Grit Blast Assisted Laser Milling/Grooving of Metallic Alloys

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Abstract

Laser machining and milling of metallic alloys and ceramics have been previously carried out by either direct vaporisation or assist gas ejection of laser-melted materials. For certain metallic materials, due to the high viscosity of the materials in the molten state, it is difficult to achieve a clean cut. Recast and heat affected zones are normally formed. This paper reports a hybrid process combining a grit blasting and laser melting for the milling and grooving of stainless steel, mild steel and titanium alloys. The work shows that up to 100% increase in material removal rate and 15% reduction in the heat affected zone size can be achieved compared with a gas jet assisted laser machining process under the same operating conditions. Surface roughness has been reduced by 60%. The effect of particle injection angle, direction on material removal rate is presented. A critical particle injection angle is established.

Keywords:

Laser, machining, powder

1 INTRODUCTION

High power lasers have been used in a wide variety of materials processing applications such as cutting, welding, drilling, marking, micro-machining, surface treatments and rapid prototyping/tooling. Very few practical applications, however, are known on the use of lasers in bulk machining operations such as turning and milling. Conventional machine tools and processes are still dominating the engineering component manufacture. For certain hard materials such as titanium alloys, tool steels, stainless steels and ceramics, extensive tool wear in the conventional machine tools has been reported [1-6]. Various special machining techniques such as diamond grinding, ultrasonic machining, electric chemical machining, and electric discharge machining are being used, as alternatives, for the machining of hard materials and engineering ceramics. The material removal rates are, however, very low with these tools [3-9]. Recently, a number of new developments have been reported on laser assisted machining (LAM) and direct laser machining (DLM) [1-15].

In the LAM processes, a laser beam (a CO_2 laser or a Nd-YAG laser) is used to preheat the workpiece locally ahead of the mechanical tool tip employed in turning, milling and grinding applications. The processes are based on the fact that many materials reduce their yield strength at elevated temperatures. For example, nickel based superalloy Inconel 718 reduces its yield strength from 1100 N/mm^2 at room temperature to 100 N /mm^2 at 980 °C [1]. Many hard materials such as Nickel alloys (e.g. Inconel 718), titanium alloys (e.g.Ti-6A1-4V), Zirconium and Molybdenum were successfully machined using the LAM technology [1-4]. It was shown that LAM had reduced tool wear by 40% and reduced cutting force by 18% whilst increasing the material removal rate by 33% over conventional turning [2]. However, certain problems have been encountered in these processes. For example, the mechanical tool is also heated up in the LAM process causing an increase in tool wear [1]. Also, as shown by Copley [2], after LAM the flexural strength of the part was reduced by up to 41.9%.

In the DLM processes, a laser beam is used to directly vaporise, decompose, oxidise or melt the work piece material which is then removed with an in-situ high pressure gas jet either coaxially or off-axially or both. These techniques have been used for the machining of ceramics such as Si_3N_4, Al_2O_3, SiC and graphite [5-10] and metallic materials such as stainless steels and mild steels [11-15]. Microcracks are often present in ceramics due to the formation of a recast layer [5]. This problem was minimised by the use of a pulsed laser such as a Q-switched YAG laser [6-7] and an excimer laser [8] or processing in water [9] or preheating the workpiece [10]. Typical material removal rates for laser machining of ceramics are around 300 mm^3/min at 400 W laser power [14]. The material removal rate achieved was up to ten times higher than diamond machining [10]. The substitution of laser grooving for diamond point grinding of ceramic materials has reduced the cost by 64-89% [7]. The removal of metallic materials with a laser beam is almost always assisted with a gas jet. A maximum of 1600 mm^3/min removal rate has been demonstrated at 1680 W laser power for tool steels [11]. O'Neill et al [12] reported a technique whereby an off-axis gas jet was combined with the coaxial gas jet to generate a high speed gas vortex which created a lift force along the erosion front in the laser generated melt pool. A removal rate of 612 mm^3/min for mild steels at 600 W power was achieved [12]. An off-axial water jet was also used to improve material removal efficiency [13]. A further improvement in the efficiency of laser machining of 3-D parts was reported by Chryssolouris et al [15] using two intersecting laser beams, each making a blind cut so that a solid block was removed.

The key problem in laser machining is not the melting of the material but the removal of the molten materials. In this paper, a new laser based machining process – grit blast assisted laser machining (GLM), is described. In this process, a high speed abrasive jet is directed towards the laser generated melt pool to remove the molten materials in-situ. Wide track (up to 4 mm width) machining of various engineering metallic materials such as titanium alloys, stainless steel and mild steels is reported.

