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METALLOGRAPHIC ANALYSIS OF SURFACE LAYER AFTER TURNING WITH LASER-ASSISTED MACHINING OF COMPOSITE A359/20SiC$_p$

The composite materials of Al/SiC are increasingly used in various industrial fields such as automotive, aerospace. However, making full use of composite materials is possible when effective methods of machining these materials are known. Due to the content of hard particles, these materials are classified to the group of hard to machine materials. One of the effective method to achieve better performance indicators for making machine parts and equipment is hybrid machining, by which, using the existing way of working, improves machinability. This process is achieved by simultaneously feeding extra heat to the cutting zone, for example by using a laser beam. The work reported here focus on analysis the composite microstructures of A359/20SiC$_p$ (F3S.20S DurAlcan^{TM}) heated by a laser beam and laser-assisted turned. During analysis of the microstructures of the composite material, the influence of the laser beam on the workpiece was determined and liquid, liquid-solid and neutral matrix zones were identified. The sample surfaces after conventional turning and laser-assisted turning were compared. From the surface layers of the composite there a zone of smaller contents of SiC particles during laser beam heating was determined. As the wedge works in the areas of liquid and liquid-solid, a reduction of the cutting forces, tool wear and the machined surface roughness is expected.

Keywords: laser assisted machining, metal matrix composite, composite microstructure

ANALIZA METALOGRAFICZNA WARSTWY WIERZCHNIEJ KOMPOZYTU A359/20SiC$_p$ PO TOCZENIU ZE WSPOMAGANIEM LASEROWYM

Materiały kompozytowe typu Al/SiC znajdują coraz większe zastosowanie w różnych obszarach przemysłu, np. samochodowego, lotniczego. Jednakże pełne wykorzystanie materiałów kompozytowych możliwe jest w sytuacji, gdy znane są efektywne metody obrabiania tych materiałów. Z powodu zawartości twardych cząstek SiC materiały te zaliczane są do grupy trudno skrawalnych. Jednym z efektywnych sposobów uzyskania lepszych wskaźników użytkowych procesu kształtowania elementów maszyn i urządzeń jest obróbka hybrydowa, dzięki której, wykorzystując już istniejący sposób obróbki, osiąga się poprawę skrawalności poprzez jednoczesne doprowadzenie do strefy skrawania dodatkowej energii cieplnej, np. za pomocą wiązki lasera. W pracy zamieszczono analizę mikrostruktury kompozytu A359/20SiC$_p$ (F3S.20S DurAlcan^{TM}) toczonego ze wspomaganiem laserowym. Analizując mikrostruktury materiału kompozytowego, określono wpływ oddziaływania wiązki lasera na materiał obrabiany i wyznaczono strefę występowania osnowy ciekłej, ciekło-stałej oraz neutralnej. Porównano powierzchnie próbki toczonej zarówno tradycyjnie, jak i ze wspomaganiem laserowym. Wyznaczono z warstwy wierzchniej kompozytu nagrzewanego laserowo strefę o mniejszej liczbie cząstek SiC. Ponieważ ostrze porusza się w obszarach ciekłej i ciekło-stałej osnowy, należy spodziewać się zmniejszenia siły skrawania, zużycia ostrza oraz chropowatości obrobionej powierzchni.

Słowa kluczowe: skrawanie ze wspomaganiem laserowym, kompozyty metalowe, mikrostruktura kompozytu

INTRODUCTION

Metal matrix composites (MMCs) represent a generation of materials with great potential for novel properties. Thus, they have significant scientific, technological and commercial importance. Increasing quantities of metal matrix composites are being used to replace conventional materials in many applications, especially in the automobile and recreational industries, owing to increasing performance requirements [1]. Among the various types of MMCs, aluminum alloy based composites are finding increasing applications. The SiC particle reinforced aluminum alloy composites which are most widely used as composites materials, can be produced through a number of ways including melt processing and powder metallurgy. Those kinds of composites offer various advantages in applications where high specific strength, stiffness and wear resistance are required. Therefore, they are being used as a replacement material in various engineering applications such as for cylinder block liners, vehicle drive shafts, automotive pistons, bicycle frames, etc. [2].

Although MMCs are often fabricated with casting techniques, a number of secondary machining operations is always necessary. The main concern when machining particulate metal matrix composites is the extremely high tool wear due to the abrasive action of the reinforcing ceramic particles and poor surface quality [3, 4].

