

EFFECTS OF ENERGY LEVEL OF IRRADIATION FOR LASER WELDING

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ABSTRACT For laser welding is important the quantity of melt produced in the material. Melted material zone is analyzed for laser welding of steels. Irradiation conditions are characterized by the ratio between the intensity of laser beam on the workpiece surface and welding speed. Melted material zone is characterized by sizes measured on the weld surface and on the weld cross section. Crater at the end of the weld shows melt movement welding bath. It presents mathematical models using regression functions. Analyzed sizes shows similar function of variation, from this is characterized the melted material zone.

KEYWORDS laser keyhole welding, metal melting, laser beam intensity, weld cross section.

1. INTRODUCTION

Laser welding of steels have a wide applicability. Characteristics of laser welds were presented in studies [1]. Interest in welding process occurs for the material structure for molten zone geometry and less on sizes that shows melt movement in welding bath.

Using industrial lasers for laser welding process involves obtaining of molten zone at the piece surface. This is achieved by adjusting the laser beam intensity to the material surface and time of interaction between laser and material. These sizes are dependent on the varied parameters. Sometimes this dependence is not explicit.

For laser welding applications, laser beam intensity has values between 10^5 - 10^7 W/cm² and the time of interaction between laser radiation and material 10^{-3} - 10^{-2} s. [2]. It was shown that the main dependences for melted zone characteristics are due by parameters laser power and welding speed. Focal plane position relative to suprafața song called defocus effect influences the two parameters.

In this paper are presented sizes that characterize the melting obtained from laser welding on steel plates. The variation of these sizes will be studied in relation to a single parameter namely the ratio of the intensity of laser beam on the workpiece surface and welding speed and also called energy of interaction. This account treated as one experimental field situations where defocus was change. Modeling using regression functions present in the general

evolution of the molten zone in the material. Wanted to express the material melted zone depending on the energy transferred to it independently of the varied parameters laser power and welding speed.

2. EXPERIMENTAL PROCEDURE

The experiment consisted in made lines of fusion (welds) ,110mm long , on Dillimax 500 steel plates with thickness of 10 mm (carbon steel, carbon content ≤ 0.16 %). Was used a Nd: YAG Triumph Haas 3006D laser source with 3kW maximum power on a continuous wave regime CW. Laser beam was transmitted through a optical fiber with core diameter of 0.6 mm. The focus system made a focal spot with 0.6 mm diameter. Lens focal length was 200 mm. As protective gas argon was used with a flow rate of 20 l / min. Were used 6 sheets of material with dimensions of 100×130×10mm for which were made between 5 and 8 welds, with a distance of over 10 mm between welds.

In experiments was varied the laser power, welding speed and distance between focal plane and piece surface (defocusing or defocusing depth). Welds were cut in the stable part of the weld near the place where welding process was stopped. Weld section was processed metallographic. Weld width, near the piece surface, and weld depth were examined using a microscope with precision of 0.01 mm. Melted area was measured directly by its footprint.

For comparison with molten zones produced by static irradiation average weld width L [mm] were measured using three

measurements on the piece surface at the beginning, middle and end of the weld. Pictures of machined pieces are shown in Figure 1.



Fig.1 Steel plate with welds a) Plate surface b) Cross section through plate

3. APPROACH TO INTERPRETATION OF EXPERIMENTAL RESULTS

Intensity laser beam to piece surface is the ratio between the laser beam power and spot area on the piece surface. This area increases with the focus within the play or negative values for defocusing.

Laser spot diameter at piece surface variation with defocusing is given by an empirical relationship. Laser beam intensity to piece surface is given by the following:

$$I = \frac{4 P}{\pi D^2} = \frac{4 P}{\pi (0.12|\delta| + 0.6)^2} \text{ [W/cm}^2\text{]} \quad (1)$$

Interpretation of experimental results followed a uniform characterization of welds obtained. This was achieved by introduction a calculated size to take into account the variables laser power, welding speed and defocusing. Was introduced as “interaction energy” E_v [J/cm³].

Interaction energy is defined as the ratio of laser intensity on the piece surface and welding speed. Laser intensity has been determined by varying laser power and spot size on the piece surface. Laser spot size on piece is determined by the conditions of focusing expressed by defocusing.

