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LASER BEAM DEFOCUSING EFFECTS ON LASER WELDS SURFACES

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Abstract: *It presents experimental results for laser welding of carbon steel. Weld surface shows issues of the welding process dynamics. It analyzes several dimensions that characterize the weld surface. Changes in their aspects shows melt movement and vaporization of material which appear under keyhole welding regime. It examines the effect of defocus on particular areas of welds. It examines the crater obtained at the end of the welding process after stopping irradiation.*

Keywords: *laser welding, steel, weld surface, weld crater*

1. INTRODUCTION

Laser systems are used in welding technology. The laser beam is used as a heat source to achieve melting of the material. For laser welding are two welding regimes conduction regime and the keyhole regime. For keyhole welding regime take place for the material vaporization and a strong movement of the melt. These produce changes in surface characteristics of welds.

Laser welding of steels has been presented in the works [1,2]. Study of characteristics of welding work was presented in works [3,4]. In laser welding usually are varying the average laser power and welding speed. A better characterization of the condition in which laser welding has been achieved has been presented in works [5,6]. Defocusing or depth of focus is the distance between the focal plane (minimum diameter of the laser beam is the focal plane) and the workpiece surface. Negative values for defocusing means positioning of laser beam focal plane below the workpiece surface.

This method provides convergent laser beam propagation in the interaction zone. Focus within the song was used in the work [7,8].

The study of laser welds surfaces provides information about the dynamics of the welding process. Welding starts with an elevation zone of the weld. This is due by melt movement to back of the welding bath.

At the beginning of the welding process welding bath is unstable. At the end of the welding process is a crater. It is associated with a stable region of the weld. The crater has the shape of the welding bath. Weld width, waves appear on the piece surface and crater at the end of the weld provides information about the movement of melt in the welding bath. Welds were made in keyhole regime. It shows that for this welding regime to obtain interesting effects sizes that characterize the welds surfaces.

The aim of this work is to study the effect of defocus on some quantities that characterize the welds surfaces for laser welding. Experiments consisted of classic experimental series that were varied laser power and welding speed.

For this was achieved variation of linear energy which is given by the ratio between laser power and welding speed. Most welds were showed keyhole welding regime. Analyzed sizes were characteristics of the weld surface that can be linked to vaporize and melt movement.

2. EXPERIMENTAL PROCEDURE

The experiment consisted of fusion lines (welds) with the line length of 110mm on steel Dillimax500 plates with thickness 10 mm.An industrial laser machine Nd: YAG Trumph Haas 3006D was used. It emits radiation with wavelength λ = 1.06 μm and have a maximum power of 3kW. Irradiation was performed in continuous regime. Laser beam was transmitted through a fiber with 0.6 mm diameter. The focusing system assures the spot in focal point with 0.6 mm diameter.

The focal distance of lens was 200 mm. As protective gas was argon with a flow rate of 20 l/min. On the 6 sheets of material with $100\times130\times10$ mm dimensions was made between 5 and 8 welds on each plate, total 37 welds.

The material used was steel Dillimax500 EN 10137. This is a fine grain steel with high elasticity limit elasticity. Chemical composition, the upper limit expressed as a percentage is given as follows $C\leq0.16$, $Si\leq0.5$, Mn≤0.1.6, $P\leq0.02$, $S\leq0.01$, $Cr\leq0.7$, $Ni\leq1$, $Mo\leq0.6$, $V+Nb\leq0.08$

The radiation was controlled by variation of three parameters: laser power, welding speed and defocusing distance (position between the focal point and the piece surface).

Analyzed sizes in the paper were weld width L [mm], the area of crater which was obtained at the end of the welding process acr[mm^2], crater shape as expressed by the deviation from circularity abc[%], and the crater depth i[mm] and the crater volume V[mm^3]. Weld width L [mm] was measured at the surface of the weld. It was considered an average value based on three values measured at the beginning of the weld in the middle and end of weld. Crater dimensions (X axis in the direction of welding, and the Y transversal axis elongation b) and its area were measured indirectly using its image, figure1,2 .

