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MACHINING OF ALUMINIUM MATRIX COMPOSITE WITH LASER ASSISTED MACHINING (LAM)-A REVIEW

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ABSTRACT

Al/SiC Metal Matrix Composites (MMCs) are the new class of materials and are rapidly replacing conventional materials in various applications industrial and aerospace applications. These materials are generally regarded as extremely difficult to machine, because of the abrasive characteristics of the reinforced particulates. It has poor machinability such as excessive tool wear and fracturing of the reinforcement particles on machined surface. It leaves behind adhered particle fragments, pits and cavities despite superior excellent engineering properties. Discontinuous silicon carbide reinforced aluminium alloy metal matrix composites have proved to be extremely to cutting using conventional cutting tools. Thus, there is a need to introduce new processing method in order to improve both the working conditions and the quality of the products made of metal matrix composites. Laser processing offer the advantages of high processing rates, no tool wear, no contact forces, and relatively high precision. Currently the mechanisms governing the laser cutting process of composites are not fully understood. It is the aim of the authors therefore to take a review of the physical processes of laser composite material interactions and the phenomena occurring within the cutting front, viz. the formation of chips, tool wear, and the effect they have on the resulting cutting quality.

Keywords-*Composite; Laser beam interactions; Parameters; Chip Formation; Tool wear;*

I. INTRODUCTION

Metal matrix composites (MMCs) form one group of the new engineering material that has received considerable research since 1980s. The most popular reinforcements are silicon carbide and alumina. Aluminum, titanium and magnesium alloys are commonly used as the matrix phase. Reinforcements have been used in the form of particulates, whiskers, or continuous fibers. Applications of Al/SiC metal matrix composites in a variety of engineering fields have undergone a substantial increase because of their tailor made properties by varying its composition. In general stir casting is used to prepare MMCs. In stir casting of MMCs involves producing a melt of selected matrix material followed by the introduction of reinforcement material into the melt and the dispersion of the reinforcing material through stirring. The distribution of SiC particulates in cast is a major factor in determining the properties of MMCs[1].

Despite the superior mechanical and thermal properties of particulate metal-matrix composites, their poor machinability has been the main deterrent to their substitution for metal parts. The hard abrasive reinforcement phase causes rapid tool wear during machining and, consequently, high machining costs. Although often categorized as difficult to machine, MMCs are actually readily machinable[2].

They form short cutting chips, cutting forces are moderate and the range of machining parameters at which they can be machined is quite wide. To date MMC has been used in the production of relatively thick components but more recently attempts have been made to use this material in thin sheet form[3]. Conventional cutting using diamond tools is costly and/or technically difficult. Since Wire-EDM is slow, laser machining can offer significant productivity advantages for rough cut-off applications. It is apparent that a laser is very suitable for high feed rates [4] (up to V=3000mm/min) and can produce a cut with a narrow kerf width (d=0.4 mm). Reinforcing the aluminum matrix with SiC ceramic particles improves the machinability of the Machining guidelines of Al/SiC particulate MMC composite, due to the reduction in the optical reflectivety of the material. However quality of the laser cut surface is relatively poor. Striation patterns on the cut surface and burrs at the exit of the laser (dross attachment) were observed. Significant thermal induced microstructural changes were also observed within the PRMMC[5].

1.1 Laser Machining of Composites

Machining of composite materials often poses challenge, particularly for fine profiles and counters and for hybrid laminates consisting of two or more vastly dissimilar materials. Conventional approaches used for composites, such as water- jet machining are not always sufficient. Laser machining of composites may offer a solution to some of these problems, although the laser- material interactions are not well understood[6].

• Typical machining involves:

- Cutting
- Drilling
- Milling

Laser cutting (advantages)

• Laser beam produces a spot of intense heat energy which can offer:

- Narrow kerf widths with straight edges
- Very little heat affected zone adjacent to the cut edge
- Minimum heat input resulting in minimal distortion
- possible to cut/drill very fine features

• Since light exerts no force on the work piece, lasers are noncontact tools which means:

- No mechanical distortion of the work piece
- No cutting tool wear, maintenance or replacement
- Ability to cut material regardless of their hardness
- Considerably less noise compared with water jet, plasma and mechanical techniques

• Additionally, the beam of light from the laser has a high degree of control and flexibility

Laser Cutting (disadvantages)

• High capital cost relative to other techniques (however, operating costs are lower than many other techniques)

• Micro cracking at the cut edge may occur in some materials (i.e. engineering ceramics etc)

• Toxic fumes are generated from laser cutting of some materials (i.e. plastics composites etc)

