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An Experimental Study for Machinability of Al/SiC$_p$ Metal Matrix Composites by Laser

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In this study, the laser milling process was used to investigate the machinability of particle reinforced aluminum matrix composites manufactured by powder metallurgy having different amount of SiC$_p$ (5, 10, 20 wt%). In this context, the laser parameters like scan speed and fill spacing were associated with the SiC$_p$ amount in aluminum (Al) matrix. According to the experimental results, the scan speed is dominant factor on both milling depth and surface roughness. Also, the reinforcement particle amount (wt%) is the effective factor but there is no detected significant relation between the surface roughness and reinforcement particle amount. However, the change in milling depth has been linearly changed with the increase of reinforcement particle amount.

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1. Introduction

Increased in dimensional accuracy in complex geometry requires the precision surface machining. It is well known that the cutting tool geometries and materials play a distinctive role in the precision surface machining. The non-conventional machining technologies like electrical discharge machining (EDM, WEDM), laser beam machining (cutting, drilling, engraving etc.) and water-jet are the non-contact machining techniques. Due to absence of cutting tool force on the machining surface, the some tool based problems can be eliminated [1, 2].

Among the non-conventional machining technologies, the laser beam machining provides some advantages such as precision machining and dimensional accuracy [3]. Milling by laser beam is performed by a high intensity beam. The laser beam interacts with the material and subsequently is converted into heat energy. This energy vaporizes the material in a short time. The intensity of this heat energy and temperature per unit area are determined by the process parameters namely laser power, frequency and beam scan speed.

To the best of our knowledge, no study has been detected related to the laser milling of particle reinforced aluminum matrix composites (PRAMCs) produced by powder metallurgy (P/M) in the open literature.

Most of the existing studies are concentrated on machining of steel and aluminum workpieces. A few of these studies are: Kacar et al. [2] performed a study relating to the drilling of alumina ceramic using Nd:YAG pulsed laser. Chang and Kuo [4] have studied on the machining of Al_2O_3 ceramic material by CO_2 laser with a power of 25 W. They calculated the temperature distribution inside the ceramic workpiece to determine the subsurface damages.

In the present study, the selected workpiece materials are Al/SiC$_p$ metal matrix composites (MMCs) produced by P/M. It is known that the SiC$_p$ has the abrasive properties and causes some problems during the conventional machining process. The laser milling process was considered to be an alternative machining process to reach the better surface and machining performance. In this context, different amounts of SiC$_p$ were added to Al matrix in order to investigate the effect of SiC$_p$ amount on the surface roughness of PRAMCs.

2. Experimental studies

In the current study, samples were manufactured by conventional P/M process. The amount of SiC$_p$ reinforcement is 5, 10, 20 wt%. The SiC$_p$ reinforcements (69 μm) and Al powders (84 μm) weighed using an analytical balance were placed in a three-dimension mixing machine and mixed for 60 min at 50 rpm, in a homogeneous way and homogeneous distribution of the reinforcement particles in the matrix was provided. After the mixing procedure, green samples were obtained by waiting the green samples for 5 min under 440 MPa pressure by pressing cold uniaxially.

Sintering process was carried out at 150, 300, 450 °C for 30 min, then there was final heating to 600 °C keeping at that temperature for two hours. The machining experiments were performed by a fiber laser marking machine having 50 W power. The surface of samples was machined in a square shape of 10×10 mm^2. The focal length of laser beam was 160 mm and set at this value for all experiments. The scanning of surface was repeated 20 times at the same condition. The parameters used in machining applications are scan speed (400, 600, 800, and 1000 mm/s) and fill spacing (0.03 and 0.05 mm). Totally 32 experimental runs were performed for determining the effects of parameters on the responses. The milling depth and surface roughness were considered as the milling responses.

After milling experiments, the surface roughness of the samples was measured by Mitutoyo SJ-301 surface roughness tester. The surface roughness was characterized by R_a. The evaluation length and cutoff length was

4 mm and 0.80 mm, respectively. Totally at the least four measurements at scan direction and perpendicular direction for each surface were carried out to determine the surface roughness (R_a). The average of these four measurements was used as the ultimate R_a value. Also, the milling depth (D_M) was measured by Mitutoyo digimatic indicators. Totally three measurements were carried out to determine D_M value. The average of three measurements was used as the ultimate D_M value.

3. Results and discussion

This study was performed to investigate the effect of laser milling process on the machining results that is milling depth and surface roughness.

For this purpose, two milling parameters varied at different levels given in Table were used for analyzing procedure. Accordingly, eight experiments were performed for each group of samples. In surface milling operation, minimizing the surface roughness is the base machining and objective criteria. Firstly, the effect of scan speed (SS) on the evaluation of the surface roughness was studied. During the investigation, the fill spacing (FS) was held constant.

The first evaluation was performed while fill spacing at 0.03 mm and graphical results for each group of samples were given in Fig. 1. According to this graph, except unreinforced aluminum matrix (0 wt% SiC_p), the R_a values of all other samples having 5, 10, 20 wt% SiC_p were increased with increasing scan speed. A similar result was found when fill spacing at 0.05 mm (see Fig. 1). This can be explained by the SiC_p amount. It is known that laser milling process is the thermal machining process and also vaporizes the material at the interaction region. In this regard, unreinforced matrix is vaporized by volume and the remaining surface has the melted and rapidly re-solidified layer. Also, this layer determines the surface roughness value.