Crater depth was measured using a comparator device. Weld width, crater dimensions X, Y, b, crater depth and crater area are directly measured quantities.Deviation from circularity and crater volume are calculated sizes. They are given by the following relations:

- for the deviation of circularity:

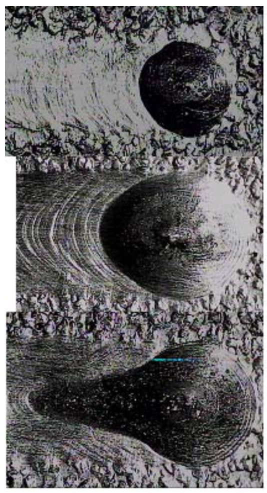
$$abc = \frac{b - r_{med}}{r_{med}} [\%] \quad (1)$$

with:

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

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

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



a)
b)
c)

Fig.1 Crater obtained at the end of the welding process with the following forms: a) circular b) oval c) oblong

To assess the effects of melt movement and vaporization compared with that of the material melting is compared the weld depth with the crater depth. This comparison is done by the ratio between crater depth and weld depth named G ratio. It will discuss the variation of ratio G with energy linear.

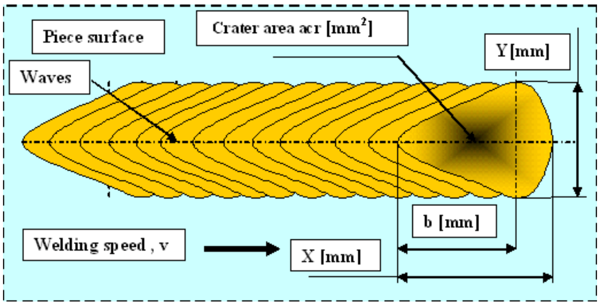


Fig. 2 Weld surface with analyzed sizes

By variation of these parameters was made the control of two parameters: the laser beam intensity and time interaction time. Both parameters were calculated in relation to the size of 0.6 mm focal spots. To achieve a complete characterization of experimental conditions were presented in term of calculated parameters interaction relative to the size of focal spots and the laser beam intensity.

Laser spot on the workpiece surface is circular. It is characterized by its diameter. The relationship between defocusing and spot diameter on the workpiece surface D was determined by measuring the focal spot. These are presented in Table 1. On the basis of their relationship was made the following correlation between defocusing and focal spot diameter D. It took into account the range of variation of experimental values for defocusing.

$$D = 0{,}12|\delta| + 0{,}6 \quad [\text{mm}] \qquad (4)$$

Applying this relationship (4) to defocus values used in the experiments are presented in Table 2.

Linear energy E_l is a quantity that characterizes the material irradiation in terms of the relative motion between the piece and laser head, and in terms of ability to radiate the laser material with laser beam.

Table1 Experimental variation of laser beam spot diameter with defocusing

Defocusing δ [mm]	0	± 5	± 30
Spot diameter D[mm]	0,6	1.2	5

Table2 Calculate variation of laser beam spot diameter with defocusing

Defocusing δ [mm]	0	-2	-4
Spot diameter D[mm]	0,6	0,84	1,08

For welding the linear energy is a standard size that characterize heat source. Linear energy show energy that is sent to the material per unit length traveled. Energia liniară se calculează prin raportul dintre putere şi viteză. Linear energy is calculated by ratio between laser power and welding speed.

$$E_l = \frac{P}{v} \quad [\text{J/cm}] \qquad (5)$$

3. WELD WIDTH AND WELD HEIGHT ABOVE THE SURFACE

Figure 3 shows variation of the weld width with the energy linear. There is a tendency to increase weld width is with linear energy for all three values of defocus. The highest weld widths are obtained for laser beam focusing surface.There is a minimum around 3 kJ / cm for all three values of defocus. The type of variation presented shows that the weld width increase with increasing linear energy are limited.

