DAMIAN PRZESTACKI*, MARIAN JANKOWIAK**

INVESTIGATION OF TEMPERATURE CHANGE DURING SURFACE HEATING OF MMC BY LASER BEAM

This paper reports on experiments carried out for surface temperature measurements of aluminium alloy reinforced by silicon carbide (Al-SiC) heated by laser beam. The non-contact pyrometers operating on infrared radiation were used to determine a temperature. The present study investigates the influence of laser beam speed \( v_l \) along the cylindrical surface of MMC on its temperature \( \Theta \) and determines temperature alterations of heated area by laser beam in function of angle rotation \( \varphi \). It was noticed that due to high thermal conductivity of matrix the heat area was cooled down rapidly and after rotation of sample by an angle \( \varphi = 90^\circ \) its temperature decreased more than twice. The results showed that surface heated by laser beam effectively increases temperature in plane cutting zone, therefore it is possible to benefit from an integration of laser technology in turning process.

Key words: temperature, laser assisted machining, metal matrix composite

1. INTRODUCTION

Metal matrix composites are engineered materials formed by the combination of metal matrix and reinforcement materials. They have a stiff and hard reinforcing phase in metallic matrix. The matrix includes metals such as aluminium, magnesium, copper and their alloys. The reinforcing phase in the composite can be in the form of continuous fibers or discontinuous fibers/particles and the reinforcing materials are advanced ceramic materials like alumina, silicon carbide, boron nitride, etc. Incorporation of ceramic reinforcement phase enhances the properties like adhesive, abrasive and diffusion wear resistance, thermal properties, hardness, strength, stiffness etc. The mechanical properties can be fine tuned to the requirement by choosing the size, shape and size distribution of the reinforcement a part from selecting different proper matrix alloys.

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Metal matrix composites are advanced composite materials that exhibit tremendous potential for a number of important applications in all sectors. In particular, SiC-particle-reinforced aluminium matrix composites have found many applications and have been produced on a commercial scale [4, 7]. Machining metal matrix composites are difficult to machine [1–3, 14, 15] after fabrication due to the inclusion of ceramic particles as reinforcement and results in accelerated tool wear and a poor machined surface being the major problems. During machining MMCs, ceramic particulate cracking and debonding are typical damage mechanisms that greatly affect the integrity of surface produced [5, 6, 8, 13]. The particles pulled out by the tool during cutting process leave behind large pit holes, voids and craters that facilitate the formation of fatigue cracks [8, 10]. This difficulty increases with increasing volume fraction of the reinforcement. Techniques employed for machining MMC [4, 7] include cutting by diamond tools [1–3, 14, 15]. The cost of PCD tools increases the cost of production so it is necessary to find an alternative method to machine MMCs. As a consequence, hybrids machining processes, e.g. Laser Assisted Machining (LAM), are become more popular to machine difficult machining materials. Laser is one of the choice for assisted machining composite materials such as MMC because can reduce tool wear and improve surface quality.

It is generally observed that the machinability of metal matrix composite are dependent on cutting conditions, tool geometry, and temperature process.

In this present study, the laser heating of metal matrix composite surface is considered. The temperature in the laser irradiated region and cutting zone are recorded by pyrometers. Compared with conventional temperature sensors such as thermocouples, this measurement by pyrometer technique has the advantage of being non-contact measurement and having a very short response time [9].

The objective of this study is to determine surface temperature in different areas of sample in order to determine heating speed and laser power necessary to laser assisted turning metal matrix composite.

### 2. RANGE, CONDITION AND TECHNIQUE OF RESEARCH

The research includes following problems:
- determination of surface temperature ($\Theta_1$, $\Theta_2$, $\Theta_3$) after rotation of sample by an angle of $30^\circ(B)$, $45^\circ(C)$, $90^\circ(D)$ for difference laser beam speeds
- determination of influence of laser power on temperature in $A$ ($\Theta_4$) and $B$ ($\Theta_5$) regions

The CO$_2$ technological laser (TLF 2600t, TRUMPF) delivering nominal output power of 2.6 kW is used to heat the workpiece surface. Laser is integrated
with universal lathe type TUM 25D1 with stepless spindle rotation control. The view of the laser heat is illustrated in Figure 1.

A metal matrix composite is used as the workpiece material. The workpiece material consisted of a AlSi9Mg aluminium alloy matrix (9.2% Si, 0.6% Mg, 0.1% Fe) to which 20% of SiC with a particle size of between 8 to 15 μm had been added. The workpieces (cylindrical shape of 10 mm length and 60 mm in diameter) were painted twice by absorptive coating (gouache) each time to increase laser beam absorption.

Fig. 1. Schematic of metal matrix composite laser heating and measuring of surface temperature.

Surface temperatures were measured by three RAYTEK pyrometers (Table 1). One of these measured temperatures in heating area by laser beam (Fig. 1) and the others in zone B, C and D at the same time. Angle between area heated by laser beam and zone B, C and D was suitably 30, 45 and 90 degree. Emission was set in the software based upon calibration tests primary made. Our previous work [11] shows that, emission coefficient strongly depends on the temperature and surface roughness. If the real temperature changes, the emission coefficient should be also changed to get the correct value of temperature. Methodology of determination and definition emissivity coefficient ε was presented in [11].