Welding speed is a parameter that is adjusted directly. Interaction energy has no direct physical significance as the energy brought in a certain volume. Higher interaction energy values are justified by the small size of laser spot at piece surface. Interaction energy shows laser ability to produce thermal phenomena in the material. Thermal effect of laser beam is proportional to the laser intensity on the material surface and interaction time between laser radiation and material. This is inversely proportional to the welding speed. The size interaction energy ensures a complete definition of the conditions in which take place the laser irradiation of material.

$$E_v = \frac{I}{v} \left[\frac{j}{\text{cm}^3} \right] \quad (2)$$

Sizes are analyzed in the paper are main sizes that characterize the weld, figure 3. They were measured on the weld cross-section. Obtain a uniform characterization of the welding process at a time.

Sizes analyzed in the paper were width of weld L [mm], the crater area which was obtained at the end of the welding acr [mm²], crater shape as expressed by the deviation from the crater circularity abc [%], the crater depth i [mm] and crater volume V [mm³]. Weld width L [mm] was measured at the weld surface. It was considered an average based on three values measured at the beginning of the weld in the middle and at end of welding.

Crater size (X axis in the direction of welding, transverse axis Y and elongation b) and its area was measured indirectly using images of the crater, figure 2. Crater depth was measured using a comparator. Weld width, crater dimensions X, Y, b , crater area and the crater depth are measured sizes. Deviation from circular and crater volume are calculated sizes. They are given by the following relations:

- for deviations from circularity:

$$abc = \frac{b - r_{med}}{r_{med}} \text{ [%]} \quad (3)$$

$$\text{where: } r_{med} = \frac{1}{2} \left(\frac{Y}{2} + X - b \right) \text{ [mm]} \quad (4)$$

-for the volume of the crater (it was considered the conical shape of crater)

$$V = \frac{i}{3} \times acr \quad (5)$$

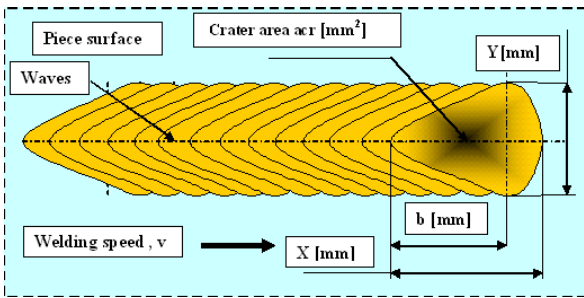


Fig 2. Scheme weld surface with crater obtained at the end of the weld

4. WELD SURFACE

The surface of laser welds is distinguished by the presence of some solid waves. We have analyzed aspects of the weld width and weld height in the final of welding process near the crater.

Figure 3 shows that with increased of E_v is obtained logarithmic increase of weld width. This shows that the increase in weld width is limited. Achieving moderate width of the weld is an important aspect of quality. We used two correlation functions to describe the type of variation.

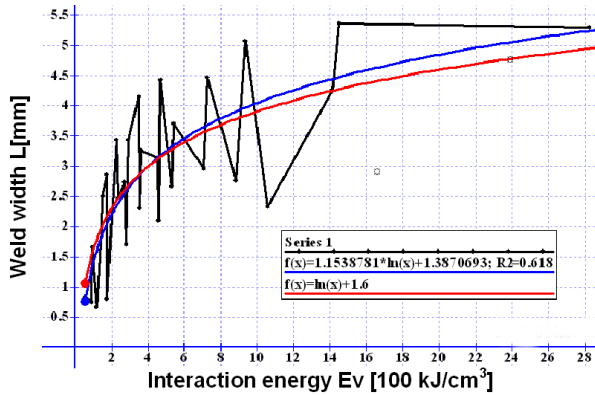


Fig.3: Weld width depending on the interaction energy

Figure 4 shows variations of the weld height with interaction energy. Welds obtained were generally low height.

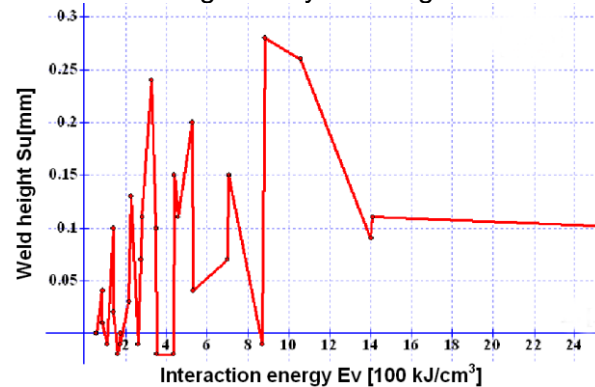


Fig. 4 Weld height depending on the interaction energy

We notice the presence of two maximum values near 400kJ/cm^3 first and the second near 1000kJ/cm^3 . At low values of interaction energy there are strong scattering experimental results.

