Polish Society of Composite Materials
Polskie Towarzystwo Materiałów Kompozytowych
12: 3 (2012) 155-158
COMPOSITES THEORY AND PRACTICE

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Received (Otrzymano) 10.02.2012

THE INFLUENCE OF LASER BEAM ON STRUCTURE SURFACE LAYER OF COMPOSITE A359/20SiC$_P$

In terms of applications, aluminum alloys share a larger fraction of Al-SiC composites due to their high wear resistance and different specific mechanical properties. Because of the increasing requirements of these construction materials, different methods of machining, including laser assisted machining, have to be recognized. In many publications one can find that the machinability of metal matrix composites is dependent on the temperature of the process. This paper describes the influence of laser beams on metal matrix composites. In particular, experiments, measurements of the surface temperature and microstructure analyses of an aluminum alloy reinforced by silicon carbide (Al-SiC) heated by a laser beam were carried out. The influence of a laser beam on the microstructures of machined samples was investigated and some mechanisms of surface layer alteration were discussed. It was noticed that the laser beam impact on the workpiece induced the immersion of the reinforced particles into the soft matrix.

Keywords: **laser heating, metal matrix composite, microstructure of composite**

WPŁYW ODDZIAŁYWANIA WIĄZKI LASERA NA STRUKTURĘ WARSTWY WIERZCHNIEJ KOMPOZYTU METALOWO-CERAMICZNEGO A359/20SiC$_P$

W ostatnich latach wzrosło zapotrzebowanie na lekkie materiały konstrukcyjne, np. stopy aluminium, w tym również materiały kompozytowe składające się z osnowy aluminiowej i ceramicznego zbrojenia. Materiały te charakteryzują się dużą odpornością na ścieranie i lepszymi właściwościami mechanicznymi od klasycznych stopów aluminium. Ze względu na zawartość twardych cząstek zbrojenia materiały te należą to grupy materiałów trudno skrawalnych. Nowoczesne metody ich obróbki, w tym laserowe wspomaganie skrawania, stają się coraz częściej przedmiotem badań. W wielu publikacjach stwierdzono, że poprawę skrawalności kompozytów metalowo-ceramicznych osiąga się poprzez podwyższenie temperatury skrawania, dzięki czemu zmniejsza się twardość osnowy. W przeprowadzonych badaniach przedstawiono wpływ nagrzewania za pomocą wiązki lasera na strukturę materiału kompozytowego. W szczególności skupiono się na określeniu temperatury procesu oraz analizie mikrostruktury warstwy wierzchniej kompozytu. Przeanalizowano mikrostrukturę badanych próbek i stwierdzono, że w obszarze oddziaływania wiązki lasera w wyniku gwałtownego wzrostu temperatury zachodzi w ciekłej osnowie warstwy wierzchniej sedymentacja cząstek SiC.

Słowa kluczowe: **nagrzewanie za pomocą wiązki lasera, kompozyty metalowe, mikrostruktura kompozytu**

INTRODUCTION

Metal matrix composites, especially Al alloy matrices, have found widespread use in many engineering applications. The primary support for these composites has come from the aerospace industry for airframe and spacecraft structures. More recently, automotive, electronic and recreation industries have been working with these composites. The driving force behind the development of most of the existing composites has been their ability to be designed to provide required types of material behavior. Particle reinforced composites have the advantage of being formable by standard casting methods. The structure of SiC/Al composites consists of a soft matrix and hard reinforcing particles, and due to hard reinforcements in their structure they are difficult to machine using traditional methods.

Many industrial and research centers have made an attempt to apply new processing technologies in order to improve machinability and reduce the cost of the final products of hard-to-machine materials. One solution that provides economic and technological benefit effects is to deliver additional forms of energy to the cutting zone in the form of a plasma jet or laser beam. Among these methods, laser technology has found the widest application in many areas of modern production. Because of the high power density, the ability to control its value and the possibilities of accurate laser beam orientation, the laser has become a flexible tool in many areas of production technology. Therefore, laser-assisted machining has been considered as an alternative for wear-resistant materials such as metallic alloys and ceramics. It is a high temperature cutting process using a laser beam as the heat source. That method performs machining on workpieces using laser preheating. In the range of high temperature, the hardness significantly decreases, making this material more easily cut machined with a general cutting machine. The aim of the process is to reduce the cutting force necessary to machine the material by increasing the temperature to the point where the strength of the material is reduced.