Other researchers [5-7] limited their studies to relating the effect of the machining cutting parameters and tool wear to the workpiece surface roughness produced. Most researchers concentrated on investigating the effect of the cutting parameters on the sub-surface deformation produced due to high stresses and the temperatures generated during cutting as well as to the chip formation mechanism. However, it is also important to obtain knowledge about the surface layer.

Polycrystalline diamond tools (PCD) are often recommended for machining this particular class of materials. The high cost of PCD tools increases the cost of machining metal matrix composites. Therefore, there is still a demand for MMC processing methods capable of enhancing material removal rates, improving tool wear and increasing the surface quality of the workpiece. One of effective way to get high utilization indicators of the machining process is by connecting different physic-chemical influences on the machining material. This new approach to forming materials is enabled by so called hybrid machining. Previous researches [8-13] of machining effects found that in many cases, a laser beam as an aid tool during conventional machining improves product quality and reduces production costs. Chryssolouris [14] tested the application of LAM to general metals and found a reduction in tool wear and a cost reduction of 60÷80% over conventional grinding. Laser assisted machining (LAM) is one of the most advanced machining technologies, which adapts to the machine of difficult machining materials [13]. In LAM the workpiece area is heated directly by a laser beam before the cutting edge.

In our previous LAM investigation of aluminum reinforced with 20 vol.% of SiC, a CO_2 laser was involved in the process. The laser power range was $P = 0 \div 2.34$ kW [15]. Those experiments proved that LAM is an effective method of SiC_p/Al composite machining, especially in a low range value up to 1 kW of laser power. The LAM of MMCs has been studied to demonstrate tool life and show improvement of the machined surface quality as well.

Currently our study is an extension of previous work by examining the surface layer when turning the Al/SiC composite. This paper also reports up-to-date Al/SiC composite LAM results using a CO_2 laser.

RANGE, CONDITION, TECHNIQUE AND ANALYSIS OF RESEARCH

The objective of the research was to determine the influence of laser-assisted turning on the microstructure of the surface layer.

A CO_2 technological laser (TLF 2600t, TRUMPF) delivering a nominal output power of 2.6 kW is used to heat the workpiece surface. The laser is connected to a universal lathe type TUM 25D1 with a stepless spindle rotation control. The view of the laser-assisted turning is illustrated in Figure 1. The experiments were carried out by turning with uncoated sintered carbide inserts SNMN 120408 H10S BAiLDONiT.

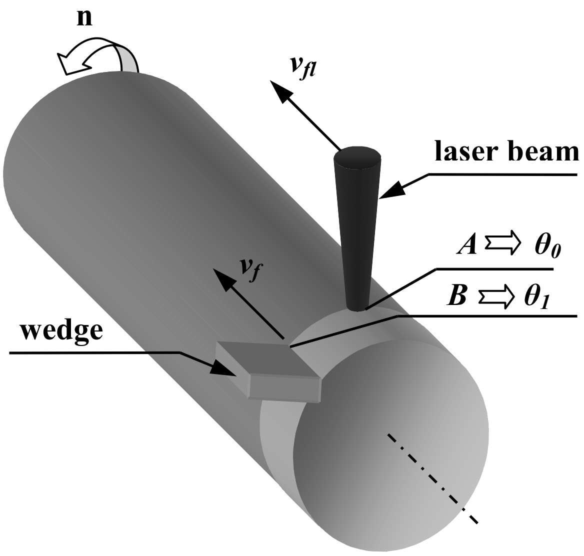

Fig. 1. Schematic of experimental set-up. Designations: A - laser beam-heated area, B - machining zone, θ_0, θ_1 - temperature measurement areas, v_f - feed speed, v_{fl} - laser beam along heated surface, n - rotation speed

Rys. 2. Schemat przebiegu procesu toczenia hybrydowego. Oznaczenia: A - obszar nagrzewany wiązką lasera, B - strefa skrawania, v_f - prędkość posuwowa, v_{fl} - prędkość przemieszczania się wiązki lasera po powierzchni próbki wzdłuż jej osi, n - prędkość obrotowa

