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Experimental study on fiber laser microcutting of Nimonic 263 superalloy

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Abstract

Laser cutting of NIMONIC 263 sheet was investigated by using a 100 W Yb:YAG fiber laser. The study was divided in two phases. In the first one, the critical cutting speeds were found fixing the average power (80 W), changing the pulse duration, the cutting speed, the nozzle diameter and the focus position. Then, a full factorial design was adopted according to the DoE methodology. In order to determine which of the process parameters affect the kerf geometry and how, Analysis Of Variance (ANOVA) was used. Experimental results show the possibility to obtain kerf characterized by narrow width and low taper angle values.

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Keywords: Laser microcutting; Fiber laser; Nimonic 263 superalloy; DoE, ANOVA

1. Introduction

Nowadays, laser technology is one of the most widely used manufacturing processes in material processing. This is thanks to its peculiar characteristics, such as: high precision, high flexibility, low thermal modifications and high productivity. This is particularly true especially when cutting or drilling are performed aerospace engine. In this components field, strict quality standard are required in terms tolerances and metallurgical characteristics (such as recast layer, oxides, etc.) perpendicular surfaces, no burr and no recast layer are required. High brilliance laser sources, such us fiber laser, allows to machine with reasonable precision most of the metallic materials.

The material removal rate (MRR) and the kerf geometry are functions of the process parameters, such as the type of adopted source (including wavelength, beam quality and beam spot dimension), the average power, the cutting speed, the focus position, the type of assistant gas and its pressure. Moreover, in case of pulsed laser sources, the MRR and kerf characteristics are also influenced by the pulse frequency, the pulse duration and the overlapping percentage. Consequently, the investigation of laser machining of aerospace materials is a topic in increasing interests. The effects of the process parameters on the kerf characteristics have been widely studied in the past. In [1-2] the influence of power and cutting speed in laser cutting of different steels adopting a CO_2 laser source, was studied. It was found that kerf width increases when the laser power increases and the cutting speed decreases. Moreover, in [1] it was found that the adoption of a reactive gas as assistant gas, instead of an inert gas, leads to a wider kerf and higher roughness. Also the focus position influences the kerf geometry; in [3] it was found that the minimum kerf width is obtained by setting the focus on the workpiece surface for thin sheets (< 1.5 mm) and inside the workpiece for thicker sheets (> 1.5 mm). In [4] a study on the influence of process parameters of Nd:YAG laser drilling of Ni-based superalloy sheet (1 mm in thickness) was presented. In the study, it was found that a spot overlap increase produces an enlargement of kerf, while a short pulse duration allows for a low kerf taper angle, if compared to a longer duration pulse. This results are consistent to what observed in similar studies on laser cutting of stainless steel [2, 5].

When Nd:YAG laser source were adopted, some negative effects, including micro-cracking, spatter, dross, and taper of the kerf were observed [4, 6-12]. Moreover, this kind of laser

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sources often operated in low-order Gaussian modes and rarely in TEM_{00}. In comparison to that, the beam quality of a fiber laser is independent from the output power, over a wide range. This results in a better focussing and then higher cutting speeds with comparable or better kerf quality, in term of: small dimension, spatter and dross absence, recast layer and HAZ extension. Furthermore, these characteristics are enhanced by the use of high quality short and ultrashort pulsed laser [13-17]. However, when the material thickness is limited (< 1 mm), the use of a high quality fibre laser, working in CW or modulated regime, could be an economical and practical solution, as shown in [18-21].

In a previous paper [22], the possibility to have cuts characterised by a narrow kerf, low taper angle on Nimonic 236 sheet, 0.38 mm in thickness, was investigated by adopting a 100 W single-mode fibre laser. The results showed that an increase of the average power (by way of the on time) and of the gas pressure allowed to obtain regular kerfs, with no burrs. Consequently, in this work, the average power and the pressure were kept constant, while the pulse duration, the nozzle diameter and the position of the focusing lens were varied. A full factorial design was developed according to the Design of Experiments (DoE) methodology. The kerf geometry was measured by optical microscopy according to the UNI EN 12584 2001 and ISO 9013:2002 standard. The ANOVA was adopted to verify the influence of the process parameter on kerf geometry.