Most researches on LAM have focused on different kinds of ceramics, inconel 718, white cast iron but there is not much about metal matrix composites [1-5]. A large number of studies on LAM have focused on increasing tool life, surface roughness in machining processes but left out important aspects of the microstructural changes.

The analysis of literature revealed that the use of laser-assisted turning should be carried out at a temperature of about 500°C for aluminum matrix composites. In this process after preheating a workpiece using a laser beam, a general cutting tool such as sintered carbide will be used. Such a laser beam affects the material surfaces and cutting tools are greatly influenced by temperature. It is possible not only to reduce machining times and costs but also to achieve excellent machining qualities due to the softening of materials compared to conventional processing methods such as diamond machining. Thus, it is necessary to establish a temperature control system that applies a pyrometer for measuring and controlling the material temperature. In addition, it is necessary to estimate the temperature distribution at the region treated by the heat source and the thermal influence in the cutting zone.

These experimental results have demonstrated that the laser-assisted machining method can offer a number of advantages over conventional turning methods, such as higher turning efficiency, lower tool wear, smaller cutting forces, and better surface quality.

The main tasks involved in this study include, (I) a surface layer analyses after laser heating, (II) some influences of laser irradiation on the surface temperatures in two regions: Z_1 laser heated, Z_2 cutting zone.

EXPERIMENTAL PROCEDURE

Laser heating was carried out with a 2.6 kW CO_2 laser (2.6 kW Trumpf, type TLF2600t).

The workpiece material consisted of an AlSi9Mg aluminum alloy matrix (composition: 9.2% silicon, 0.6% magnesium, 0.14% iron, 0.11% titanium, 0.01% copper, 0.02% zinc, aluminium balance) to which 20% silicon carbide with a particle size of between 8 to 20 µm was added. The investigated material was fabricated by molten metal mixing and direct chill casting by the Duralcan company. The workpieces (cylindrical shape 10 mm in length and 60 mm in diameter) had an absorptive coating applied each time to increase laser absorption (Fig. 1). The experiments were carried out by turning on a TUM 35D1 lathe with an infinitely variable adjustment of rotational speed. The selected machining parameters were: laser speed (v_l = = 10 m/min), feed rate (f = 0.04 mm/rev), workpiece diameter (d = 60 mm), laser beam diameter (d_l = 2 mm), laser power (P = 1000 W).

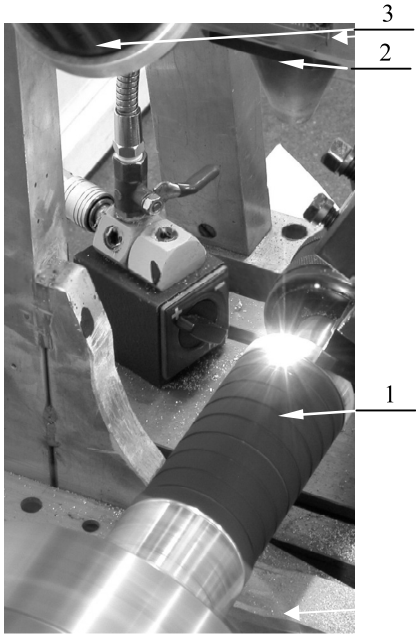

Fig. 1. View of workstation: 1 - workpiece material, 2 - laser head, 3 - high-temperature pyrometer (measurement temperature in heating zone by laser beam)

Rys. 1. Widok stanowiska: 1 - materiał obrabiany, 2 - głowica laserowa, 3 - pirometr wysokotemperaturowy (pomiar temperatury z obszaru nagrzewanego przez wiązkę lasera)

The surface temperatures were measured by two Raytek pyrometers [4]. One of them measured the temperatures in the heating area by the laser beam Z_1 and the others in zone Z_2 at the same time (Fig. 2).