In the studies, the standard metal matrix composite marked with the feature F3S.20S [16], produced by the ALCAN company was used as the workpiece material. The composite was delivered in the form of cast ingots. The F3S.20S composite of a chemical composition similar to the AlSi9Mg alloy is reinforced with SiC particles with a particle size of about 20 μm and mass fraction about 20%. In Table 1 the chemical constitution (by certificate) of the alloy matrix material used in the research is shown. According to the same certificate, the contents of the reinforcing phase in the MMC was 21.6%. The microstructure of the composite and roller test used in the research are shown in Figure 2. The research workpieces were prepared by gravity casting. The material was melted in a crucible resistance furnace according to the manufacturer's instructions [16] and the suspension was poured into graphite moulds, producing rollers with a diameter ø 70 mm. In order to equalize the surface, the shafts were turned to ø 55 mm in diameter and divided into areas with a width of 10 mm. The workpieces were painted twice with an absorptive coating (gouache) each time to increase laser beam absorption.

TABLE 1. **Chemical constitution of MMC alloy F3S.20S**
TABELA 1. **Skład chemiczny stopu osnowy kompozytu F3S.20S**

Chemical element	Si	Fe	Cu	Mg	Ti	Zn	Al
Content %	9.2	0.14	0.01	0.6	0.11	0.02	bal.

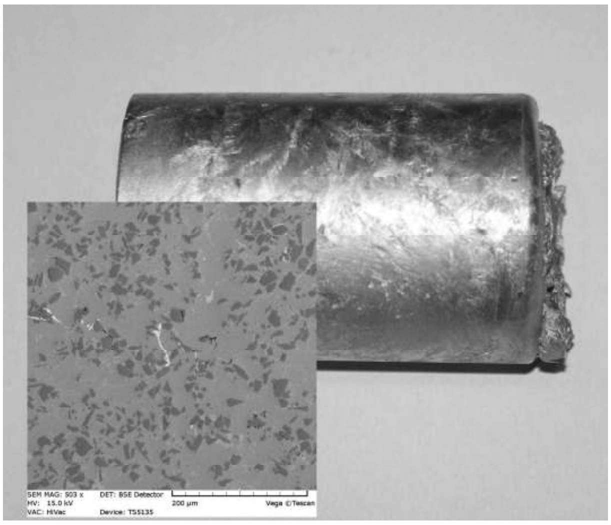

Fig. 2. Roll cast composite F3S.20S

Rys. 2. Odlany wałek z kompozytu F3S.20S

The machined material was cut to observe the microstructure of the samples from the area marked in Figure 3. For observation, recording images and analysis of the components, a Neophot 32 microscope and scanning microscope of the TESCAN company, type VEGA TS 5135 with a system for X-ray microanalysis AWALON 4000 were used.

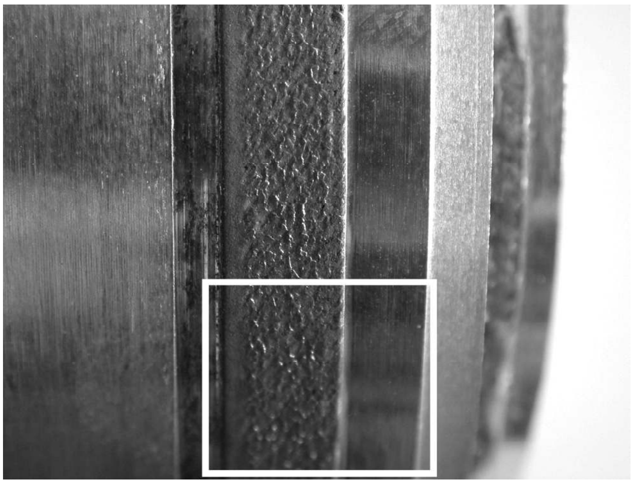

Fig. 3. Zone sample cut off for microanalysis

Rys. 3. Strefa próbki do mikroanaliz

The surface temperatures were measured and controlled by two RAYTEK pyrometers (Table 2). One of them measured the temperatures in the heating area by the laser beam (Fig. 1) and the second in the machining zone *B* at the same time. The distance angle between the area heated by the laser beam and machining zone was 30 degrees. The emission was set in the software based upon calibration tests previously conducted. Our previous work [17] shows that the emission coefficient strongly depends on the temperature and surface roughness. If the real temperature changes, the emission coefficient should be also changed to receive the correct of temperature value. The methodology of determining and defining the emissivity coefficient ε was presented in [17]. In work [18] it was shown that there were considerable differences in the temperatures in the heated zone and plan machining area. It was noticed that the temperatures in areas *A* (form 1910 to 1990°C) and *B* (form 294 to 530°C) increase with time.