Figure 4 shows the variation of weld height with linear energy. Welds made had generally a low height over the piece surface. At high values of welding speed welds were lowered below the surface of the workpiece. Higher values for weld height were obtained for the laser beam focusing to the workpiece surface $\delta = 0$. It is noted that for all three values of defocus to obtain a maximum value close to 3 kJ /cm. This increase of weld height is associated with decreased for weld width shown in Figure 3. At low linear energy and high linear energy welds height are low.

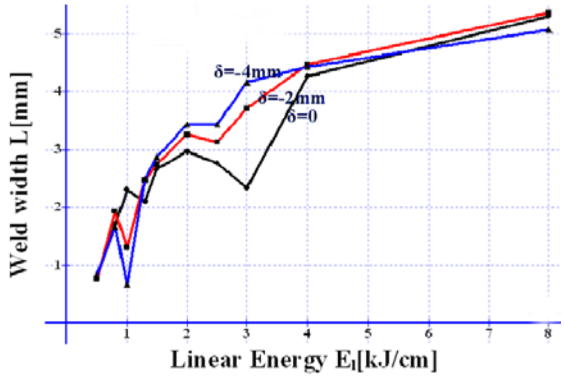


Fig.3Weld width variations depending on linear energy

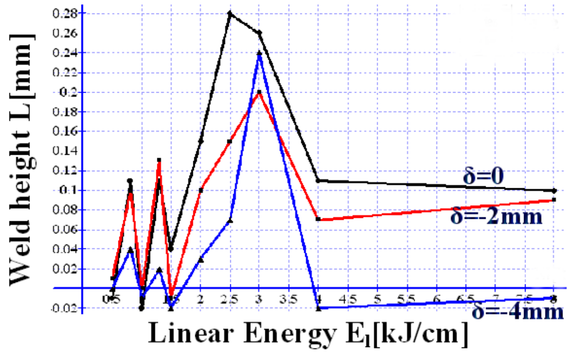


Fig.4 Weld height variations depending on linear energy

3. CRATER OBTAINED AT THE END OF WELD

Figure 5 shows the variation of deviation from circularity of the crater with linear energy. The largest variations of crater dimensions were obtained for the focus to surface. Near linear energy 3kJ/cm is observed a maximum. This signifies a strong deformation of the crater. Deformation of the crater is due to melt motion in the welding pool. Deformation of crater has minimum values d at the beginning and at the end of the experimental area.

Figure 6 shows the variation of crater area with linear energy. Crater area increases with linear energy. This increase is close to a logarithmic function for three values of defocus. The highest values for the crater area are obtained to focus the laser in depth piece $\delta = -2\,mm$. In this situation are favored vaporization and melt movement leading to crater formation.

