Machining of silumins with carbide phase addition – the analysis of inserts temperatures during the cutting process

Kształtowanie siluminów z dodatkiem fazy węglikowej – analiza temperatury narzędzi podczas skrawania

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The stability of PCD inserts in the machining of cast composite materials containing 10 vol.% of ceramic phase is presented. Tests were carried out using the turning and milling center Mori Seiki NL2000SY and by polycrystalline diamond cutting tool and. The flank wear VBB wear parameters of inserts according to the standard ISO 3685: 1996 were determinated. The influence of the cutting parameters (speed, feed rate, depth of the cut) on the temperature of PCD inserts were investigated. The analysis of chip formation mechanism during the processing at different cutting parameters was performed. The study was carried out using the FLIR A655 thermal camera and the high speed camera Phantom MIRO M310.

KEYWORDS: composite materials, cutting process, EDM process

Metallic materials reinforced with ceramic phases are increasingly used in modern engineering constructions. They are formed by introducing a ceramic or intermetallic reinforcing phase into the matrix alloy [1, 2]. Such strengthening increases the strength, hardness, stiffness and wear resistance of composite materials. As reinforcing particles, for example: carbides, oxides, nitrides and borides are used [3-5].

Composites with aluminum matrix reinforced with ceramic particles (e.g. Al_2O_3, SiC) are gradually being introduced into production in the automotive, electronics or aviation industries - primarily due to their high wear resistance under friction conditions. Industrial composites produce high friction wear, such as pistons, drums and brake discs [6]. Technologies for these materials production are mainly based on powder metallurgy, infiltration of porous ceramic preforms, die casting or liquid pressing [7, 8]. Obtaining materials with increased mechanical properties requires the use of *in situ* reinforcement that is thermodynamically stable, has less tendency to crack, and because of the lack of intermediate layers it is well bonded to the matrix [9, 10].

One of the major advantages of composites is the ability to obtain the material properties by its microstructure formation in a technological process. The choice of matrix material, type, size and volume fraction of reinforcement phases as well as technological parameters allows to design materials with features exceeding the properties of matrix material [11]. Still, significant cost reductions in the wider implementation of composites are indicative of the cost of production and, above all, the cost of mechanical machining [12].

These materials, due to the hard ceramic phase, are hardworking materials and require special technologies and tools in shaping processes [13-16]. In the case of carbide tools, intensive wear of cutting blades is observed, and the problem of ensuring dimensional stability in the tolerances provided for a machining operation. The machining of cast ceramic composite materials is intermittent and characterized by dynamic impact on the cutting edge.

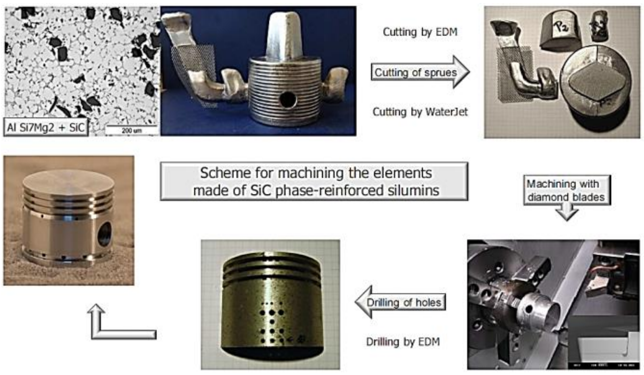

Fig. 1. Silicon carbide SiC reinforced machining scheme

Material and methodology of research

The subject of the research was a metal composite alloy casting type AK7 (AlSi7Mg2) reinforced with SiC particles, developed at the Institute of Materials Science of the Silesian University of Technology. The volume fraction of the reinforcing phase was 10%. The composite was made in the framework of industrial research at Złotecki Ltd.