TABLE 2. **RAYTEK pyrometers parameters used in research**
TABELA 2. **Parametry użytych w badaniach pirometrów firmy RAYTEK**

Pyrometer model	MA2SC	S5XLT
Optical resolution	300:1	32:1
Temperature measuring range, °C	350÷2000	−20÷870
Spectral range, μm	1.6	8÷14
Repeatability of measurements	±{0.01% of measured value +0.1°C}	±{0.5% of measured value+0.1°C}
Answering time, ms	1	400
Emissivity	0.10÷1.00	

The research was carried out with the following parameters: feed rate $f = 0.04$ mm/rev, cutting speed $v_c = 10$ m/min, laser power $P = 1000$ W, depth of cut $a_p = 0.1$ mm, laser beam diameter $d_l = 2$ mm.

Figure 4 shows a photograph of the surface layer with a hybrid turning area. The area has been divided into zones "A", "B" and "C". The undeformed chip includes areas "A" and part of area "B" and symbol "C" designated the neutral zone. The line separating zone "A" from "B" marks the limit of the SiC particles, which is shown in Figure 5. It follows that the composite matrix located in the "A" zone during the hybrid turning process in the laser activity area is in a liquid state at a depth of about 140 μm. The accumulation of SiC particles on the surface is due to the influence of the centrifugal force on them in a liquid matrix. Zones "B" and "C" were contractually determined after analyzing and comparing the microstructures of the surface layer of the composite during conventional turning (Fig. 7) and laser assisted turning (Fig. 6). It was observed that the microstructure of the surface layer composite during conventional turning has irregularities in the surface finish, which were the result of pulling the SiC particles out of the solid matrix by the wedge during turning (Fig. 7). The composite surface after hybrid turning shown in Figure 6 is homogeneous with no visible removal of SiC particles or grooves on the surface. Comparison of the microstructures shown in Figure 4-6 and 7 shows that the matrix in zone "A" is in the liquid state and the limit of particles at the same time sets the border area for "B", in which the matrix is the state of a liquid-solid and does not allow the movement of particles but allows them to be affected by the reorientation of the matrix plasticity. The composite material structure remains unchanged below zone B.

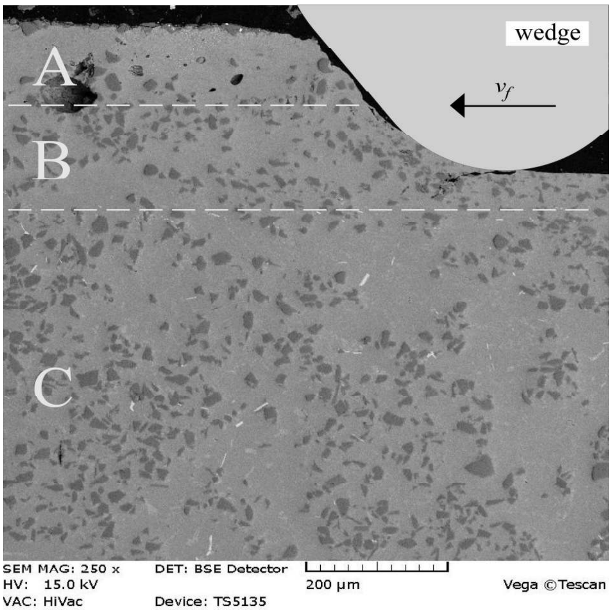

Fig. 4. Transitional layer of area of hybrid turning and laser-heated area with marked established zones boundaries: A - overheating composite zone, B - liquid-solid matrix zone undergone plastic deformation, C - neutral zone

Rys. 4. Warstwa przejściowa z widocznym obszarem toczenia hybrydowego oraz obszarem nagrzewanym laserowo z zaznaczonymi umownymi granicami stref: A - strefa przegrzania kompozytu, B - strefa ciekło-stałej osnowy poddana odkształceniu plastycznemu, C - strefa neutralna