2. Equipment, material and experimental procedures

2.1. Equipment

The cutting tests were performed adopting a 100 W Fibre Laser (SPI-RedPower SP100C), working at the wavelength, λ = 1090 nm. The laser source is transferred via an optical fibre, 6 m in length, to a laser head (from HAAS LTI) mounted on a 3+1 axis CNC system. The laser source was controlled via an external laser controller (MCA LCT3001), which allows the setting of the power (from 10% to 100% maximum nominal power) and the regime: CW or modulated. In this last case it was also possible to set the pulse frequency and the pulse duration. The laser source power, the geometric patterns and the beam speed were controlled by the CNC system.

Table 1 shows the detailed characteristics of the laser system.

2.2. Material

The investigated material was the Nimonic 263® (UNS N07263/W. Nr. 2.4650) in form of rolled sheets 0.38 mm in thickness.

Nimonic 263 was developed by Rolls-Royce (1971) Ltd. to provide a sheet material which offer improved properties in terms of proof stress and creep strength. The chemical composition and the main properties of Nimonic 263 are reported in [22]. This material is often adopted in the combustion chamber of aeronautical engine.

Table 1. Laser source characteristics (SPI -RedPower SP100C).

Parameters	Value	Unit
Wavelength	1090	[nm]
Nominal power	100	[W]
Mode operation	CW or Modulated	--
Pulse frequency	1-18	[kHz]*
Pulse duration	1-0.01 ms	[ms]*
Beam diameter (1/e²)	5.0 ± 0.5	[mm]
Full angle divergence	<0.4	[mrad]
Beam Quality	TEM_{00} (M^2 <1.1)	--
	BPP 0.38	[mm.mrad]
Beam expander	0.32 x	--
Focal length	50	[mm]
Beam diameter at the focal spot	$\phi \approx 48$	[μm]

* in modulated regime

2.3. Experimental procedure

The study was divided in two phases. In the first one, the critical cutting speeds, defined as the speed beyond which it is not possible to cut the sheet, were found. For this purpose, linear cuts were performed fixing the average power (80 W), the pressure and the type of the assistant gas (12 bar and Nitrogen) and the stand-off distance (0.2 mm) while varying beam travel speed, the pulse duration, the nozzle diameter (0.5 and 1 mm) and the position of the focusing lens (the beam was focused on the surface, (0 mm position) and 0.2 mm inside the sheet.

Then, the second phase a tests was performed to verify the influence of the process parameters on the kerf geometry. Linear cuts 40 mm long were performed at 90% of the critical cutting speed found in the first experimental phase. A full factorial design was developed according to the Design of Experiments (DoE) methodology [23].

The control factors were the following: pulse duration (D), focus position (F) and nozzle diameter (N). In order to determine which of the process parameters affect the kerf geometry and how, ANalysis Of VAriance (ANOVA) was adopted.

The control factors were selected on the bases of a previous work [22]. In particular the average power and the pressure were kept constant, near at the maximum values settable on the machine (80 W and 12 bar, respectively), while the pulse duration, the nozzle diameter (0.5 and 1 mm) and the position of the focusing lens (on the surface and inside the sheet) were varied. Table 2 summarizes the levels of control factors and their settings. Four replications for each treatment (i.e. process condition) were performed, resulting in a total of 64 experimental runs. The replications of each treatment were performed to provide more consistent response repeatability. To reduce the disturbance of any unconsidered noise factor, the order of trials was randomized both in the treatments and in their replications.

After the tests, part of the samples were cut, included in epoxy resin and then polished using abrasive paper of grit size up to P2500 (Standard ISO 6344). Then, images of the kerf sections were taken by an optical microscope (Zeiss