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The Effects of the Laser Pulse Duty and the Wobble in Case of Manual Laser Welding

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Abstract

In our research we investigated the effects of the laser pulse duty and the wobble on the weld geometry in pulsed mode manual laser welding. Our experiments showed that, for the parameters studied, complete fusion can be achieved without laser wobbling at 500 W power for a material grade of 1.4301 and a wall thickness of 1.4 mm. Increasing the laser wobble amplitude led to an increase in weld width and a decrease in weld depth and weld area. Increasing the pulse duty also increased the weld width, weld depth and weld area. Without laser wobbling, a weld with an area of 1.1 mm^2 was produced when the pulse duty was set to 70%, while a weld with an area of 1.6 mm^2 was produced when the pulse duty was set to 100%, so that the area of the weld welded with a pulse duty of 70% was approximately 70% of the area of the weld welded with a pulse duty of 100%.

Keywords: *manual laser welding, pulsed laser, pulse duty, laser wobble, weld geometry.*

1. Introduction

The mechanised version of laser welding is widely used in the industry because of its many advantages [1]. The highly concentrated laser beam, focused on a small area, creates a very low heat-affected zone and results in low heat input compared to conventional fusion welding processes, minimizing deformation and warpage of the workpiece due to internal stresses [2, 3]. Another advantage of laser welding is that it offers high processing speeds and thus high productivity [4]. Handheld laser welding equipment, which has been introduced in recent years, is becoming increasingly common, and more and more companies are also selling and using such equipment in Hungary. The user-friendly operation provided by the lightweight welding gun and working cable, as well as the small size of the mobile laser oscillator, makes these welding machines increasingly popular [5]. However, due to its novelty, relatively little experience and research is available on this process compared to older, traditional welding processes.

In the present study, we investigated the effects of the laser pulse duty and the wobble on the weld geometry in case of manual laser welding of austenitic stainless steel.

2. Welding and evaluation procedure

Our series of experiments consisted of 12 bead-on-plate welds. The experimental welds were made on 1.4301 grade austenitic stainless steel tubes of 1.4 mm wall thickness and 34 mm outer diameter by manual laser welding. No filler material was used.

During the preparation of the welds, the handheld laser welding gun was clamped in the device to ensure its stability, thus minimising errors due to the instability of the human hand. Uniform travel speed was ensured by rotating the workpiece by a rotary motion. The percentage chemical composition of the used steel is shown in Table 1 according to EN 10088-1:2014.

Table 1. *The percentage chemical composition of 1.4301 grade austenitic stainless steel* [6]

C	Si	Mn	P	S
≤0.07	≤1.00	≤2.00	≤0.045	≤0.015
N	**Cr**	**Ni**	**Fe**	
≤0.11	17.5–19.5	8.0–10.5	mar.	

The experimental welds were made on a LightWELD XC type, optical fibre, hand-held welding machine, manufactured by IPG Photonics Corporation of the USA. The welding machine is capable of producing a monochrome, coherent and low divergence laser beam with a maximum power of 1500 W and a wavelength of 1080 nm. An online, computer-accessible control interface provides the possibility to adjust the laser power, the wobble width and frequency, the pulse frequency and the pulse duty in pulsed mode. In pulsed mode, the pulse frequency is the number of pulses per second emitted by the laser oscillator and the pulse duty expresses the ratio between the pulse duration and the time elapsed from the start of one pulse to the start of the next, in percentage form. In our experiments, the travel speed (v) was 80 cm/min and the laser power (P) was 500 W. The energy input was calculated using the following formula:

$$E = \frac{P(kW)}{v\left(\frac{mm}{s}\right)} = \frac{0,5}{13,33} = 0,0375\ \frac{kJ}{mm} \qquad (1)$$

The shielding gas used was nitrogen of 4.5 purity at a flow rate of 18 l/min. The pulse duty was varied between 70% and 100% at 10% intervals, and the laser wobble amplitude was set between 0 mm (i.e. the case without wobbling) and 2 mm. Both the pulse frequency and the wobble frequency were 200 Hz for the 1 mm and 2 mm cases. Laser wobbling is performed inside the welding gun by an optically refractive oscillatory motion of the laser beam [7].

