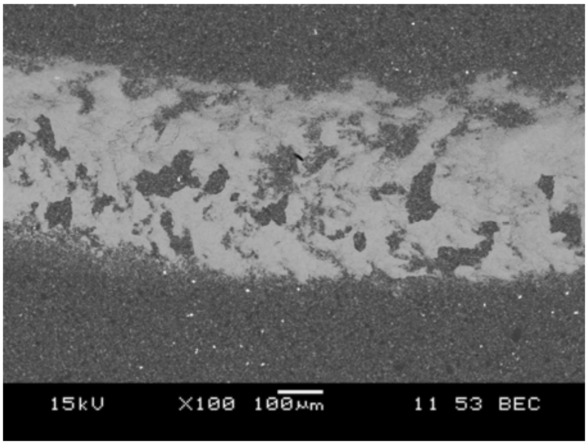

Fig. 7. Wear track of Al_2O_3-Ti(C,N) ceramic with 5 vol.% TiB_2

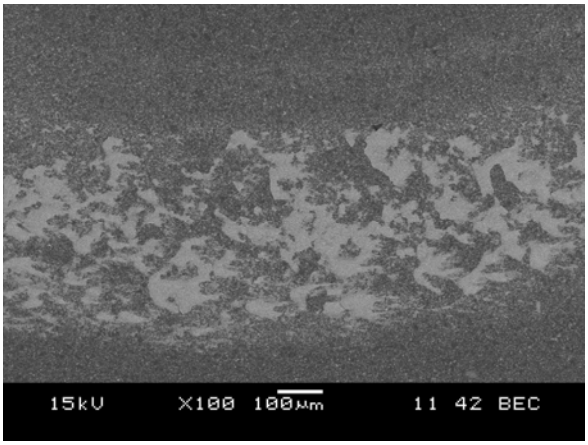

Fig. 8. Wear track of Al_2O_3-Ti(C,N) ceramic with 10 vol.% TiB_2

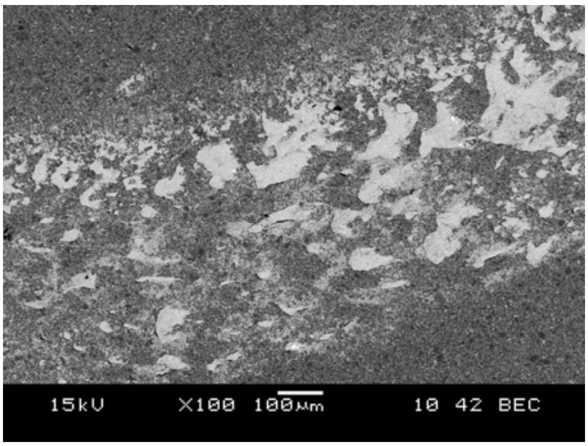

Fig. 9. Wear track of Al_2O_3-Ti(C,N) ceramic with 30 vol.% TiB_2

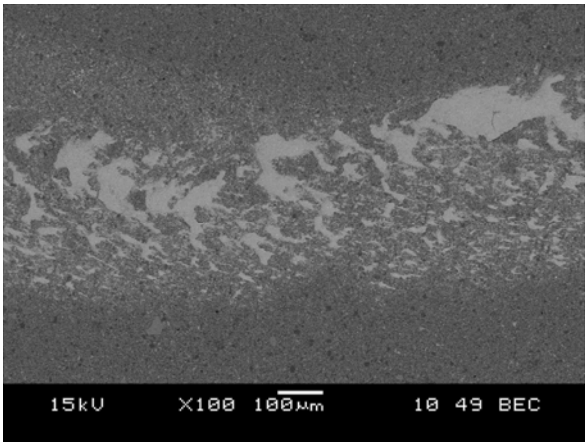

Fig. 10. Wear track of Al_2O_3-Ti(C,N) ceramic with 50 vol.% TiB_2.

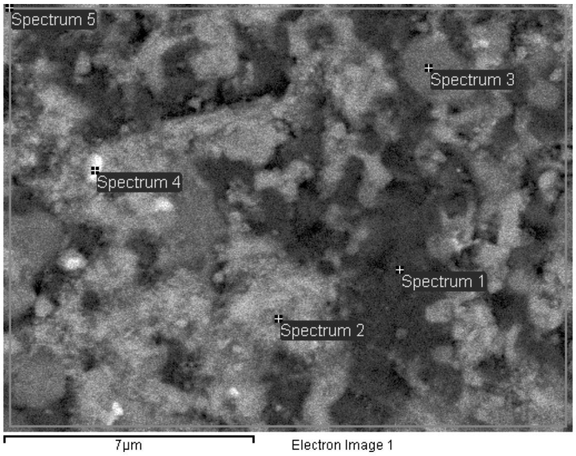

Fig. 11. Wear track of Al_2O_3-Ti(C,N) ceramic with 30 vol.% TiB_2 additive, EDS-Analysis.

4. Conclusions

The paper presents results of the mechanical properties and tribological properties of Al_2O_3-Ti(C,N) ceramics with the titanium diboride addition The materials were obtained using the SPS sintering method. This method allows to sintering process ceramics in a much shorter duration and at a lower temperature. The materials after SPS-sintering process are characterized by higher hardness and Young's modulus than the materials manufactured using the free sintering method. Materials with the TiB_2 addition were characterized lower value of relative density than the matrix. All materials were characterized similar values of Young's modulus. With increasing of TiB_2 participation the slight increase of hardness HV1 is observed. There is a bigger influence of TiB_2 addition on tribological properties of Al_2O_3-Ti(C,N) ceramic. The value of friction coefficient for Al_2O_3-Ti(C,N) ceramics with titanium diboride is in range of 60.8% to 96% in relation to the friction coefficient for the matrix material. The lowest value of friction coefficient has been measured for the material with the addition of 50 vol.% TiB_2.

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