The chemical composition of the alloy is shown in Table. I. Silicon carbide (SiC SIKA ABR P Saint-Gobain)

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particle with a grain size of 40.5 µm was used as the reinforcing phase. The base AK7 alloy was melted at 720 °C and then refined for an hour with argon. Ceramic particles, after preheating, were applied to a spinning metal mirror. The process of homogenization and degassing of the suspension was carried out under argon depressed conditions. Piston blanks (diameter ⌀68 mm and length l = 54 mm) were cast into a metal mold.

TABLE I. Chemical composition of AK7 alloy (expressed in % by weight)

Al	Si	Fe	Mg	Sr	Ti
92,56	6,50	0,52	0,23	0,002	0,03

Cutting machining, water-jet cutting and electro-discharge drilling were selected for the treatment of SiC reinforcing composite materials. A schematic diagram of the process of shaping elements from AK7 carbide matrix reinforced with SiC carbide is shown in fig. 1.

Materials - after cutting off the sprues - were subjected to longitudinal turning tests using polycrystalline diamond tools. The durability of PCD tools was determined using the NL2000SY cutting-milling center (Mori Seiki) with a main drive power of 18.5 kW. The nature of the wear and its size on the wear surface was checked (VBB max and VBC according to PN-ISO 3685: 1996). As a limitation, the blade life value is assumed to be its working time, after which the VBB or VBC clipping parameter reaches a value of 0.3 mm. The apparatus for determination of blade durability during the machining of Al-carbide die-casting composite with SiC carbide phase is shown in fig. 2.

a) *b)*

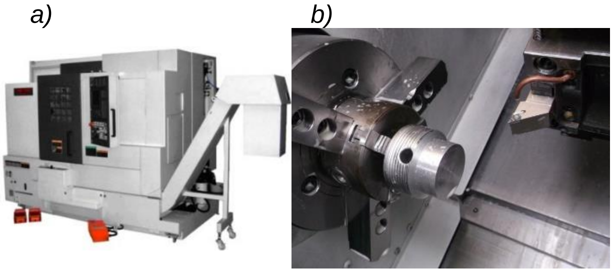

Fig. 2. Position NL2000SY for cutting tests (a), view of machining system: handle - workpiece (piston) - tool (b)

The impact of cutting parameters (speed, feed and depth of cut) was also determined on cutting tool temperature. The chip shaping mechanism was analyzed during machining with different cutting parameters. Both the temperature measurement and the chip formation analysis were performed at the position shown in fig. 3.

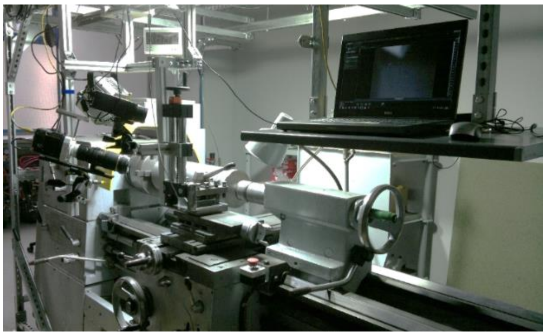

Fig. 3. Apparatus for temperature measurement and analysis of chip formation mechanism during turning

Fig. 4. FLIR A655 thermal imaging camera, Phantom MIRO 310 high speed camera, halogen lighting

a) *b)*

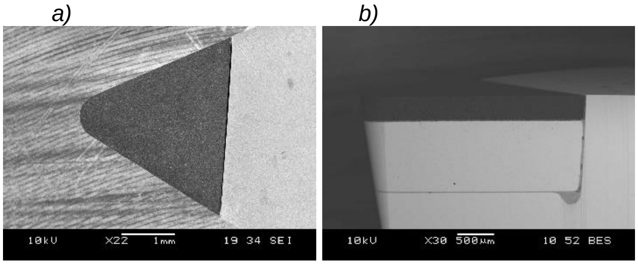

Fig. 5. Polycrystalline diamond plate marked NP-DCMW11T304 MD220: *a)* rake surface, *b)* grinding surface and cutting edge

The station consists of a TUR50 machine, a FLIR A655 thermal imager, and a Phantom MIRO 310 high speed video camera. The parameters of the thermal camera (e.g. emissivity of individual materials, transmission value and parameters of external optical system), fast camera parameters (resolution, sample rate, exposure time) and the type of light and way of illumination were selected during the cutting tests. A polycrystalline diamond blade analysis was also performed using the JEOL JSM 6460LV electronic scanning microscope.

