THE INFLUENCE OF THE LASER PARAMETERS ON THE QUALITY OF WELDING

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ABSTRACT:
The laser technologies having a series of advantages: a large area of machining (cutting, welding, local hardening and drilling) and a large area of workable materials. Also compared with the conventional machining are mentionable: the high speed of machining, the high precision, the high energy and the low thermo influences of the area.
The quality of the welding process is directly determined by the following parameters: pulse power, pulse duration and focus position. These three parameters have particular values for different type of alloys, different working speeds and different protective gases. The team made some researches regarding the influence of those parameters on the width, on the deep and on the surfaces quality of the seam welding. These researches were made on the Trumpf HL54P laser equipment. The results of these researches can be used for the simulation and the optimization of the machining to improve the quality of the welding.
Keywords: welding quality, laser welding, laser parameters

1. INTRODUCTION

The laser beam as a thermal device is a relatively new practice in finishing technologies. In order to process raw materials, one can use the following procedures: cutting, welding, local hardening and drilling.
The use of this procedure reduces the heating of the working area because the energy is introduced faster and on a small surface. This is why large power densities can be reached. Other advantages are flexibility and accessibility.
These researches were made on the Trumpf HL54P laser equipment which have a Nd:YAG rod. The Nd:YAG lasers emit light in the near infrared range, at a wave-length of 1.06 µm. This means that the light emitted by Nd:YAG lasers is almost in the visible range. The laser light of a Nd:YAG laser can be routed through glass optics and optical fibers.
In processing, the laser power absorbed by the material causes the latter to heat up rapidly and if the intensity is sufficiently high - results in melting or even vaporization of the material. The better a material can absorb the wave-length of a laser, the greater the amount of energy that can be introduced into the material. This means that the efficiency of the laser beam increases proportionately with the capacity of the material to absorb the laser wave-length.

The degree of absorption varies with the material and with the wave-length of the impinging laser light. Metals can better absorb the wave-length of the Nd:YAG laser than that of a CO_2 laser.
For Nd.YAG lasers with one cavity, up to 800 W power ratings can be attained with one single laser rod. The beam parameter product in this case is about 30 mm*mrad. Although higher laser power could be generated by using larger laser rods or higher ion concentration levels, the resulting beam would be of very poor quality.
We need to take some safety measures because the wave-length of the Nd:YAG laser is almost in the visible range where the human eye is particularly vulnerable. Suitable safety measures are therefore imperative for this type of laser.

2. TEORETICAL ASPECTS

The average power of pulsed (P_{av}) lasers is the average value of the power during a longer time. In spite of using high pulse powers (several kilowatts), the result is a small average power (few hundreds watts), because the pulse duration is smaller than the breaks between the pulses (fig. 1.).

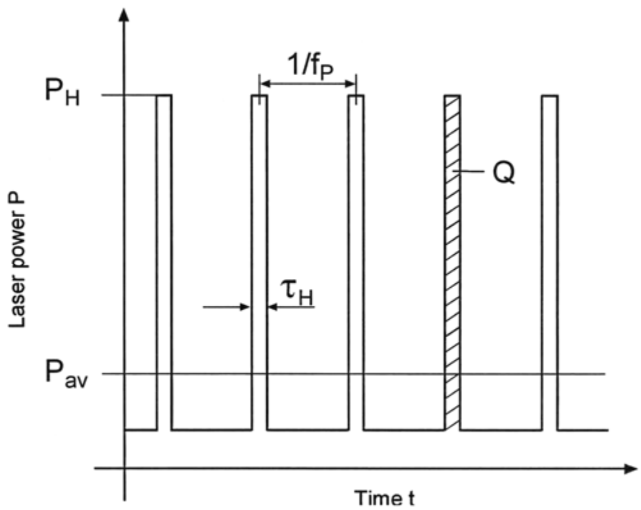

Fig. 1. Laser power diagram:
P_H–pulse power in case of pulsed lasers; P_{av}–avarage power; Q –pulse energy; τ_H–pulse duration; f_p –pulse repetition frequency[4]

The average power is the product of pulse power, pulse duration and pulse repetition frequency [4]:

$$P_{av} = Q \cdot f_p = P_H \cdot \tau_H \cdot f_p \text{ [W]} \qquad ...(1)$$

The pulse repetition frequency (f_p) indicates the number of laser pulses per second.
The pulse energy (Q) indicates the quantity of energy which is contained in a laser pulse. In the power-time-diagram of a laser pulse corresponds to the pulse energy of the surface in the laser pulse [4].