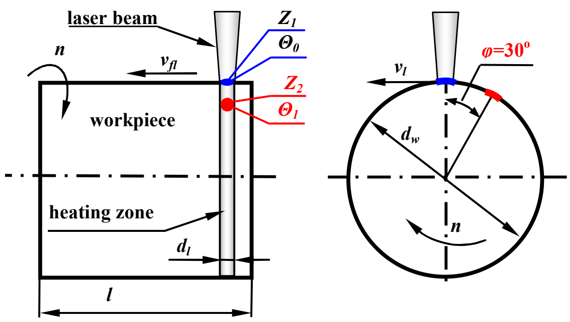

Fig. 2. Diagram of metal matrix composite laser heating and measuring of surface temperature. Designations: Z_1 - heating area by laser beam and temperature measurements by high-temperature pyrometer, Z_2 - area of temperature measurements by pyrometer, d_w - workpiece diameter, d_l - laser beam diameter, v_l - laser beam speed along heated surface, l - workpiece length

Rys. 2. Schemat układu pomiarowego temperatury. Oznaczenia: Z_1 - obszar nagrzewany przez wiązkę lasera, Z_2 - obszary pomiaru temperatury, d_w - średnica próbki, d_l - średnica wiązki lasera, v_l - prędkość przemieszczania się wiązki lasera po powierzchni próbki, l - długość próbki

The angle between the area heated by the laser beam and zone Z_2 was equal to 30 degrees. The emission was set in the software based upon previously conducted calibration tests. Our previous work [5] shows that the emission coefficient strongly depends on the temperature and surface roughness. The methodology of determining and defining the emissivity coefficient ε was presented in [6].

The temperature was characterized by the average arithmetic temperature which was determined by the averaging of the arithmetic temperature values for 5 trials in the same conditions on a heated surface (Figs. 3 and 4).

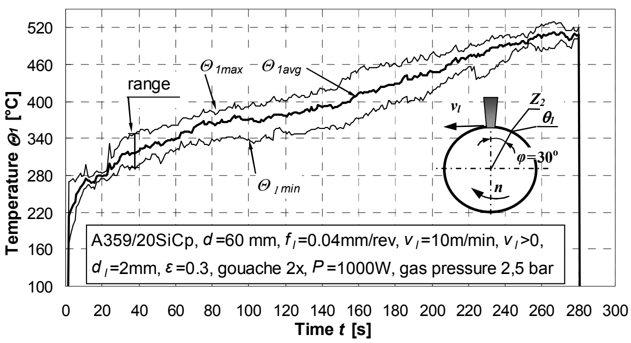

Fig. 4. Temperature Θ_I of heated MMC surface after rotation at angle $\varphi = 30^{\circ}$

Rys. 4. Temperatura Θ_I powierzchni nagrzewanej MMC po obrocie o kąt $\varphi = 30^{\circ}$

RESULTS AND DISCUSSION

Figure 3 shows the surface temperature alteration on the workpiece surface MMC in the heat zone by the laser beam (Z_I). The temperature in the laser irradiation zone is stable (Fig. 3) as opposed to the increasing temperature at the same time in the Z_2 area (Fig. 4). The average temperature in zone Z_I was about 1900°C and the range was about 200°C for Θ_0.