Machining was performed using PCD cutting inserts: NP-DCMW11T304 MD220 (fig. 2b and fig. 5) mounted in a knife holder type SDJCL2525M11. Angles: races $\gamma_o = 0°$, applications α_o = 7°, cutting edge inclination λ_s = 0°, alignment κ_r = 93°. The insert symbol means that it is a diamond-shaped plate with an angle ε_r = 55° (D), a 7° (C) insertion angle, a M (M) dimension tolerance with a partially cylindrical whole of 9.525 mm diameter (11), a thickness of 3.97 mm (T3) and a corner radius of r_ε = 0.4 mm (04). The MD220 denotes the grade of PCD blade material brazed on a cemented carbide substrate in one corner of the plate. The MD220 material contains diamond particles with an average particle size of 10 µm. The blade is intended, among others, for machining aluminum alloys with high cutting speed.

The following parameters of longitudinal turning have been adopted for the longevity tests of PCD blades:

- cutting speed v_c = 200; 300; 500 m/min,
- feed rate f = 0.10; 0.20; 0.30 mm/rev,
- cutting depth a_p = 0.5; 1.0; 1.5; 2.0 mm.

Analysis of temperature and chip forming mechanism was carried out during longitudinal turning with parameters:

- cutting speed v_c = 50; 75; 100 and 120 m/min,
- f = 0.08; 0.17; 0.34 mm/rev,
- depth of cut: a_p = 0.5; 1.0; 2.0 mm.

Results

Results of the cutting tests according to the machining parameters are shown in Table. II. The tool life *T* is defined as the time to rise the flank wear VBB equal 0.3 mm. As a result of friction between the surface of the cutting blade and the chip, a large amount of heat is generated. The temperature measurement caused by friction was carried out by measuring the temperature of the chips above the cutting edge. In order to record the temperature changes correctly, the appropriate parameters of the object (measured emissivity) and transmission (in case an external optical system in the form of an additional window is used) are selected. The use of an additional window was intended to protect the surface of the thermal camera lens from scratching the chips.

The emissivity of the AK7-SiC composite was determined during the heating of the composite material in temperature range from 50°C to 80°C. The temperature of the composite material was measured using a contact thermometer and an AR540 meter from APAR. In the calibration process, the emissivity value was changed and then the transmittance until the temperature recorded by the camera was close to the value indicated by the contact thermometer. The value of the coefficient of emissivity of the material AK7-SiC at 65°C is 0.85.

Results of the common temperature measurement of the polycrystalline diamond cutting edge during the longitudinal turning of the AK7-SiC composite material are shown in fig. 6. The sample images recorded by the FLIR A655 thermal imaging camera and the image recorded by the Phantom MIRO 310 rapid camera for three selected turning parameters are shown in fig. 7-9. Blades of polycrystalline diamond with a visible growth after turning AK7-SiC material are shown in fig.10 and 11.