5. CRATER AT END OF THE WELD

Crater is obtained at the end of the welding process due to evaporation and movement of melt in the welding bath. Crater is an image of the weld bath surprised in solidification process. It will further analyze its characteristics.

Figure 5 shows the measured variation of the crater surface. There is a logarithmic increase with interaction energy density of the crater surface. There is a weak correlation due to a large data spills. Random behavior comes from the simultaneous effect of melting and evaporation phenomena.

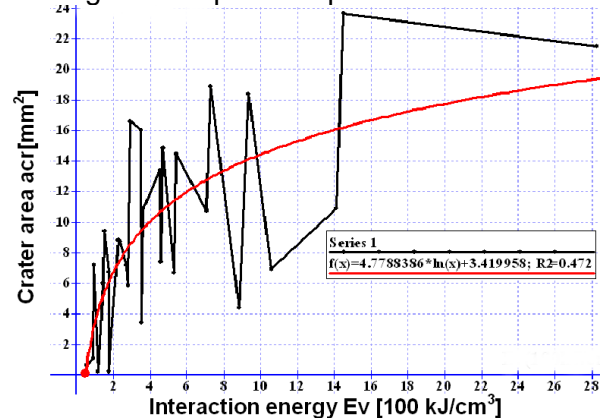


Fig.5 Crater area depending on the interaction energy

Figure 6 shows the variation of crater depth depending on the energy of interaction. There is an exponential increase of it.

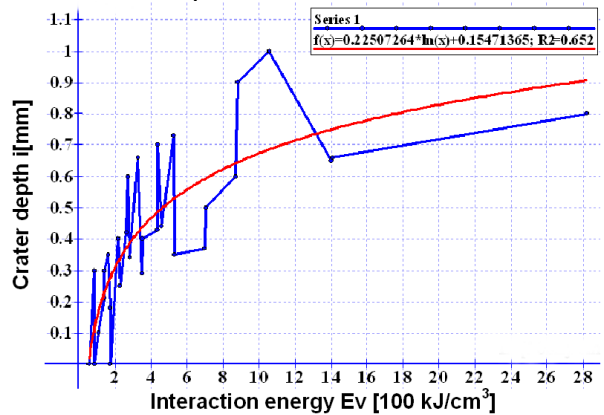


Fig.6 Crater depth depending on the interaction energy

For welding is used for interaction times higher than those used in drilling or cutting. Logarithmic increase of crater depth shown

that in the welding conditions possibilities to obtain deep cavities are limited. Main contribution to the establishment of a crater depth is vaporizing the material. The depth of the crater has a higher significance that is related to the depth of the weld (melted zone depth). This is expressed by the ratio G

Figure 7 shows the variation of G ratio with energy of interaction. G ratio is relatively low. This shows that the irradiation conditions were more favorable to obtain melt than vaporizing the material. High values of G ratio were obtained for low values of interaction energy. At high values of interaction energy there are low values of G ratio. Shown thus increasing irradiation promotes the conditions for obtaining a melt.

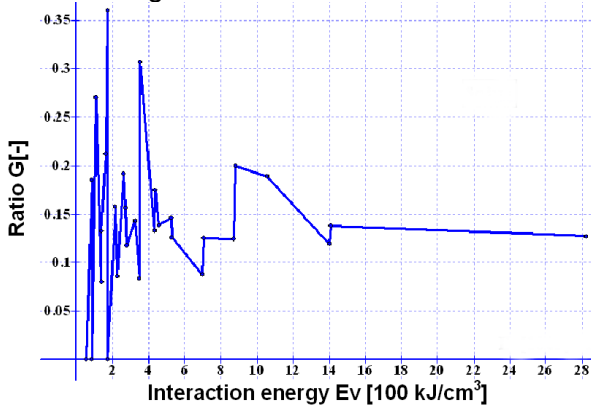


Fig.7 Ratio G (crater depth / weld depth) depending on the interaction energy

Figure 8 shows variation of crater volume with interaction energy. Crater volume indicates the amount of evaporated material and the effect due to melt motion. Crater volume increases with the energy of interaction.