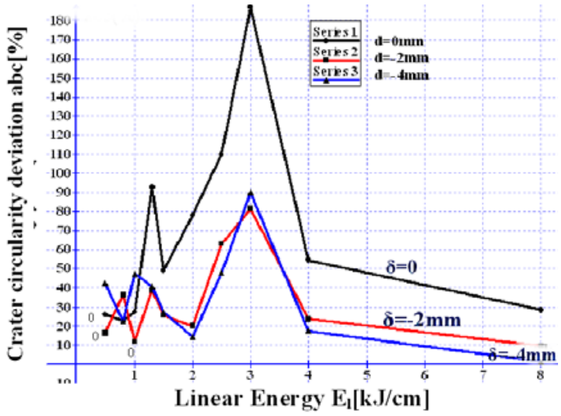


Fig. 5 Variation of deviation from circularity of the crater with linear energy

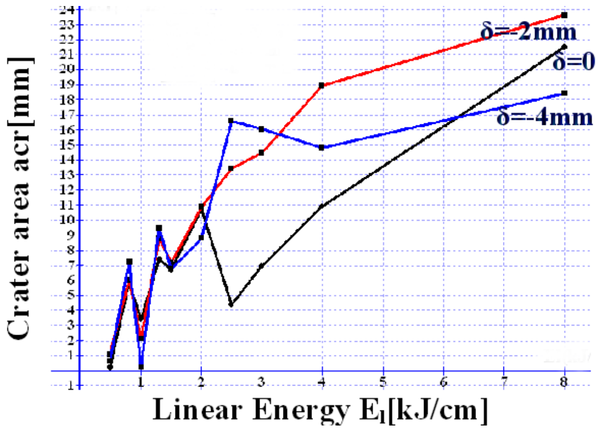


Fig. 6 Variation of the crater area with linear energy

Figure 7 shows the variation of crater depth with linear energy. There is a logarithmic increase tendency to crater depth with linear energy for all three values of defocus. It is limited and rapidly reaches a constant level. The higher values for crater depth obtained for focus on the surface $\delta = 0$.There is a maximum intensity at the surface and promotes melt movement and evaporate of material. It notes the presence of a relative maximum close to linear energy value of 3 kJ/cm.

Figure 8 shows the variation of G ratio with linear energy. G ratio has relatively small values. It shows that so much of the crater is filled with solidified melt. For all values of defocus is observed a maximum around 1kJ/cm linear energy value.

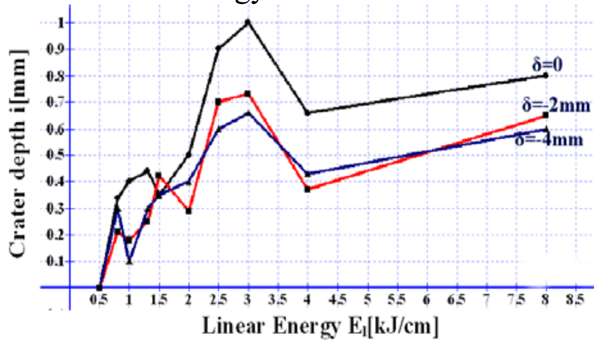


Fig. 7 Variation of crater depth with linear energy

This situation is associated with a strong movement of the melt. On the rest of the experimental field G ratio values are close, they form a constant level..

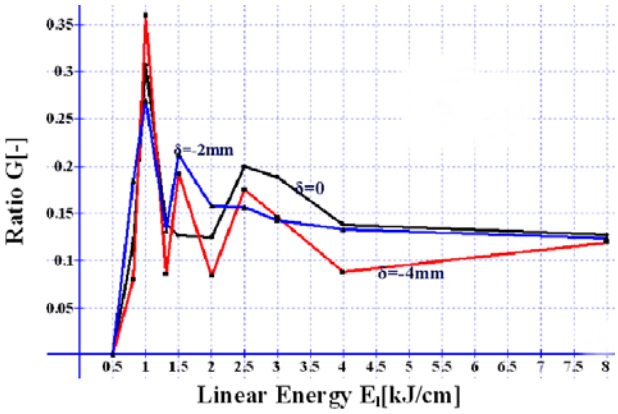
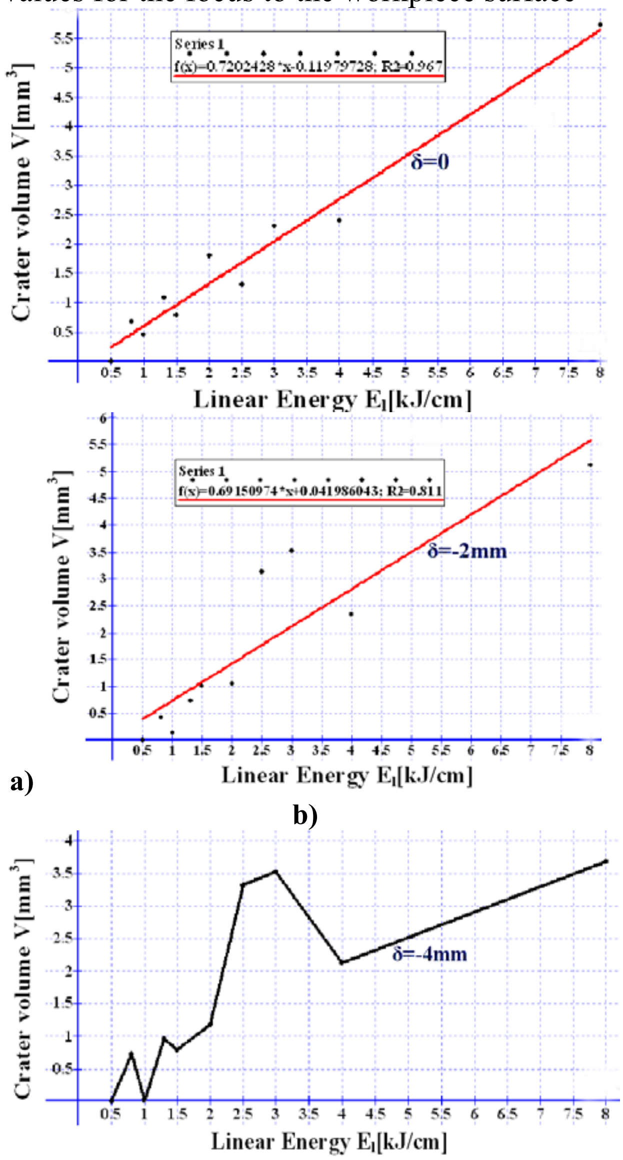