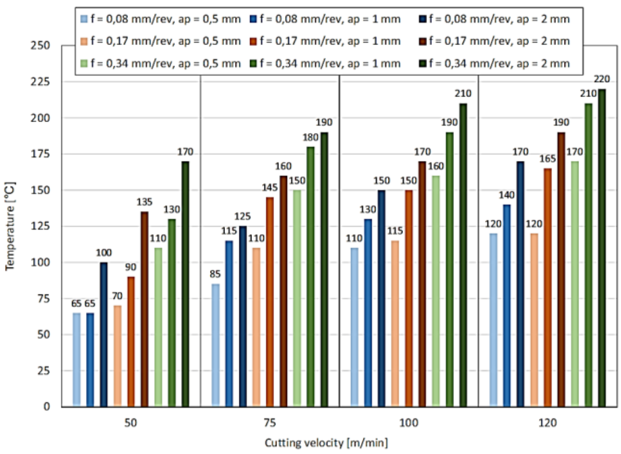

Fig. 6. Effect of cutting parameters (velocity v_c, feed *f*, depth a_p) on polycrystalline diamond blade temperature value

TABLE II. Durability of polycrystalline diamond plates during longitudinal rolling of AK7-SiC composite

Cutting parameters			Blade durability T min
Cutting speed v_c m/min	Feedrate f mm/obr	Depth of cut a_p mm	
200	0,15	1,5	12,3
300	0,10	0,5	14,7
	0,10	1,0	9,5
	0,20	1,0	12,5
	0,30	1,0	8,2
500	0,10	0,5	2,5
	0,10	1,0	1,7
	0,20	1,0	0,7
	0,20	2,0	0,5
	0,30	1,0	0,5

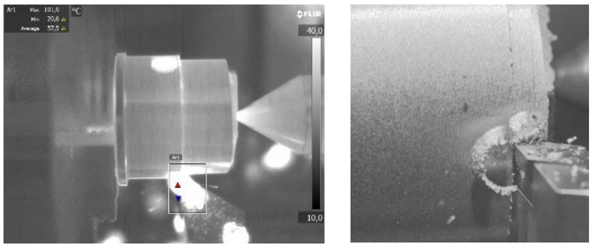

Fig. 7. Thermal imaging camera image (a), chip forming mechanism (b) (cutting speed: 45 m/min, feedrate: 0.34 mm/rev, depth of cut: 2 mm)

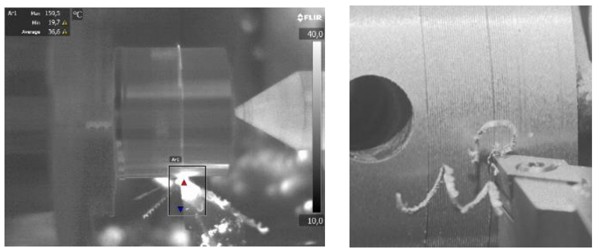

Fig. 8. Thermal imaging camera image (a), chip forming mechanism (b) (cutting speed: 100 m/min, feedrate: 0.34 mm/rev, depth of cut: 0.5 mm)

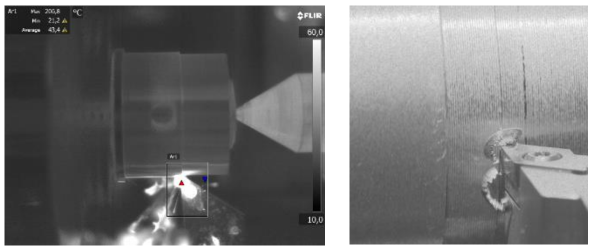

Fig. 9. Thermal imaging camera image (a), chip forming mechanism (b) (cutting speed: 120 m/min, feedrate: 0.34 mm/rev, depth of cut: 1 mm)

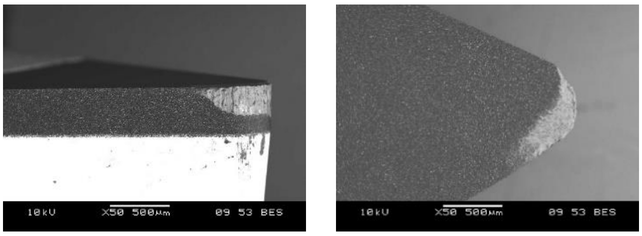

Fig. 10. PCD tools after turning AK7-SiC material: a) surface of application, b) rake surface (cutting speed: 500 m/min, feedrate: 0.10 mm/rev, depth of cut: 0.5 mm)