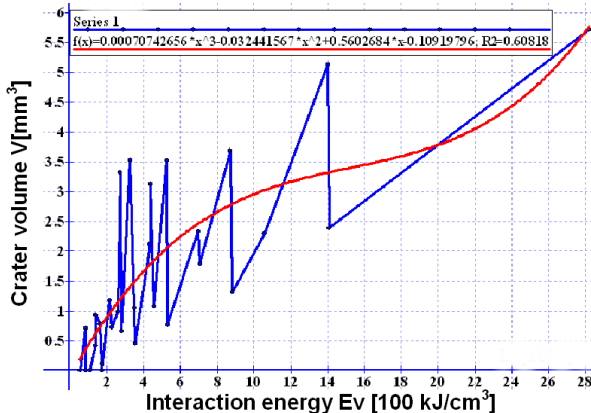


Fig.8 Crater volume depending on the interaction energy

This increase is of polynomial type of degree 3. It can be framed in a linear type increase. It looks like that increased interaction energy can provide large

cavities obtaining in the solidification of the material.

Figure 9 shows the variation for the deviation from circularity according to the energy of interaction. Deviation from circularity shows the relative variation of crater dimensions (X, Y, b). It looks like the crater elongation increases with interaction energy. We notice the presence of a peak at the center of experimental field. It looks like that under certain conditions to obtain crater elongation in excess. This is an undesirable phenomenon. Have a relatively large data scattering. The phenomena of melting, evaporation and the particular values of welding speed contributes to the large scattering of experimental data.

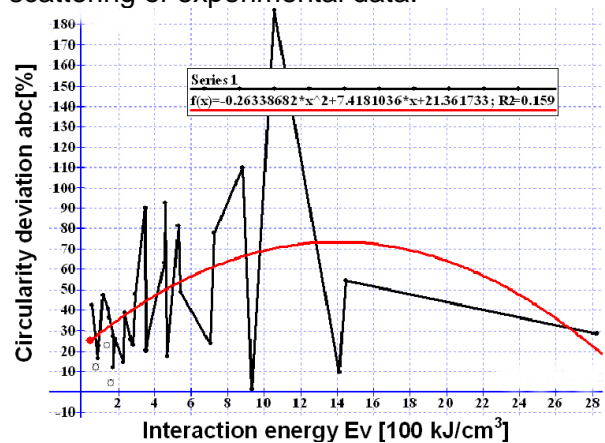


Fig. 9 Circularity deviation depending on the interaction energy

5. WELD CROSS SECTION

Main information about the welding process are given by the weld cross section. After cutting the pieces and process for obtaining metal structure on the weld cross section is observed molten zone and heat affected zone. On weld cross section was measured three areas shown in figure 10.

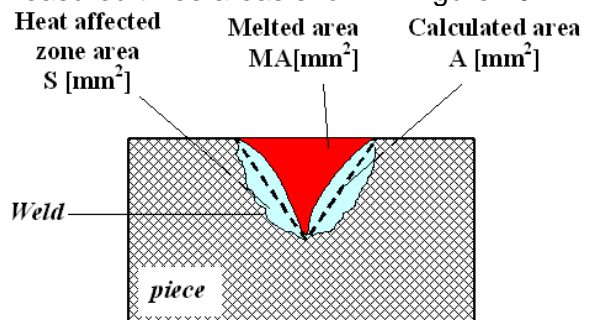


Fig. 10 Scheme of variables measured on the weld cross-section

Melted area $MA[mm^2]$ are the area where material was melted. Area $S[mm^2]$

shows the area of heat affected zone that includes the melted area. The calculated area $A[\text{mm}^2]$ is a triangular area on weld cross section defined by weld width and weld depth, figure 10. All three sizes can be used to characterize the weld cross section and the amount of melt is obtained in the material.

Figure 11 shows the variation in melt area of the weld cross section with energy of interaction. Observe the melted area volume increases logarithmically with interaction energy. It looks like the melted area increased with energy of interaction is limited. For low values of interaction energy there are very important variations in experimental condition especially those related to laser beam focus.

