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Comparison of continuous wave and pulsed wave laser welding effects

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A R T I C L E I N F O

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There are two types of lasers, continuous wave and pulsed wave lasers. The welding parameters normally associated with continuous wave lasers are laser power, beam diameter and welding speed. In pulsed wave lasers the parameters used are pulse duration, energy and beam diameter. In this paper a comparison of welds obtained using the same process parameters in continuous and pulsed wave lasers is made. In order to have the same welding parameters, for both lasers, the tests were carried out using interaction time and power density as the main process parameters. The results show that when these parameters are used the two lasers show very dissimilar behaviours in terms of penetration depth. Also the pulsed wave laser showed higher efficiency when compared to the continuous wave laser under the same welding conditions. The effect of the peak power density was also evaluated.

1. Introduction

In recent years the relevance of laser welding to several industries has increased, mainly in the automotive and aerospace industry [1–3]. There are two main types of lasers, continuous wave (CW) and pulsed wave (PW) [4]. Several studies of the effect of the different welding parameters in laser welding [5], have been made. However, most of the studies were carried out using a single type of laser, either CW [6–9] or PW [10–13]. The difficulties raised in directly comparing these two types of lasers are the parameters that are utilised. The parameters normally used for characterising a pulsed laser weld are pulse energy, pulse duration and spot size. Fuershbach and Eisler evaluated the effect of energy density and power density for different pulse durations [12]. The results showed that at a fixed power density the penetration depth went up with longer pulse durations, which means higher energy was utilised, for a PW laser. The same paper showed a comparison between a pulsed and a continuous wave laser weld, concluding that CW lasers show higher penetration than PW lasers. However, this comparison, between PW and CW laser welds, was made without using any parameter which gives a correlation between pulse duration and welding speed used in the CW welds. Just power density was used for comparison, neglecting the effect of interaction time of the laser beam with the material.

In this present paper, the fundamental material interaction parameters of power density and interaction time are used [14,15], and their influence on CW and PW laser welds is investigated. The power density is calculated for both CW laser and PW laser using the following equation:

$$\text{Average power density} = \frac{P}{A_{(\text{Beam})}}, \tag{1}$$

where P is the power and $A_{(\text{Beam})}$ is the area of the laser beam. This power density is the average power density of the laser beam profile. In CW welds P is the total power. In PW welds, P is the average pulse peak power over the duration of an individual pulse [16], as given in Eq. (2)

$$\text{Average peak power} = \frac{\text{Pulse energy}}{\text{Pulse duration}}, \tag{2}$$

A further parameter is the spatial peak power density that represents the maximum power density across the laser beam profile. This value is measured by the beam profile equipments used. For 'top-hat' profiles the spatial peak power density has the same value as the average power density.

The comparison was made between a CW weld and individual pulses (obtained with a PW laser). This allowed a comparison of the physical/material science behind the interaction of a CW laser and a PW laser with the material. One of the most important fundamental material interaction parameters in this comparison is the interaction time. The interaction time can be interpreted as the time at which a specific point, located in the centreline of the weld, is exposed to the laser beam [15]. In CW lasers the interaction time is calculated based on the following equation:

$$t_i = \frac{d_b}{V}, \tag{3}$$

where d_b is the beam diameter and V is the welding speed. The interaction time is the heating time of the process on the weld

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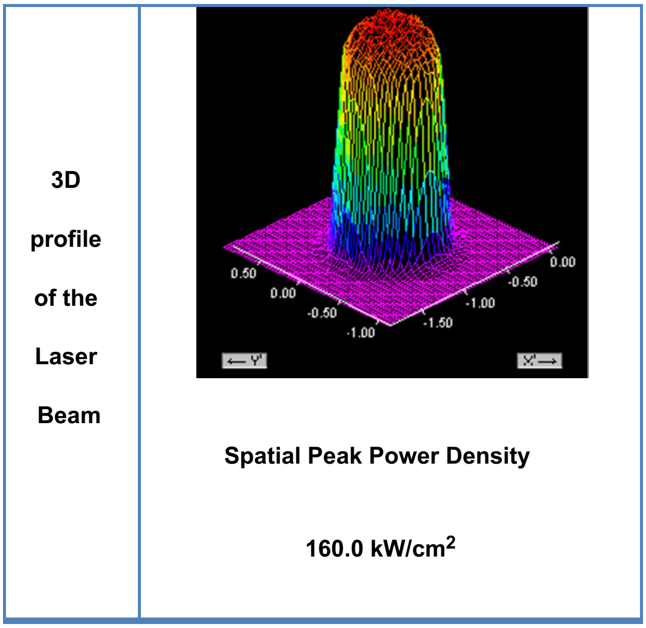

Fig. 1. 3D profile of the laser beam of the CW laser with a focussing lens of f_f=400 mm for an average power of 1000 W.