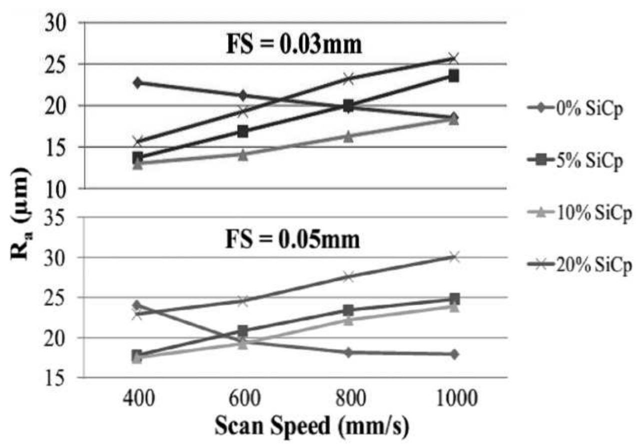

Fig. 1. The effect of scan speed on surface roughness with changing in particle reinforcement amount (wt%) for: FS = 0.03 mm and FS = 0.05 mm.

However, PRAMCs have not shown similar trend when compared unreinforced material. When the results are compared for fill spacing value at 0.03 mm, it is shown that the highest R_a value was observed at material having SiC_p with 20 wt% for all scan speed. The reason for the increase in R_a value with the increasing scan speed for the PRAMCs can be explained by the lower heat input. The lowest R_a values were observed for the PRAMCs with fraction of 10 wt% SiC_p for both fill spacing values. Also for both fill spacing values, the R_a values were increased with increasing scan speed. This result can be explained with the matter of decreased heat input. The decrease of heat input causes to reduce vaporized material.

In milling operation, maximizing of depth is another base machining criteria. Results for both fill spacing values showed that any increase in scan speed causes to decrease in milling depth.

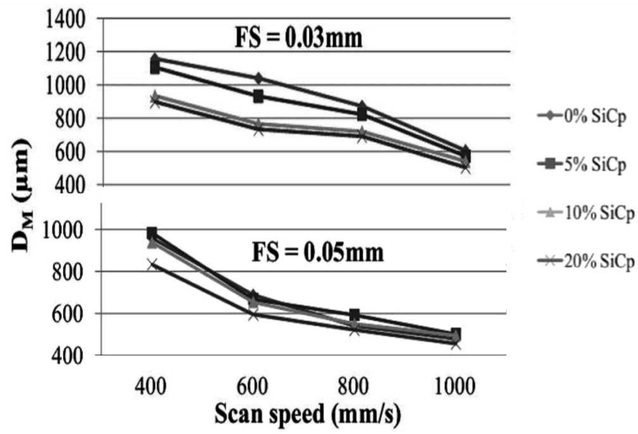

Fig. 2. The effect of scan speed on milling depth with changing in particle reinforcement amount (wt%) for: (a) FS = 0.03 mm, (b) FS = 0.05 mm.

Figure 2 shows the results of milling depth. The results compared to each other for fill spacing at 0.03 mm, lowest and highest D_M value were obtained from the PRAMCs with fraction of 20 wt% SiC_p and unreinforced Al material, respectively. Furthermore, milling depth results for the PRAMCs with fraction of 20 and 10 wt% SiC_p are almost similar between the 400 mm/s and 1000 mm/s of scan speed values. When the PRAMCs compared to each other, it is observed that the milling depth has decreased with increasing SiC_p amount. However, the results for fill spacing at 0.05 mm showed that the variation in D_M value with change in SiC_p amount is not distinct. Results are almost close to each other at any scan speed. The lowest D_M value was obtained from unreinforced material when scan speed was at 1000 mm/s.

TABLE

Laser milling process parameters.

Symbol	Parameters	Levels			
SS	scan speed [mm/s]	400	600	800	1000
FS	fill spacing [mm]	0.03	0.05	–	–

4. Conclusion

In this paper, the laser milling process was applied to PRAMCs. The milling depth and surface roughness values were accepted as the process performance characteristics and correlated with the milling parameters namely beam scan speed and fill spacing values. The investigation of scan speed effects as a function of particle reinforcement amount showed that the increase in scan speed increases surface roughness while decreases the milling depth for all particle reinforcement amount (wt%). The highest surface roughness (25.65 μm) was obtained at scan speed of 1000 mm/s when fill spacing was at 0.03 mm. Also, a similar result was observed at fill spacing of 0.05 mm. For fill spacing of 0.05 mm, the highest surface roughness was 30.09 μm and observed at 1000 mm/s. For both fill spacing values, the lowest surface roughness was achieved at scan speed of 400 mm/s and amount of 10 wt% SiC_p. As for milling depth, the lowest milling depth (457 μm) at fill spacing of 0.05 mm was achieved at scan speed of 1000 mm/s for Al/SiC_p (20 wt%) sample. A similar result was achieved at 0.03 mm for fill spacing that is 505 μm. While the highest milling depth for fill spacing of 0.05 mm is 982 μm which was obtained at scan speed of 400 mm/s for Al/SiC_p (5 wt%) sample, the value for fill spacing of 0.03 mm is 1158 μm which was obtained for unreinforced material with scan speed of 400 mm/s.

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