The temperature was characterized by the average arithmetic temperature which was determined by values for the 5 trials in the same conditions on a heated surface.
The heating of MMC samples was carried out with constant feed rate $f = 0.04 \text{ mm/rev}$ of turning kinematic, laser power was: $P_1 = 600 \text{ W}$, $P_2 = 1000 \text{ W}$, $P_3 = 1800 \text{ W}$, $P_4 = 2600 \text{ W}$, laser beam speed was: $v_l = 10$, 30, 50, 70, 100 m/min and laser beam diameter $d_l = 2 \text{ mm}$.

3. RESULTS AND DISCUSSION

In Figure 2 the influence of angle distance on surface temperature in heated area by laser beam and areas remote from this place about 30° and 90° are shown. Decrease distance between heated area by laser beam and plan machining area bring on high temperature $\Theta_2$ in this area for all investigated speeds $v_l$ (Fig. 2, Fig. 3). These were considerable difference of temperatures in plan machining areas for all laser speed both for constant time of process (Fig. 2) and constant heating distance (Fig. 3).

Insignificant differences for temperature $\Theta_3$ and $\Theta_4$ analyses after constant time of heat was found, as contrasted with significant difference of temperatures analyses for constant heating distance (Fig. 3). Analyses temperature $\Theta_1$, $\Theta_2$, $\Theta_3$ after constant distance showed that decrease laser beam speed increased temperature in all researched areas (Fig. 3). Increase laser beam speed $v_l$ means shorter time influence laser beam on sample that causes decrease temperature in $B$, $C$ and $D$ areas (Fig. 3).

<table>
<thead>
<tr>
<th>Pyrometer model</th>
<th>MA1SC</th>
<th>MA2SC</th>
<th>S5XLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical resolution</td>
<td>300:1</td>
<td>32:1</td>
<td></td>
</tr>
<tr>
<td>Spectral range [μm]</td>
<td>1</td>
<td>1,6</td>
<td>8–14</td>
</tr>
<tr>
<td>Repeatability of measurements</td>
<td>±0,01% of measured value +0,1°C</td>
<td>±0,5% of measured value +0,1°C</td>
<td></td>
</tr>
<tr>
<td>Answering time [ms]</td>
<td>1</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Emissivity</td>
<td></td>
<td></td>
<td>0,10–1,00</td>
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Fig. 2. Temperature of heated MMC surface after rotation by an angle $\phi$ for different $v_p$ values for constant time of process

Rys. 2. Temperatura powierzchni nagrzewanej MMC po obrocie o kąt $\phi$ dla różnych wartości $v_p$ przy stałym czasie procesu

Fig. 3. Temperature of heated MMC surface after rotation by an angle $\phi$ for different $v_p$ values during constant heating distance

Rys. 3. Temperatura powierzchni nagrzewanej MMC po obrocie o kąt $\phi$ dla różnych wartości $v_p$ podczas stałej drogi nagrzewania

In Figure 4 influence of laser power on temperature ($\Theta_i$), and ($\Theta_i$) during heated area by laser beam with speed $v_l = 10$ m/min are shown. It was noticed that the temperatures in $A$ and $B$ areas increases with laser power. In spite of laser power from 1000 W to 1800 W both $A$ region and $B$ area get insignificant
increase of temperature $\theta_h$ (about 50°C) and $\theta_l$ (about 20°C). Whereas over quadruple increase of laser power from 600 W to 2600 W brings on significant increase of temperature in heated area by laser beam (450°C), whereas temperature in C region increases only about 100°C. It occurs to use 1000 W of laser power in laser assisted machining which is a compromise between delivered energy and obtain increment of temperature $\theta_l$.

4. CONCLUSIONS

The effect of metal matrix composite heating by laser beam was investigated. Values of temperature have been analyzed after rotation from heated area by laser beam to plan machining area. The knowledge of this temperature is a helpful to understand the mechanisms which take place during the process. The results, which can make a ground for further investigations, are as follows:

1. laser heated effectively increases temperature in plane cutting zone therefore it is possible to benefit from an integration of laser technology in turning process

2. decreasing angle distance from 90° to 30° between heated area by laser beam and plan machining area brings on more than twice higher temperature $\theta_l$ in this area

3. the laser power of $P = 1000$ W appear to be a compromise between delivered energy and obtain increment of temperature $\theta_l$. 
REFERENCES


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ZMIANA TEMPERATURY PODCZAS NAGRZEWANIA POWIERZCHNI MMC WIĄZKĄ LASERA

Streszczenie

W artykule zamieszczono wyniki pomiaru temperatury powierzchni kompozytu metalowo-ceramicznego (MMC) podgrzewanego wiązką lasera. Do pomiaru temperatury wykorzystano pirometry bezkontakto we działające na zasadzie detekcji promieniowania podczerwonego. Celem badań było określenie wpływu prędkości przemieszczania się promienia laserowego \( v \) po powierzchni walcowej MMC na jej temperaturę \( \Theta \) oraz określenie zmiany temperatury nagrzewane-
go obszaru w funkcji kąta obrotu $\varphi$ próbk. Stwierdzono, że z powodu dużej przewodności cieplnej osnowy badanego kompozytu następuje szybkie stygnięcie nagrzanego laserowo powierzchni i po obrocie próbki o kąt $\varphi = 90^\circ$ jej temperatura maleje kilkakrotnie. Wykazano, że podgrzewanie powierzchni kompozytu wiązką lasera podwyższa temperaturę w obszarze planowanego skrawa-
nia, dlatego wydaje się zasadna integracja lasera z toczeniem kompozytu metalowo-ceramicznego.

Słowa kluczowe: temperatura, laserowe wspomaganie skrawania, kompozyt metalowo-ceramiczny