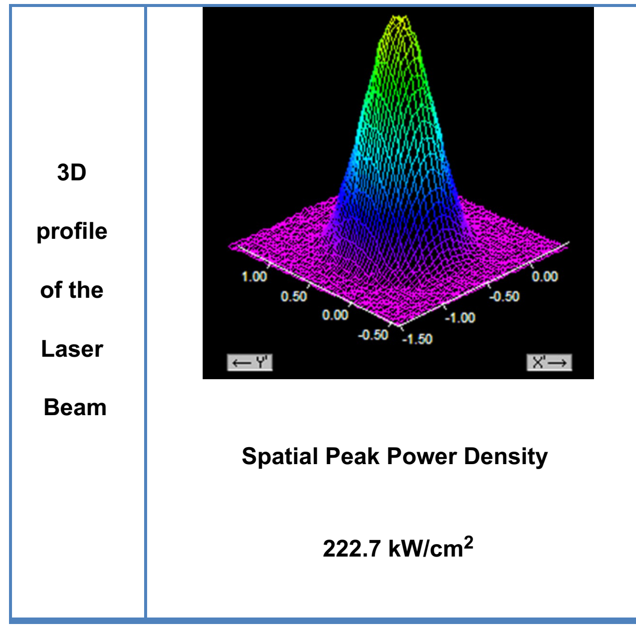

Fig. 2. 3D profile of the laser beam of the CW laser using a focusing lens of f_f=250 mm in the defocus position for an average power of 1000 W.

centreline [15]. This equation defines the maximum interaction time, which occurs in the weld centreline, for CW laser.

In PW lasers the interaction time is the pulse duration, which represents the time that a particular point in the material is exposed to the laser beam.

Using these parameters allows a like for like comparison between CW and PW lasers. The aim of this work is to compare the effect of the power regime (PW or CW) in laser welding. This comparison was made considering interaction time and power density as the main process parameters.

2. Experimental procedure

The two lasers used in these experiments are described below. The CW laser was an IPGYLR-8000 fibre laser with a maximum power of 8000 W and a wavelength of 1070 nm. The delivery system consisted of a fibre with a diameter of 300 μm, a 125 mm collimating lens, and a f_f=400 mm focal length lens, this setup produced a beam diameter of 0.95 mm with a 'top-hat' profile, using the D4σ method [17], see Fig. 1. Also used with this setup was a f_f=250 mm focal length lens that was used in a defocused position, to produce a beam diameter of 0.95 mm with a Gaussian profile, using the D4σ method [17], Fig. 2. This will allow having two different profiles with the same average power density but different spatial peak power densities. The focal position and the beam diameter were determined using a Primes GmbH Focus monitor system. The laser power was calibrated using an Ophir Laser Meter; model 20 kW.

The experiments were carried out by increasing the laser power and maintaining a constant beam diameter. This increased the power density whilst maintaining a constant interaction time. For different interaction times the beam diameter was also maintained constant and the travel speed was changed in order to obtain interaction times of 10 and 20 ms.

The PW welds were made using a GSI JK300 HP PW laser with a maximum average power of 300 W and a maximum peak power of 9 kW. The system consisted of a delivery fibre of 300 μm diameter and a processing tool with a collimating lens of 100 mm. The focusing lens had a focal length of f_f=300 mm and this produced a beam diameter of 0.9 mm, using the D4σ method [17]. The focal position and the beam diameter were determined using a Spiricon Laser Beam Analyzer; model LBA-FW-SCOR. The beam profile obtained had an approximate Gaussian distribution, see Fig. 3. The laser power was calibrated using a Gentec-EO power metre; model UP19K-15S-W5-DO and the power profile was rectangular.

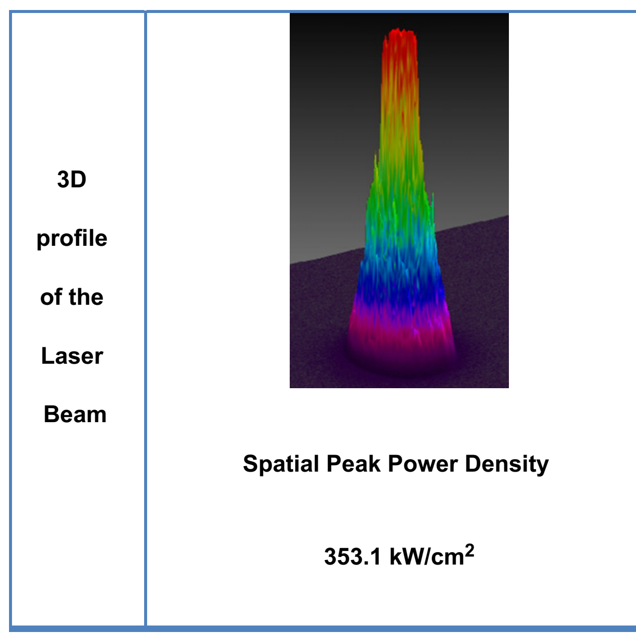

Fig. 3. 3D profile of the laser beam of the PW laser with a focussing lens of f_f=300 mm for a peak power of 1000 W.

The material used was S355 mild steel with 12 mm thickness. The plates were cleaned using a wire brush and then with acetone in order to avoid contamination of the welds. The chemical composition of the S355 mild steel is shown in Table 1. For the metallographic preparation all the samples were mounted, polished and etched using Nital 2%. The PW samples were mounted with an angle allowing the visualisation of weld profiles