THE WAVELENGTH INFLUENCE ON THE ABSORPTION OF LASER RADIATION BY AISI316L AUSTENITIC STAINLESS STEEL

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Abstract In case of metallic materials laser processing the type of the laser unit affects fundamentally the interaction process between laser radiation and material. For laser welding process, the weld bead profile depends on various parameters such as beam power, welding speed and wavelength of the laser radiation. In order to investigate the influence of the laser radiation wavelength on the absorptivity level of the material three different laser generators (Nd:YAG - $\lambda=1060\,\text{nm}$, Diode Laser - $\lambda=904\,\text{nm}$ and CO2 laser - $\lambda=10600\,\text{nm}$) were used for a complex experimental study on laser welding of AISI 316L. The evaluation of the seam quality was performed by studying the features of weld bead, such as bead width, depth of penetration and cross section area of the molten pool.

Keywords: Wavelength, absorptivity, laser welding, AISI316L.

1. Introduction

It is well known that laser welding has the advantages of deep penetration, high aspect ratio, narrow heat-affected zone, fine grains and excellent mechanical properties due to high energy density [1]. However, in case of metals laser processing the energetic efficiency is very low due to the high reflectivity level of the metallic materials. Given these issues, researchers showed special attention for developing new techniques and methods for improving the energetic coupling between material and radiation [2, 3].

The metals absorptivity capacity presents an increasing tendency in reverse ratio with the wavelength value of the incidence radiation [4, 5]. For optimal energy efficiency and high quality of weld bead, the wavelength and power of the laser generator are two parameters that must be perfectly harmonized with the welding speed and the type of material used [6]. Given these issues, for increasing laser radiation absorptivity of metals were developed a series of optical systems with nonlinear crystals interposed in the optical resonance cavity of the laser unit [7, 8]. These systems are designed to increase the frequency of radiation emitted by doubling, tripling, quadrupling, resulting a reduction of wavelength from 1064 nm to 532 nm, 355 nm and 266 nm.

Thus the technological capabilities of processing for the laser unit extends. Another major advantage in increasing frequency is the possibility of focusing the laser radiation on a small area according to:

$$s = 1.27 \times \frac{\lambda \times f}{d}$$

(1)

where $\lambda$ is the wavelength, $f$ is the focal length and $d$ is the diameter of the laser radiation that enters in the focusing lens. Taking into account these aspects, through amending the wavelength from 1064 nm to 532nm results a halving of focal spot surface and a quadrupling of power density.

However, worldwide, one of the problems that limits the widespread use of nonlinear crystals for increasing the frequency of laser radiation is the high costs of implementing this solution and technological limitations that allows a transforming coefficient of laser radiation of only 50%[5, 8].

In case of laser processing of metals the characteristics of the laser radiation (the laser unit type) must be selected according to the proces. In this paper was analyzed the influence of laser radiation wavelength and power input on the absorptivity level of AISI 316L austenitic steel. The laser welding tests were carried out on plates with the dimensions 160/80/6mm.
2. Testing and analysis equipments

Three types of laser units were used for welding (fig. 1): a ROFIN DL 027S laser diode system, with a maximum radiation power of 2700 W (wavelength 904 nm), a laser unit with solid active medium Nd:YAG ROFIN DY033 (wavelength 1064 nm), which can develop a maximum power of 3300 W with a yield of 7% and a CO₂ ROFIN DC035 laser, with a maximum radiation power of 3500 W (wavelength $\lambda = 10600$ nm), a laser unit which is coupled to a SEF Roboter, Remote Welding System for positioning the beam in the work area, while providing a generous three-dimensional work space and exceptional positioning accuracy.

As analysis equipments, a metallographic microscope OLYMPUS 900 was used (fig. 2). The experimental arrangement provides the inclusion of a FLUKE thermocouple linked to the laser head through a protection tube, with the sensing element placed at 20 mm from the focal point of the laser beam (fig. 2b). In this way, the thermocouple can routinely capture the initial temperature of welding samples for each seam. During laser welding process was used helium as the shielding gas of the laser head, at a flow rate of 15 l/min.

3. Influence of laser radiation wavelength on absorptivity of AISI316L

In case of metals, laser beam energy absorption is accomplished by the free electrons in the material, which are absorbing particles in a wide band and can absorb a wide range of wavelengths, but their coupling with the molecules of the material is poor, so only a small amount of the energy captured by the electrons in the electron cloud is ceded to the atoms of the material and the energy captured is mostly reemitted outwards in the form of photons with the same wavelength as the incident radiation.

In conclusion, the smaller the wavelength, the higher the probability of producing atomic vibrations instead of electronic vibrations, thus resulting a better coupling of the beam energy with the processed material [9].