2 EXPERIMENTAL PROCEDURE

The experimental configuration is shown in Figure 1. A Rofin-Sinar RS 1000 CO_2 laser with a TEM_{01} beam operating at continuous wave (CW) mode was used in this work. A 75 mm focal length ZeSe lens was used to produce a defocused laser beam of a spot diameter of around 5 mm on the work piece surface. Argon gas at a 10-20 l/min flow rate was blown through a coaxial nozzle to provide protection for the lens. A commercial portable shot blasting gun with a circular nozzle (4 mm exit diameter) was used to inject high speed (above 50 m/s) abrasive particles off-axially, at a mass flow rate of 0.3-2 g/s, into the laser generated melt pool at a distance of approximately 20 mm. The abrasive particles were delivered with a compressive air jet at approximately 5 bar. Three different commercial abrasives of 50-110 μm particle size with irregular shapes were used in the work. These were silicon carbide (SiC 98.0%, SiO_2 0.8%, free Si 0.6%, free C 0.2% and Fe_2O_3 0.15%), brown alumina (Al_2O_3 95.6%, TiO_2 2.6%, SiO_2 1.2%, MgO 0.45% and Fe_2O_3 0.18%) and Alumina 's' (a blend of recycled vitrified abrasives containing Al_2O_3 85.0%). Three different metallic work piece materials (304 stainless steel, En3 mild steel, and Ti-6Al-4V titanium alloy) of 50 mm x 100 mm x 10 mm size were used. The sample surfaces were shot blasted before the laser processing to provide uniform surface conditions. During the experiment the work pieces were traversed under the stationary laser beam with a CNC x-y table. A fume extraction/particle collection system was used to take away the ejected molten materials and the abrasive particles that were then examined. Laser power, work piece traverse speed and abrasive jet injection angle (set by a specially designed rig) were varied during the experiment. The effects of grit blast assisted laser machining were analysed in terms of morphology, material removal efficiency, surface roughness, and heat affected zone characteristics and were compared with laser machining without the abrasives under the same operating conditions.

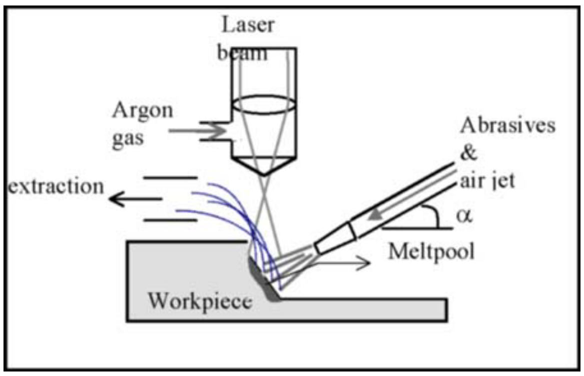

Figure 1: Experimental set-up.

3 RESULTS

3.1 Effect of grit injection angle and direction

Table 1 shows the effect of grit injection angle for machining the three different materials. In the table, '*successful*' means a complete removal of the molten material resulting in a clean slot; '*partially failed*' rmeans there are some re-solidified molten material deposited along the surface and side walls of the groove; and '*completely failed*' means majority of the molten materials are not removed and there is even the deposition of the abrasive particles in the re-solidified track.

Table 1: Effect of abrasive particle injection angle, α . (X: completely failed, Δ: partially failed, √: successful).

Workpiece materials	Injection angle			
	15°	25°	35°	45°
Titanium alloy	√	√	√	X
Stainless steel	Δ	√	Δ	X
Mild steel	√	√	√	X

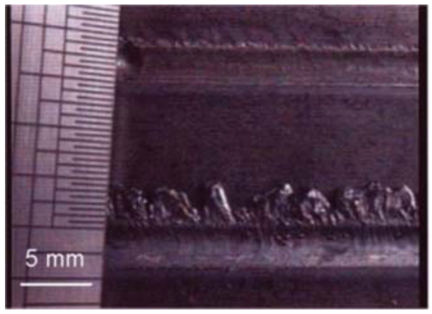

Figure 2: Effect of jet mis-alignment (upper: with grit blasting; lower: with compressed air only).

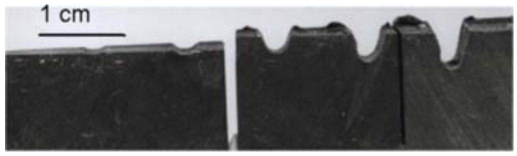

Figure 3: Typical groove cross-section geometry, from left to right: 120 W, 180 W, 240 W, 420 W, 480 W.

This table shows that only at certain injection angles can a clean removal of the melt be achieved. For the titanium alloy and mild steel samples, at injection angles below 35° a clean removal was achieved. It was noted that in general, the higher the injection angle, the deeper the resulting groove. For the stainless steel sample, however, only by injecting at 25° can a good melt removal be achieved. A comparatively deeper slot was generated for the stainless steel under the same processing conditions indicating a possible dependence of the optimum injection angle on the groove depth. α

The direction of particle injection also had a strong influence on machining performance. The experiment showed that the grit injection must be in the leading direction of laser traverse to enable a clean removal of the melt. The removal efficiency in this direction was much higher (e.g. up to four times). A possible preheating of the workpiece by the ejected molten material at the point just before laser radiation could contribute to this increase in the removal efficiency. When the abrasive/air jet was deliberately mis-aligned to the melt pool with a five degree shift, the groove produced using the GLM showed little disturbance while the one produced with the air jet without the abrasives showed a recast layer deposited on the side of the groove as shown in Figure 2.