At the end of the welding experiments, metallographic grindings were made from the test specimens using conventional methods. The weld shapes were made visible by etching. The etching was carried out using Adler etchant of the following composition:

- 9 g copper ammonium chloride;
- 150 ml hydrochloric acid;
- 45 g ferric chloride 6-hydrate;
- 75 ml distilled water.

The shape of the welds were made successfully visible by etching at room temperature for 4-5 seconds, which were examined with an Olympus SZX 16 stereomicroscope. Microscopic images of the welds were taken to measure the weld width, weld depth and weld area dimensions for evaluation.

3. Results and evaluation

Fig. 1 illustrates the resulting weld width as a function of the laser pulse duty and the wobble amplitude. It can be observed that the width of

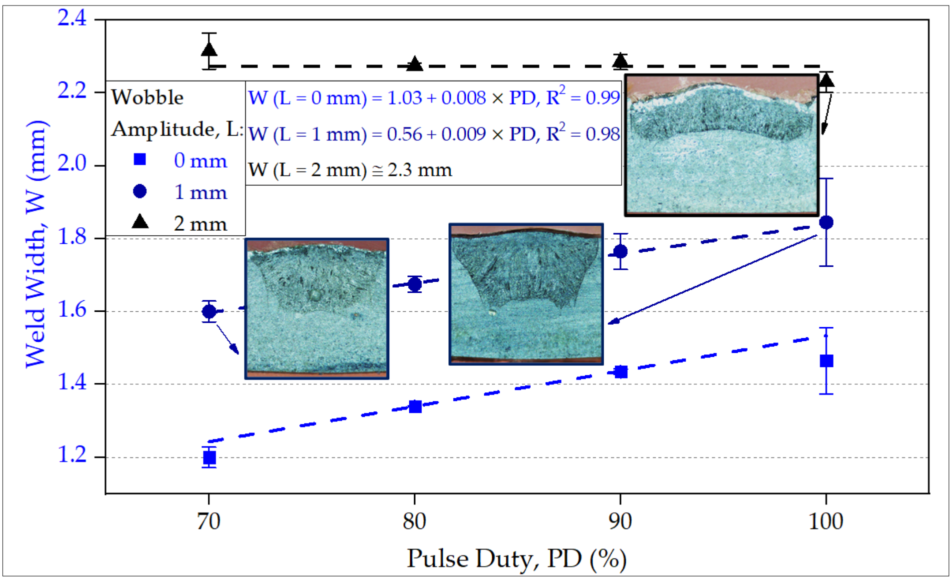

Fig. 1. *Weld width as a function of laser pulse duty and wobble amplitude, energy input was E = 0,0375 kJ/mm.*

the welds made with a 2 mm wobble amplitude became nearly constant, while the weld width increased almost linearly with increasing the pulse duty for the 1 mm wobble amplitude and no laser wobble cases. Increasing the wobble amplitude led to an increase in weld width.

Fig. 2. shows the weld depth as a function of the laser pulse duty and the wobble amplitude. It can be observed that the weld depth increases almost linearly with increasing pulse duty for both 2 mm and 1 mm wobble amplitude. It can also be concluded that for welds prepared without laser wobble, the weld depth is approximately the same, since in these cases a fully penetrated weld is formed.

Fig. 3 plots the weld area as a function of the parameters tested. The diagram shows that the area of the welds increases almost linearly with the in-