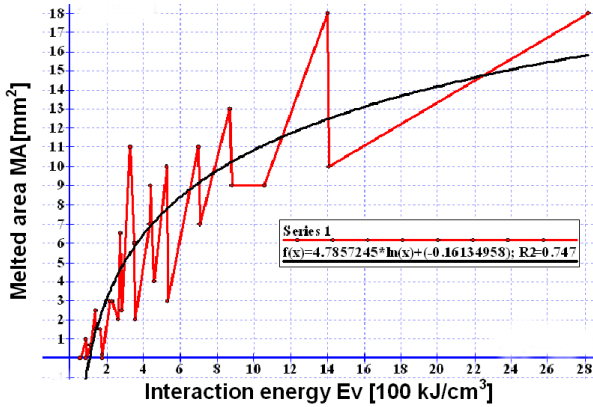


Fig. 11 Melted area depending on the interaction energy

Figure 12 shows the variation of the weld cross section total area S with energy of interaction. It is noted that this area has a linear increase with interaction energy. This linear increase is weaker than logarithmic for MA . It is assumed that for area S is a logarithmic trend to increase as to MA . For variation were observed only the low part of this increase that can be approximated by a linear function.

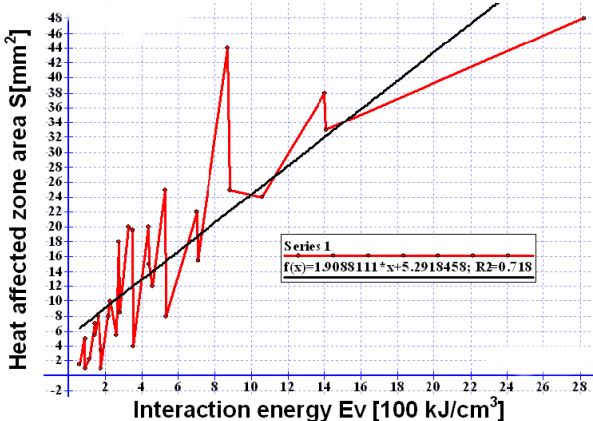


Fig 12. Heat affected zone area depending on the interaction energy

Figure 13 shows the variation of calculated area with interaction energy. It shows that the calculated area increases with energy of interaction. Basic type of increase is linear. The correlation coefficient was improved by using a function of grade 3. From this variation is shown simultaneously increase the weld width and depth with interaction energy.

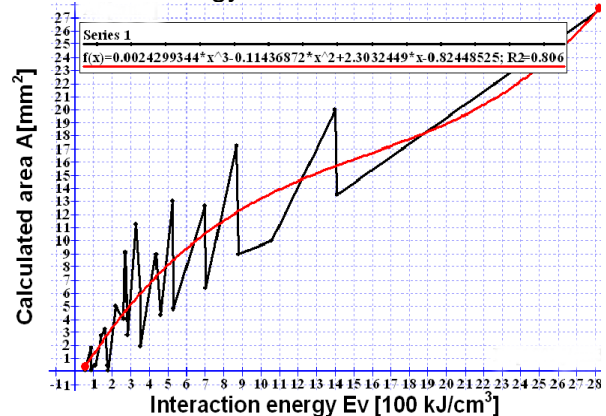


Fig.13 Calculated area depending on the interaction energy

6. CONCLUSIONS

The paper presents an analysis of the melted zone in laser welding. The level of radiation was expressed by the ratio between the laser beam intensity on the workpiece surface and welding speed. Measurement of sizes piece on piece surface is easy. This shows the dynamic aspect of the welding process. In the study an important place is for weld crater which is obtained at the end of the welding process. Sizes that characterize the crater shows the combined effect of melt movement and vaporisation. These phenomena become stronger with increasing levels of radiation. Transition from conduction welding regime to keyhole welding regime was shown by deformation of the crater. High intensity laser beam will lead to a deep crater. Weld cross section provides more opportunities to characterize the effect of irradiation. This identifies the melted zone, heat affected zone and geometric appearance of the melted area given by the weld width and weld depth. It was shown that the variations of quantities measured on the weld cross section are similar to the variations of sizes measured on the weld surface. Modeling with regression functions showed that there is a increase of production of melt, of vaporisation and melt movement

with increasing levels of radiation. Modeling took into account only the radiation given by the interaction energy and did not consider variations in power and welding speed of parameters directly varied in experiments. Therefore correlation coefficients were low in some cases. However the regression functions shows generally changes for analyzed sizes with increasing irradiation level given by the interaction energy. For sizes measured on weld cross section is observed that there is an increased on correlation coefficient compared with those sizes measured on the weld surface. Sizes determined on the weld cross section shows melting and heat loss by conduction in the material. These phenomena have a high degree of stability and reproducibility for irradiation in similar conditions. Sizes determined on the weld surface by their

association with melt movement and vaporization of the material leads to the presence of strong instabilities marked by the low values of correlation coefficient.

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