• Especial eye wear and enclosed working enclosures

II. LASER CUTTING MECHANISM

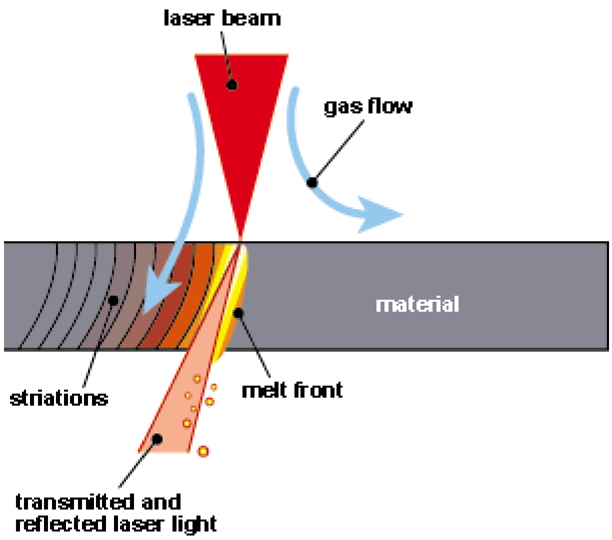

Fig.1 Mechanism of LAM[6]

The beam penetrates into the kerf (a little is reflected from the material surface) and some passes straight through. A melt- front is generated supporting the molten material which is subsequently blown away out of the kerf with an assist gas. A particular characteristic of laser cut is the formation of Striations on the cut edge. These striations play an important part in laser cutting as they effectively control the edge roughness. Mechanism for Laser cutting has been shown in Fig.1.

In general the results show:

- The fibre type had a significant influence on the cut quality, carbon reinforced materials proving to more difficult to cut
- The main problem with the carbon fibre reinforced composites was fibre/resin separation.
- The effect became more severe as the thickness of the composite increased.
- For glass and aramid reinforced composites, less separation between the fibre and resin was observed but the cut edges were still characterised by carbon deposits.

Metal matrix composites

- Work carried so far have shown that two distinct modes of behaviour in laser cutting of metal matrix composites:
- One appears to be where the composites behave effectively as metals and other where fibre and resin separation occurs similar to carbon fibre polymer composite [7].

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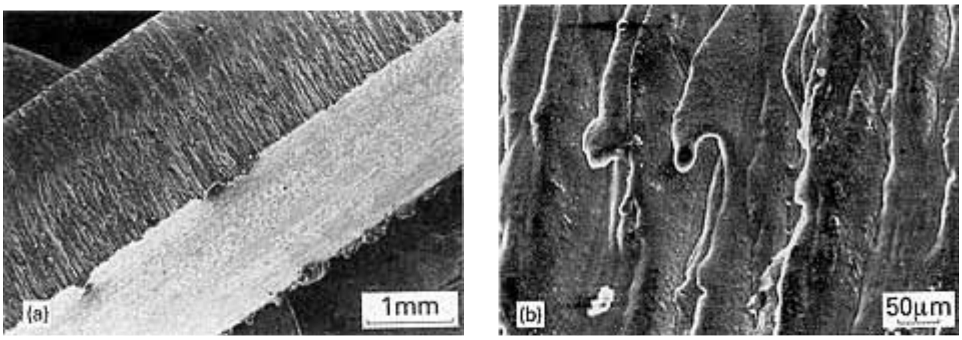

Fig.2-2mm thick Al-Li alloy reinforced with 20% (wt) SiC particulate [4]

CO_2 laser is best suited for cutting polymer composite materials. Both CO_2 and Nd: YAG can be used for cutting ceramic and metal based composite material. CO_2 laser cutting of polymer composites is dependent upon the fibre reinforcement and the thickness of composite. For carbon fibre reinforced composites it is difficult to achieve cuts in material thickness over 4mm. In addition, separation of fibre and the resin occurs. Cutting of ceramic materials is affected by cracking caused by thermal shock. Use of pre/post heating can reduce this problem but some micro cracking still occurs. In conclusion composite materials can be cut by using laser but the quality is not good as the water jet cutting. Figure 2 shows the cutting pattern of LAM on 2mm thick Al-Li alloy reinforced with 20% (wt) SiC particulate.