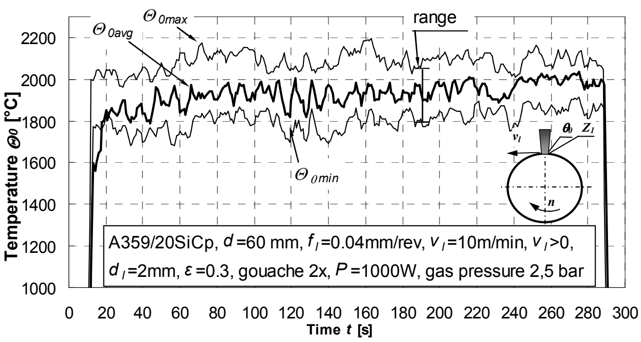

Fig. 3. Course of temperature Θ_0 during heating MMC

Rys. 3. Przebiegi temperatury Θ_0 w czasie nagrzewania MMC

Figure 4 shows the course of the surface temperature during heating with turning kinematics by the laser beam in the Z_2 zone (turn of workpiece 0.094 s, angle $\varphi = 30°$ in relation to Z_I area), this is the planned cutting zone. The temperature in the initial stage of the process averaged 220°C and increased in time to about 490°C at the end of the process (Fig. 4). This is caused by the accumulation of heat in the sample. The range of temperature Θ_I is about 70°C. It is caused by the different absorption layer thickness of coating (gouache) on the sample as well as the difference in the structure of the sample (eg. surface roughness).

The aim of this study was to evaluate the metallographic structure of the surface layer of a composites material after heating by a laser beam. The metallographic microscope Neophot 2 produced by Carl Zeiss Jena and Nikon microscope equipped with camera BRESSER were used. To determine the distribution of reinforcing phase contribution in the surface layer, the program for image analysis ImageJ was used.

After the heating process, a rough surface with blebs was observed (Fig. 5), which indicates the abruptness of the laser heating process. Figure 5 shows the dark color of the surface layer which is a residue of the laser irradiation absorbing coating (gouache). The area of the material sample was cut and applied to prepare the metallographic microsection for observation of the structure in the plane perpendicular to the heating surface.

Fig. 5. Photo of laser heated area

Rys. 5. Fotografia obszaru wałka nagrzewanego laserem

The micrograph (Fig. 6) indicates two areas: *A* - with a minor percentage of reinforcing phase in with gas bubbles, which are visible from the adjacent SiC particles, and the *B* area with a distinct sedimentation layer of SiC particles.

The volume of SiC particles in the *B* area is approximately 28.9%, whereas the calculated average value for *A*+*B* areas was 20.38%. This means that in the laser heated zone, sedimentations of the liquid matrix SiC particles were observed, and thus they increased the volume fraction of the reinforcing phase in the selected area *B*. In addition, the emerging gas phase induced the formation of bubbles and agglomerates of SiC particles and their flowing up to the surface. The emerging gas bubbles are probably the effect of magnesium boiling, which is the alloy addition to matrix composites. The heating by a laser beam of the investigated sample induces magnesium desorption.

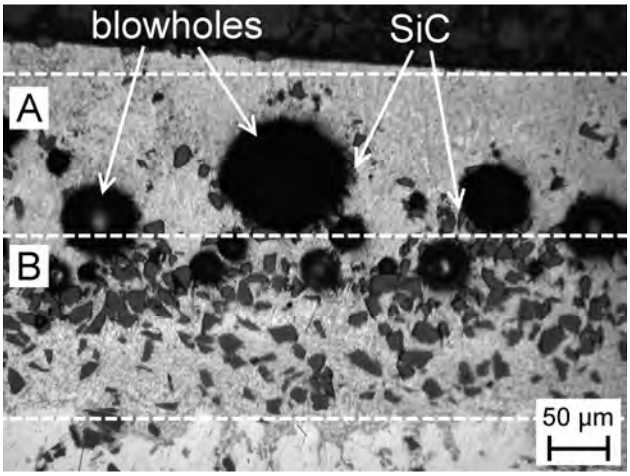

Fig. 6. Micrographic of surface layer heated by laser beam

Rys. 6. Mikrografia warstwy wierzchniej nagrzewanej laserem

CONCLUSIONS

These experimental results and studies allowed us to determine the laser heating process temperature and revealed obvious changes in the surface layer of the metal matrix composite. Heating by a laser beam of the surface layer of the composite induces the sedimentation of SiC particles and their uniform density in the area of planned machining. Using the process of laser assisted machining and taking into consideration the sedimentation layer of particles, it is possible to obtain a material with an increased concentration gradient of particle reinforcing phase in the surface layer.

The results, which can make grounds for further investigations, are as follows:

1. Laser heating effectively increases temperature in the plane cutting zone, therefore it is possible to benefit from the integration of laser technology in the turning process for MMC materials.
2. The usability of the new approach of metal matrix composites machining called sequential machining.

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