$$Q = P_H \cdot \tau_H \text{ [J]} \qquad ...(2)$$

The pulse duration (τ_H) indicates the time during which pulse power is emitted in case of pulsed lasers.
For material processing the laser beam has to be focused to the necessary power density using convex lens (fig. 2.). The size of the focal spot depends on the laser divergence θ and the focal length of the lens f. The length of the optical axes in the focus, on which the focal diameter d_{0f} changes only negligible, s, is called depth of focus(s=2·Z_R , Z_R - Rayleigh length) [5].

$$d_{0f} = f \cdot \theta \text{ [mm]} \qquad ...(3)$$

$$Z_R = \frac{f^2 \cdot \theta}{d_0} = \frac{d_{0f}}{\theta_f} \text{ [mm]} \qquad ...(4)$$

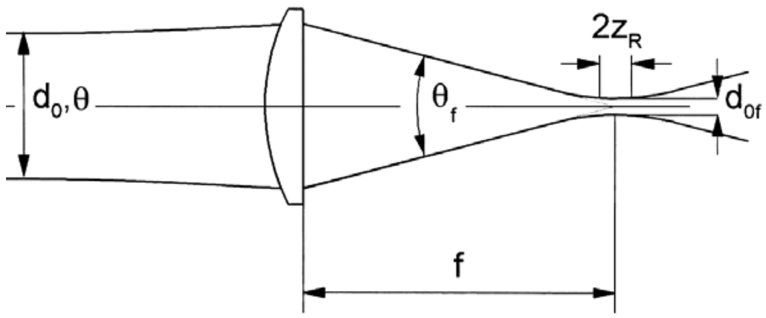

Fig. 2. The depth of focus (Z_R).
f - focal length of the lens; θ – divergence; θ_f – divergence of the focused beam; d_0 – waist diameter; d_{0f} – focal diameter[5]

The product from divergence and beam diameter $\theta \cdot d_0$ is constant in an optical reproduction. An increase of the divergence can be achieved by reduction of the focal length of the lens. The focal diameter becomes as a result smaller and a higher power density can be achieved, but the depth of focus decreases.
The beam quality of the laser, q_L at the exit of the laser, is determined by the beam parameter product, beam diameter (d_{0L}) and beam divergence (θ_L) [4]:

$$q_L = \frac{1}{4} \cdot d_{0L} \cdot \theta_L \text{ [mm·mrad]} \qquad ...(5)$$

The beam quality q, at the exit of the laser light cable is constant and remains constant after focusing on the work piece [4]:

$$q = \frac{1}{4} \cdot d_K \cdot \theta_K = \frac{1}{4} \cdot d_{0f} \cdot \theta_f \text{ [mm·mrad]} \qquad ...(6)$$

where d_K is beam diameter and θ_K beam divergence at the exit of the laser light cable.

3. EXPERIMENTAL REZULTS

The team has studied the influence of the pulse power, the pulse duration and the focus position: on the overlap welding and on the edge-to-edge welding. The pulse power and the pulse duration determine the weldability and the average power determines the welding velocity. For an average laser power less then 200 W and a comparatively large work piece the surface cools down before next pulse. By overlapping the spots we obtained the seam. Overlapping of the welding spots should be 60%. The diameter of the spot is determined by the focus position.

In the first case, figure 3 and figure 4, we modified the pulse power and all other parameters being constant: τ_H=8 ms for overlap welding, τ_H=10 ms for edge-to-edge welding, f_p=6 Hz and d_{0f}=1.2 mm.

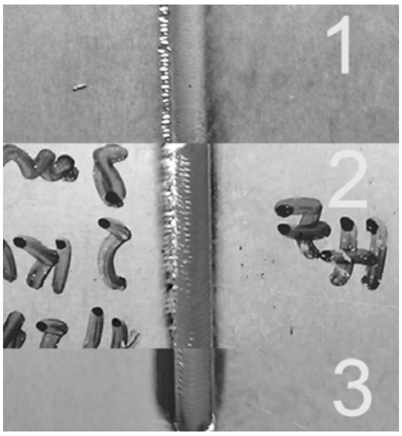

Fig. 3. Overlap welding with pulse power: 1) P_H= 2.5 kW; 2) P_H= 2 kW; 3) P_H= 3 kW.