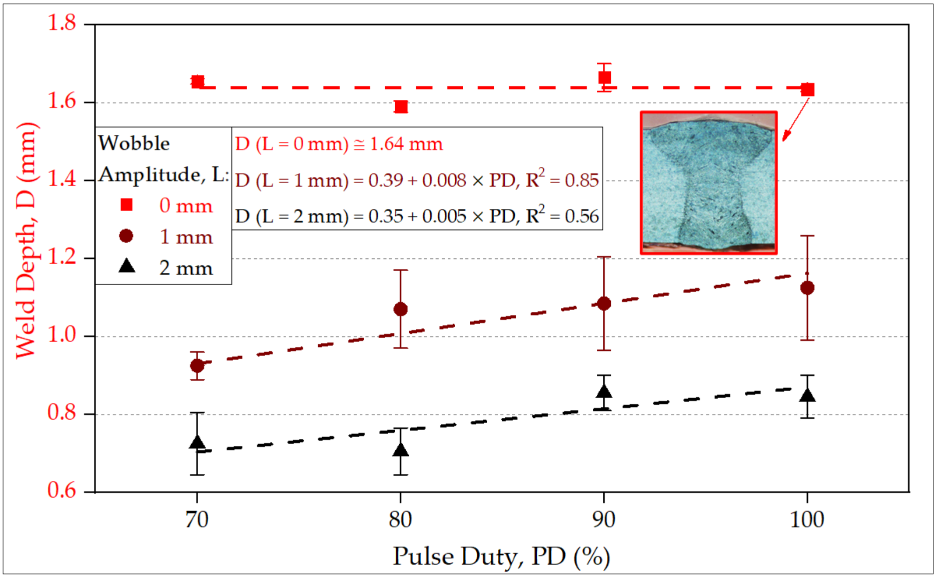

Fig. 2. *Weld depth as a function of laser pulse duty and wobble amplitude, energy input was E = 0,0375 kJ/m.*

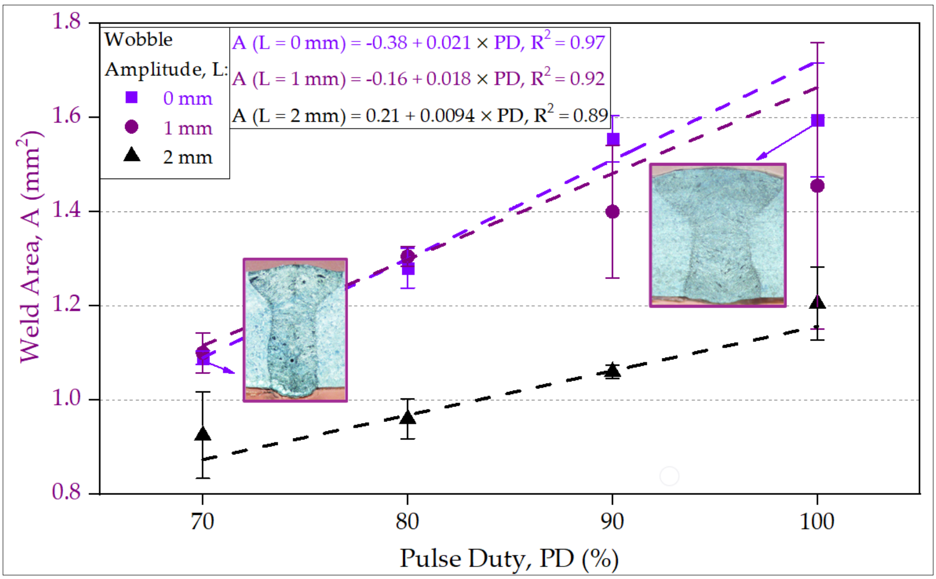

Fig. 3. *Weld area as a function of laser pulse duty and wobble amplitude, energy input was E = 0,0375 kJ/mm.*

crease of the pulse duty in the case without laser wobble, and also in the case of 1 mm and 2 mm wobble amplitude. This is clearly shown in the two micrographs pasted on the slide. By comparing the values of the weld area of these welds, it can be concluded that without wobbling the laser beam and with the 70% laser pulse duty setting, a weld of 1.1 mm^2 was obtained, while with the 100% pulse duty setting, a weld of 1.6 mm^2 was obtained. It is interesting to note that 1.1 mm^2 is approximately 70% of 1.6 mm^2, so the area of the weld welded without laser wobble and with 100% pulse duty is 70% of the area of the weld with 70% pulse duty.

4. Conclusions

In the present study, bead-on-plate welds were welded by manual laser welding on stainless steel tubes to investigate the effect of the laser pulse duty and the wobble on the weld geometry. Based on our results, the following conclusions can be drawn:

- at the parameters tested, full penetration was only achieved without laser wobble;
- increasing the laser wobble amplitude increases the weld width, but decreases the weld depth and the weld area;
- all three geometric dimensions of the welds increase as the pulse duty increases;
- in the case without laser wobble, the area of the weld welded with a pulse duty of 70% was 70% of the area of the weld welded with a pulse duty of 100%.

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