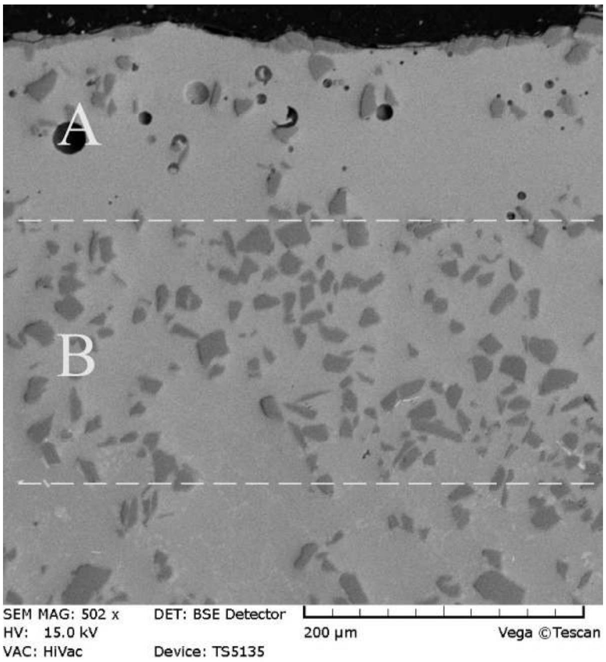

Fig. 5. Microstructure of surface layer zones: A and B (by Fig. 4)

Rys. 5. Mikrostruktura warstwy wierzchniej stref: A i B (wg rys. 4)

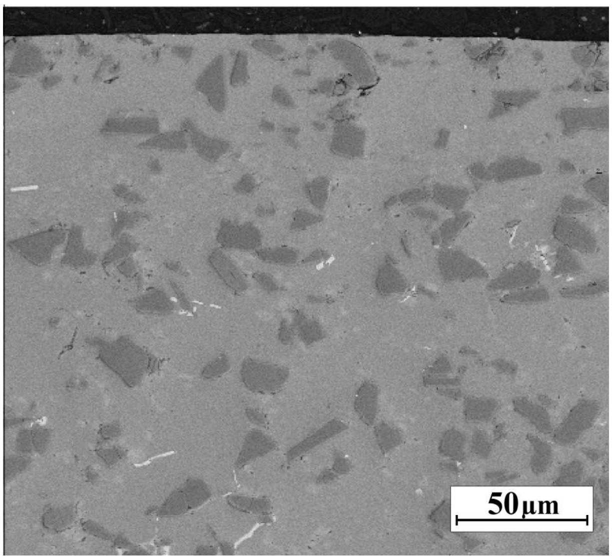

Fig. 6. Microstructure of surface layer end core after laser-assisted turning

Rys. 6. Mikrostruktura warstwy wierzchniej i rdzenia po toczeniu ze wspomaganiem laserowym

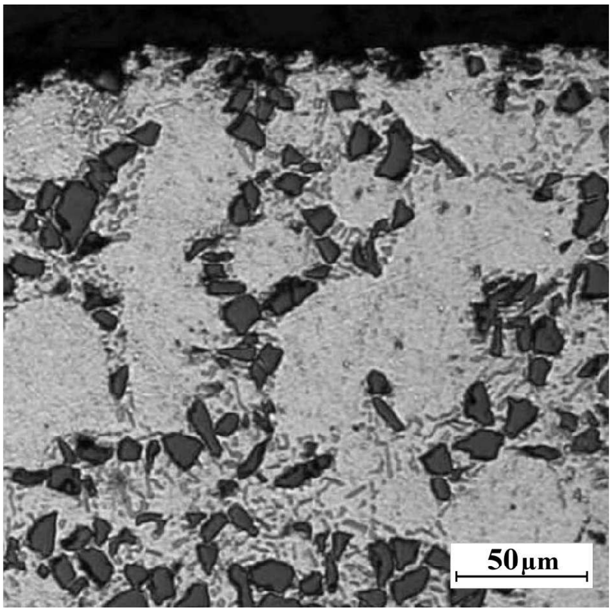

Fig. 7. Microstructure of composite after conventional turning

Rys. 7. Mikrostruktura kompozytu po toczeniu tradycyjnym

CONCLUSIONS

The analysis of composite material microstructures allowed us to designate the laser beam-influenced zone. A matrix liquid zone was observed and also liquid-solid and neutral zones. The research shows that heating composite material using a laser beam with turning kinematic couses decreases the content of SiC particles in the surface layer of the composite. The observations showed a smaller number of removed SiC particles in the surface finish during the hybrid turning process (zone liquid-fixed) in comparison to conventional turning. As the wedge works in the areas of liquid and liquid-solid, it a reduction of the cutting forces, tool wear and the machined surface roughness is expected. This implies the need to continue research in this direction.

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