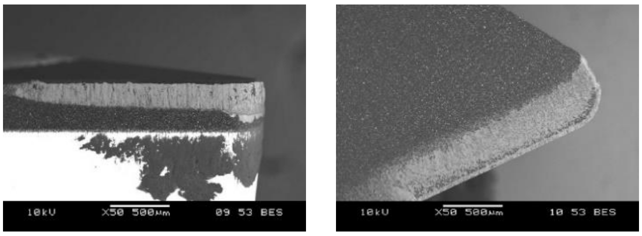

Fig. 11. PCD tools after turning AK7-SiC material: a) surface of application, b) rake surface (cutting speed: 500 m/min, feedrate: 0.20 mm/rev, depth of cut: 2.0 mm)

Conclusions

Results obtained from the SiC (10% vol.) aluminum alloy piston turning tests confirmed the difficult machinability of this alloy and the impact of cutting speed on tool life. The diamond blade durability during the machining of aluminum matrix material with 10% SiC at 500 m/min - regardless of the feedrates and cutting depths - did not exceed 4 minutes. With a reduction in cutting speed up to 300 m/min at 0.10 mm/rev and 0.5 mm cutting depth, the tool life has been increased to 15 min. The tough machinability of the aluminum matrix material with the addition of the carbide phase confirms the results obtained at turning speeds of 200 m/min, feed rate of 0.15 mm/rev, and 1.5 mm cutting depth. The PCD blade durability in the rolling process was 12.3 mins, which is 2.46 km per cut. According to the manufacturer's specifications, the consumption of polycrystalline diamond during high-Si aluminum alloy machining (alloy contains no SiC carbide phase) at 200 m/min, feedrate 0.15 mm/rev and depth of cut 1.5 mm, exceeds 24 km.

After the rolling process, blades were subjected to microstructure analysis using the JEOL JSM 6460LV scanning electron microscope. The purpose of these analyzes was to determine the mechanism of blade wear according to the cutting parameters. The wear of polycrystalline diamond PCN blades was mainly due to the accretion of the workpiece material. During the course of turning with all tested boards, the chips were obtained in a preferred form (according to shavings classification in PN-ISO 3685: 1996), irrespective of the cutting parameters accepted.

The analysis of temperature distribution using the FLIR A655 Thermal Imager revealed that the maximum impact on the amount of heat generated during cutting and the temperature value is exerted by the rotational speed (cutting speed) of the workpiece. Subsequently, the workpiece temperature is influenced by the cutting depth and feedrate. Depending on the value of feeds and depth of cut, the temperature of the PCD blade at a cutting speed of 50 m/min ranged from 65 °C to 170 °C. At a cutting speed of 75 m/min, 100 m/min and 120 m/min, the temperature of the PCD blades ranged between 85 ÷ 190 °C, 110 ÷ 210 °C and 120 ÷ 220 °C. It should be added that, due to limited access to the surface of the cutting edge, the chip temperature was measured during the turning. In the analysis using the thermal imaging camera, it was assumed that, as a result of friction of the workpiece with the surface of the cutting edge, these elements heat up to the same temperature. The study of temperature distribution was preceded by the system calibration stage and the emissivity coefficient of the aluminum matrix material with addition of the SiC carbide phase.

The chip forming step as a result of PCD diamond blade processing was also recorded by the Phantom MIRO 310 rapid camera. During the course of cutting, all the test plates, regardless of the cutting parameters, were shaved in a preferred elemental or spiral form; their length did not exceed a dozen or so millimeters. Depending on the machining parameters (speed, feed, depth of cut), the chip breaking occurred as a result of contact with the workpiece face (at low feedrates), lateral surface of the workpiece, rake surface (at the lowest machining speed, feedrate and cutting depth) or applying a cutting blade (at high cutting speeds, regardless of feedrate and cutting depth).

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