Fig. 8 Variation of ratio G with linear energy

After the main peak were observed that higher values are obtained for the ratio G to focus within the piece for $\delta = -4\,mm$ and $\delta = -2\,mm$, in relation with focus on the surface $\delta = 0$. It looks as though the focus within the piece that increases the coupling between laser radiation and material this is favoring the melt movement and not production of melt. At high values of linear energy G ratio has higher values for the focus to the workpiece surface



a)

b)

c)

Fig. 9 Variation of crater volume with linear energy at defocusing a) $\delta = 0$, b) $\delta = -2\,mm$, c) $\delta = -4\,mm$

Figure 9 shows the variation of calculated crater volume with linear energy. For all three values of defocus is observed a linear increase in the volume of the crater with linear energy. The volume of the crater has a relatively uniform reaction to the change in linear energy. This shows the amount of compensation between crater depth and crater area.

3. CONCLUSIONS

The welds surfaces provides information about the dynamics of the welding process. Weld width, weld height and size of the weld crater providing information that interrelated describes the dynamic aspect of the welding process. Linear energy characterizes the conditions for achieving the effect of laser irradiation by combining separate effects of changes in power and welding speed. It noted that:

- Focus on the workpiece surface produced the highest values for the sizes analyzed. In this case the melt movement is strong and also powerful evaporation of irradiated material takes place.
- Effects for focus in piece depth at $\delta = -2mm$ are stronger than those for focus in piece depth at $\delta = -4mm$. From this it showed the contribution of phenomenon keyhole in welding bath to increase the laser radiation absorption by multiple reflections.
- There is a clear tendency to increase weld surface deformation with increasing linear energy.

Reaching a certain maximum for crater deformation was associated with the maximum effects of keyhole welding regime.Using the linear energy as a parameter for irradiation conditions in welding provides the opportunity to observe some important energy balance between the considered sizes. Weld width increases with linear energy while the weld height decreases. The area of the crater and crater depth increases with linear energy while the crater deformation decreases. This shows that it forms a relatively limited amount of melt at a given value of linear energy. This is substantiated by the linear variation of crater volume obtained for all three values of defocus.

For laser welding it is important to obtain a significant amount of melt and the smallest part of the energy transmitted to the material to be used for metal vapor production and movement of melt. To obtain this situation is recommended laser beam focus $\delta = -2\,mm$. Reduce the intensity of the workpiece surface in this case had a favorable effect on the welding process.

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