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Laser cutting of aluminum alloy Al-2024-T3

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Abstract

Laser cutting is a standard industrial process for cutting sheet metals. The process relies on the removal of the melted material with the aid of a pressurized assist gas. Among the main variables controlling the process, the supply system, and the gas nature are essential factors. While the effect of different supply systems and assist gases have been extensively studied in steels, their influence during laser cutting of aluminum alloys is not well studied. In this work, the authors have examined the influence of two different supply systems (subsonic, and supersonic jets) and assist gases (argon, nitrogen, oxygen and air) on the edge quality and its surface chemistry during laser cutting of a typical Al-Cu alloy. New supersonic cutting heads show superior cutting performance than conventional cutting heads.

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Keywords: laser cutting; assist gas; oxidation; aluminium alloys; edge quality.

1. Introduction

Laser cutting is commonly used in the industry for cutting sheet-metal parts. During the process, the material melted by the laser beam is extracted from the kerf with the aid of a pressurized assist gas. It is well-know the crucial role of the assist gas and the aerodynamic interactions of this with the workpiece on the cut quality [1-3]; however, this gas can also chemically react with the molten material. Assist gases used in laser cutting can be classified, in general terms, as inert or reactive gases [4]. When a reactive gas is used, it delivers additional exothermic energy through the chemical reaction between the gas and the molten material. This reaction supplies additional energy that enhances the cutting process. For example, the utilization of oxygen during the laser cutting of mild steel supplies around 60% of the energy required to cut this material. Thus, cutting speeds can even be doubled using oxygen as assist gas [5]. However, because of this chemical reaction, a very thin resolidified layer of metal oxides is formed along the cut edges. In order to avoid this reaction, inert gases, such as argon or helium can be used [4]. These gases only provide the mechanical action required for the extraction of the molten material from the cut zone; at the same time, these gases prevent from undesirable chemical reactions (such as the oxidation of the cut edges). In this sense, nitrogen is used for cutting carbon and stainless steels when high quality edges are required [4]. On the other hand, several works have reported a great influence of the gas purity on the laser cutting efficiency and edge quality [6-9]. It was demonstrated that cutting speeds are reduced by 50% or even more if the oxygen purity is reduced by even a 3% [9].

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Despite the large number of industrial applications of aluminum and alloys (such as in the aerospace or automotive industry), the influence of the supply systems (subsonic, and supersonic jets), and assist gas type on the laser cutting efficiency and edge quality is not well-studied. Several authors consider that subsonic nozzles and nitrogen are the best alternative when cutting aluminum alloys, whereas oxygen is recommended for pure aluminum [11]. However, these recommendations are not supported by comprehensive experimental studies on the interaction of the gas jets with aluminium during laser cutting.

In this work, we have studied the impact of two supply systems (i.e. a cutting head assisted with a subsonic or a supersonic nozzle), and four common assist gases (argon, nitrogen, oxygen, and compressed air) on the cutting speed, edge quality, and surface chemistry during laser cutting of Al-2024-T3 sheets (3 mm thick).

2. Material and methods

Flat sheets of a 2024-T3 commercial aluminum-cooper alloy, 3 mm thick, were used as processing workpiece. The experiments were carried out using a 3.5 kW CO_2 slab laser, the laser mode being a TEM_{00}. The laser beam was focused onto the surface of the workpiece using a 127 mm focal length lens. Tests were only performed in CW mode. In this work, all tests were performed using a computer numerical controlled (CNC) X-Y table. Cutting experiments were only performed on a unidirectional straight line.

Four kind of assist gases were used in this study (argon, nitrogen, oxygen and air). The commercial designation, quality, and main impurities for the four considered assist gases are summarized in Table 1.

Cutting tests were performed using a conventional cutting head, and a cutting head incorporating an off-axis supersonic nozzle to study the influence of the supply system. The conventional cutting head injects the assist gas into the interaction zone by means of a subsonic (converging) nozzle, coaxial with the laser beam. The nozzle, with 2 mm in exit diameter, was placed 1.5 mm over the surface of the workpiece as in common applications to cut metals. On the other hand, we have also used a supersonic cutting head which incorporates an off-axis supersonic nozzle non-coaxial with the laser beam. This nozzle injects the assist gas in supersonic regime (at a Mach number $M > 2$). In order to obtain a jet free of shocks, the inner profile of the nozzle is converging–diverging and designed for a constant operation pressure ($P/P_0 = 8$). The off-axis supersonic nozzle was set forming an angle of 35° with the laser beam axis, and at a distance of 4 mm to the workpiece. More details concerning with this assist gas injection system can be consulted in Refs. [12,13].

After cutting experiments, some selected samples were sectioned perpendicularly to the cut edge with a precision cut-off machine (Struers Minitom), and subsequently embedded in epoxy resin, and finally grinded with SiC paper and polished by diamond paste up to 1 μm finishing. These specimens were inspected in frontal and cross-sectional direction to the cut edge using an optical stereoscopic microscope (Nikon SMZ-10A) with a photographic system in order to record and store the images. Furthermore, both the cut edge, and its cross-section were studied after the laser cutting process through scanning electron microscopy (SEM). Samples obtained from each specimen were covered with a thin gold layer and examined in a Philips XL-30 SEM.

Chemical composition on the surface of the cutting edges of samples was determined by means of XRD and XPS surface measurements. XRD was performed in grazing incidence geometry in order to determine the surface composition of the cut edge of analyzed samples. On the other hand, the XPS measurements were performed using monochromatic Al-Kα radiation by means of a Thermo Scientific K-Alpha ESCA instrument.

Table 1. Quality and main impurities (in ppmv) for the studied assist gases.

Gas designation	Quality	Impurities (ppmv)
Air S1	77-80% N_2	< 10 H_20
	20-23 % O_2	
Oxygen 5.0	99.999%	$H_20 \leq 2$; $C_nH_m \leq 0.1$; $CO_2 \leq 0.2$; $CO \leq 0.2$; Inerts ≤ 10
Nitrogen S1	≥ 99.99%	$H_20 \leq 10$; $O_2 \leq 10$
Argon 4.8	99.998%	$H_20 \leq 4$; $O_2 \leq 3$; $N_2 \leq 15$; $C_nH_m \leq 1$

3. Results

3.1. Influence of the supply system (subsonic vs. supersonic nozzles). Cutting performance.

Fig. 1 depict the maximum cutting speed as a function of the laser power for a cutting head assisted with a subsonic, or a supersonic nozzle. The cutting speed is linearly increased with the laser power for all the experimental conditions, as expected. However, the utilization of supersonic nozzles give cutting speeds higher than using subsonic nozzles, even for higher supplying pressures in these subsonic nozzles. Maximum cutting speeds for the cutting head with the supersonic nozzle range from 2.5 to 3 times higher as compared to the subsonic nozzle working at a supplying pressure around 4 bar (for laser powers higher than P=1500 W).