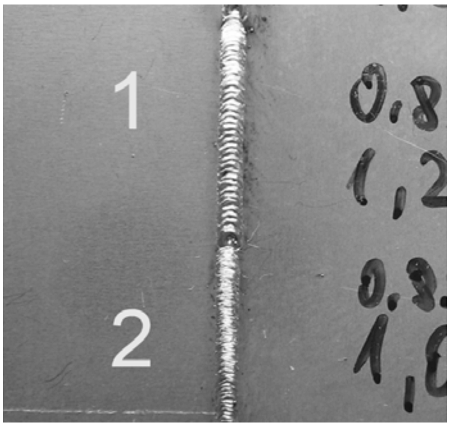

Fig. 4. Edge-to-edge welding with pulse power: 1) P_H= 1.2 kW; 2) P_H= 1 kW.

Increasing the pulse power, we get a better depth of the seam and a better surface of the seam, but the laser beam produces splashes and a slot close to the seam.

In the second case, figure 5 and figure 6, we modified the pulse duration all other parameters being constant: P_H=2 kW for overlap welding, P_H=1.1 kW for edge-to-edge welding, f_p=6 Hz and d_{0f}=1.2 mm.

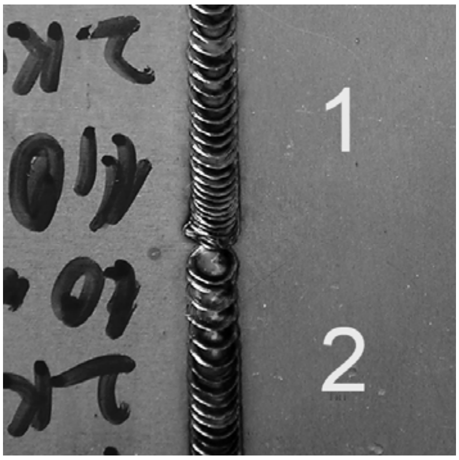

Fig. 5. Overlap welding with pulse duration: 1) τ_H=8 ms; 2) τ_H=10 ms.

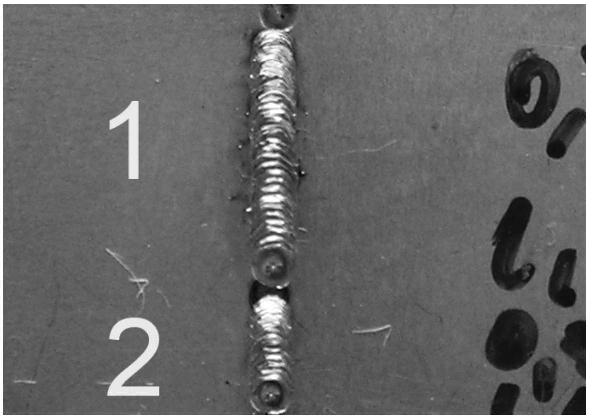

Fig. 6. Edge-to-edge welding with pulse duration: 1) τ_H=10 ms; 2) τ_H=9 ms.

The increasing of the pulse duration and the pulse energy too, is followed by the increasing of the dimensions of the seam, width and depth. The surface of the seam is not good, it can be seen the trace of the spots. If the pulse duration is too long, this will be followed by splashes and an increased heat of the metal close to the seam.

In the third case, figure 7 and figure 8, we modified the spot diameter by modifying the focus position and all other parameters being constant: P_H=2 kW, τ_H=8 ms for overlap welding and τ_H=10 ms for edge-to-edge welding, f_p=6 Hz.

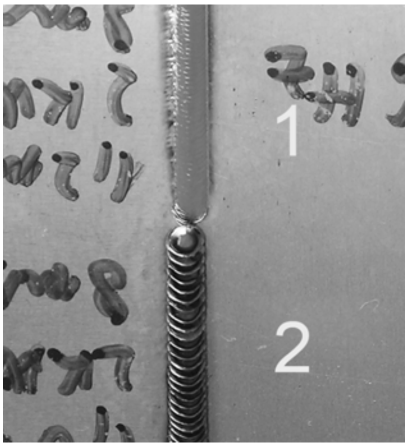

Fig. 7. Overlap welding with spot diameter: 1) d_{0f}=1.2 mm; 2) d_{0f}= 1mm.