TABLE 1 PARAMETERS FOR CONTINUOUS MODE OPERATION [8]

Processing parameters	Unit
Laser Power	W
Cutting Speed	mm/min, m/min
Type of Assist Gas	Oxygen, Nitrogen, Argon
Gas Pressure	Bar
Focal Length of lens	mm
Focal Diameter	mm
Focus Position	Surface of work material
Nozzle Tip Distance	mm
Nozzle Diameter	mm
Material Thickness	mm

III. EFFECT OF CUTTING PARAMETERS ON SURFACE QUALITY

The surface quality of a machined component was demonstrated by measuring the surface roughness and surface/sub surface damage. Many research works have been reported in literature on surface roughness; surface/subsurface quality for LAM of ceramics, metals and ferrous alloys. However, very few studies are available on the composite material. Dandekar et al[1], reported the work on LAM machining of Al_2O_3 fibre reinforced composites and found the variation of surface roughness with respect to workpiece temperature. Surface roughness has been significantly reduced (65%) in LAM up to surface temperature of 300°C, in comparison with conventional machining. Beyond 300°C, debonding between the fiber and the matrix, micro cracking of fibers and fiber pullout is observed, and this has resulted in a slight deterioration of surface quality. The subsurface damage depth after a laser assisted turning process shows less fiber damage. The damage depths are 167–157 µm with assistance of the laser, and these are smaller than those of 137– 125 µm performed by using conventional turning at the same cutting conditions. However, the experiment performed on the particulate composites shows that the surface damage is independent of surface temperature and that it depends on the particle size. The effect of cutting speed and rake angle on subsurface damage for the machined long fiber MMC was compared to that of conventional machining. At low cutting speed and large rake angle, the higher surface roughness and minimum sub surface damage rate have been produced, which was controlled by minimum particle fracture or fiber pull-out rates[9].

Compressive residual stress is observed on the laser assisted machined surface of Al_2O_3/A1 and the magnitude of residual stress has been increased 3 times by conventional machining. The reason is that the softened matrix is easily squeezed out from the machined surface, while Al_2O_3 particle is pushed in from the machined surface, thus producing a higher concentration of Al_2O_3 particles in the surface layer and increasing the wear resistance of the machined surface. This has resulted in an improved surface finish.

IV. CHIP MORPHOLOGY DURING LAM

Due to high hardness and brittleness in nature, the formation of chips during machining of brittle material does not occur by plastic deformation. But the strength and brittleness can be reduced at elevated temperature; thereby the material is removed by both brittle fracture and plastic deformation. A multi- scale finite element modelling of LAM of fibre and particulate reinforced MMC was developed by Dandekar and Shin[1] to study the sub-surface damage in terms of particle fracture, matrix void formation and debonding depth. The result showed that micro cracks initiated and propagated under the loading of tool at material removal temperature of 300° C. The micro cracks propagated and coalesced into a macro crack in the shear zone, which produced a sharp decrease in main cutting force. There is a lack of a detailed study on the chip formation and its mechanism for composite material under LAM conditions. The types of chips produced in conventional machining and LAM could prove to be essential in predicting tool wear and surface damage[10].

V. EFFECT OF TEMPERATURE ON TOOL WEAR

The tool wear strongly depends on the laser power or work surface temperature. As a result of higher material removal temperature, the tool strength can be reduced and consequently the tool life decreased. Several investigations reported that there is an optimum surface temperature for every material that minimizes the flank wear and improves the tool life [1] Andrews et al [3]studied the effect of the laser power on tool wear during LAM of aluminum matrix composite reinforced with 62% volume fraction alumina fibers. It was reported that LAM significantly reduced the progression of tool wear with increasing surface temperature and feed respectively compared to conventional machining. The author also performed experiments with the particulate composite (Al359/20% SiC) using LAM and found that the dominant tool failure mode is the result of gradual flank wear at high workpiece temperature and that this progression of flank wear has been significantly reduced with increasing workpiece temperature up to a point (300°C). Besides, a further increase in temperature has a negative influence on the reduction in tool wear. The study also reported that cutting speed has a substantial effect on tool wear as well as material removal rate[1].

VI. CONCLUSIONS

This paper gives a survey of the thorough literature so as to understand the complex mechanism of machining MMCs by conventional method and laser assisted machining. LAM proved the benefits of improved machinability and higher productivity when compared to conventional machining. The review of available literature shows that LAM of metal matrix composites is mainly focused on experimental investigation into the process characteristics and its benefits. The following are the general conclusions that can be drawn for LAM of MMCs. Laser power and surface temperature are the most influential factors on the process characteristics.
The preliminary experiments are required to determine the optimal temperature range for the suitability of material characteristics. According to the selection of heat source location and thermal conductivity of the material, processing depth and cutting speed can be selected. Taguchi based experimental design and modeling is of great importance to a better process understanding and process optimization. As there is a lack of a complete study on optimization of cutting conditions and laser parameters in the published work, these aspects could be considered in future research.

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