In order to track the influence of the wavelength of the laser radiation on the profile and characteristics of the material in the welding zone, were selected three types of laser units, namely: Nd:YAG ($\lambda = 1060$ nm), Laser Diodes ($\lambda = 904$ nm) and CO₂ laser ($\lambda = 10600$ nm). For the results to be conclusive, were set three different power modes 1.5 kW, 2 kW, 2.5 kW according to table 1, operating speed of 10 mm/s, spot diameter 3 mm and the initial temperature of the material was 30°C.
The Wavelength Influence on the Absorption of Laser Radiation by AISI316L Austenitic Stainless Steel

Table 1

<table>
<thead>
<tr>
<th>P [kW]</th>
<th>Wavelength [nm]</th>
<th>D [mm]</th>
<th>Speed [mm/s]</th>
<th>Penetration depth average [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>904</td>
<td>3</td>
<td>10</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>1060</td>
<td></td>
<td></td>
<td>0.49</td>
</tr>
<tr>
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<td>10600</td>
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<tr>
<td>2</td>
<td>904</td>
<td>3</td>
<td>10</td>
<td>1.45</td>
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<tr>
<td></td>
<td>1060</td>
<td></td>
<td></td>
<td>0.75</td>
</tr>
<tr>
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<td>10600</td>
<td></td>
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<td>0.39</td>
</tr>
<tr>
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<td>904</td>
<td>3</td>
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<td></td>
<td>10600</td>
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<td></td>
<td>0.45</td>
</tr>
</tbody>
</table>

For accurate measurements, for each power mode 5 weld seams were made (Fig. 1), being recorded the penetration depth for each, following which has been made an average. In case of samples used in the fundamental study of the metals absorptivity behaviour and the factors affecting the absorptivity evolution, in the carried out experiments the austenitic stainless steel AISI 316L was used [10], whose properties are listed in table 2.

Table 2 - AISI 316 stainless steel properties

|-----------------|-----------------------------|------------------------|--------------------------|-----------------------------|------------------------------------------|-----------------------------------------------|--------------------------|-----------------------------|

Microstructural analysis was performed using a metallographic microscope OLYMPUS. Depending on the wavelength of the laser radiation, the surface of the resulting seam section varies, as shown in table 1 and it displays a sensitive enlargement of the surface with the variation of the wavelength of the laser radiation (Fig. 3).

Starting from the geometric profile of the molten material that was fully characterized has been calculated the absorptivity level of laser radiation in case of AISI 316L for each wavelength and value of the power input.

![Figure 3: Welding seams sections](image)

Neglecting the radiating power and convection losses, which are generally low, the laser power absorbed by the material may be expressed by the equation:

\[
P = \rho \omega v \left[ C_p (T_a - T_0) + L_m \right] + P_{con}
\]  (2)

Where \( \rho \), \( C_p \) and \( L_m \) represent the density, the heat capacity and the melting latent temperature of the metal, \( T_0 \) is the ambient temperature, \( T_a \) is the preheating temperature of the material. One might assume that the heat dissipation in the metal is made tridimensionally while the welding point penetrates the material surface. In such approximation case, the power losses by conduction may be determined by Fourier’s law of heat conduction:

\[
P_{con} = -wK \frac{dT}{dx} - 2\pi \tau tK \frac{dT}{dy}
\]  (3)

Where \( \tau = \frac{l}{v} \), is the travel time in which the laser beam can cross his own diameter, l. It can be assumed that the temperature is decreasing from the melting temperature to the ambient temperature below the diffusion’s value, \( 2(\alpha \tau)^{1/2} \), resulting:
By using these equations, the absorbed laser total power, the power loss by conduction and the precise laser power used when melting the metal samples, the absorptivity may be calculated through the equation:

\[ A = \frac{P}{P_{\text{total}}} \]  

(5)

Applying these equations to the data registered within the metallographic assay of the samples has been obtained the relative absorptivity degree of each welding route on the samples surface. In particular, in the case of AISI316L austenitic stainless steel, experimental results confirm the studies in the field [3, 4, 5] and the dependence of the penetration depth on power and wavelength is concretely established (fig. 4).

By analyzing the curves of evolution of laser radiation absorptivity level in the case of AISI316L austenitic stainless steel, it was noticed that the difference between the degree of absorptivity for the 3 wavelength levels, increases in direct proportion with the power of laser radiation.

While for the input power of 1.5 kW, the differences between laser radiation absorptivity for all three wavelength levels are reduced, for the input power of 2.5 kW, in case of laser generator with wavelength of 904nm, the absorptivity of the material increases exponentially, reaching an absorption level two times higher than in the case of the laser unit with a 1060nm wavelength and approximately 4 times higher than in the case of the laser generator with wavelength of 10600nm.

In the case of the AISI 316L austenitic stainless steel analyzed in this paper, for the CO₂ laser generator (wavelength 10600nm), the penetration depth for the input power \( P=2.5 \text{ kW} \) is almost identical to the depth for \( P=2 \text{ kW} \) power, given that a saturation of the coupling of the laser beam photons and material occurs[9]. As a result, in the case of a 2.5 kW power, absorptivity rate decreases, a part of the radiation is reflected and another part produces the evaporation phenomenon of the material from the surface of the part.

4. Conclusions

In case of AISI316L, all three beam sources studied differ fundamentally in their process behavior during welding.

Due to the specific behavior of the materials depending on the wavelength of laser radiation incidents the degree of absorptivity is a particular problem for each processing operation.

For each wavelength level studied in this paper the absorption of laser radiation by AISI 316L stainless steel increases with the power input until a saturation appear.

For optimal energy efficiency and high quality of juncture in case of laser welding, the wavelength and power of the laser generator must be correlated with the type of material.

Considering the major influence of the wavelength on the energy efficiency of laser processing technologies, the development of laser units with variable wavelength is a necessity for industry.

5. Acknowledgement


6. References