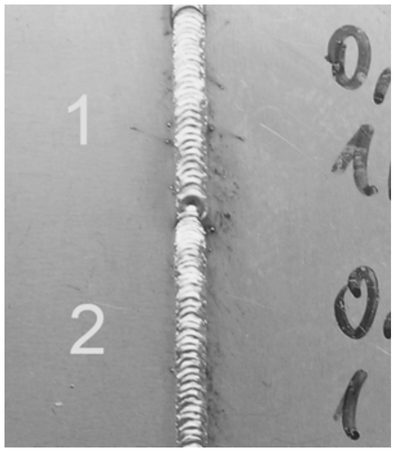

Fig. 8. Overlap welding with spot diameter: 1) d_{0f}=0.8 mm; 2) d_{0f}=0.85 mm.

The increasing of the focus position will be followed by the improving of the seam's surface and will reduce the splashes. However, the depth will be reduces too.

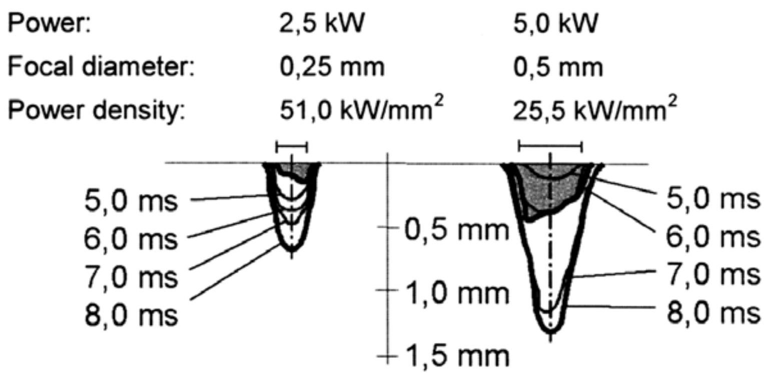

Fig. 9. Welding depths for copper [4].

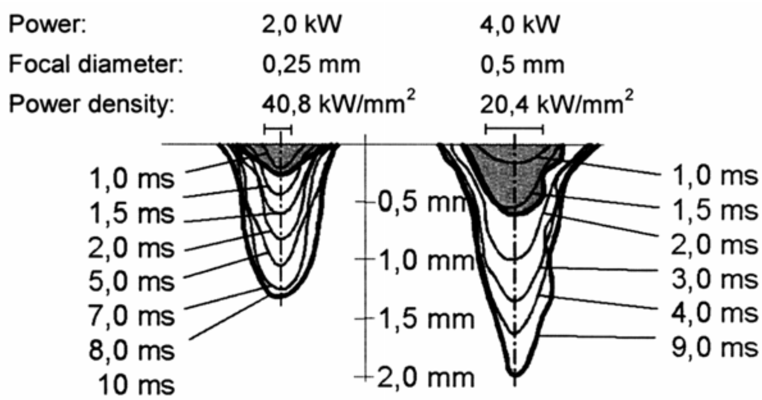

Fig. 10. Welding depths for aluminum [4].

For metals like aluminum and copper the parameters welding velocity, focus position, laser power and so on have to be set more exactly than for steel to achieve the required welding depth. The maximum welding depth depends on the material to be welded, for copper the maximum depth is approximately 1 mm and for aluminum is approximately 1.5 mm. If the depth is exceeded the material is ejected at the welding point (figure 9 and figure 10).

4. CONCLUSION

The aim of this experiment was to identify the influence of each of the laser parameters on the welding process.

In this paper, the team analyzed the influence, of the three laser's parameters: pulse power, pulse duration and focal position, on the quality of the welding. The amount of melt material depends on the energy transferred by the laser beam in the material to be weld. The energy value represents the product of the value of the pulse power and the value of the pulse duration. Focal position is important because in case on overlap welding the laser beam has to be focused between the two metal sheets.

The pulse power has to be set in order to avoid the splashing. A longer duration of the pulse determines a bigger volume of the melt material, covering the slots close to the seam. A longer duration of the pulse decreases the feed speed.

Considering that the modifying of one parameter influences directly or indirectly the process of welding, a simulation and an optimization of the process is required. This will significantly reduce the time of the process and the losses of the material.

The researches were made on the Trumpf HL54P laser equipment. The results of these researches can be used for the simulation and the optimization of the machining to improve the quality of the welding.

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