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ANALYSIS OF SPECIFIC AREAS ON LASER WELDS CROSS-SECTION

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Abstract: *There have been made welds on carbon steel plates. Laser welding process is characterized by obtaining the melting of material. There is an analysis of welds cross section made by laser Nd:YAG laser operated continuously. Were varied the laser power, welding speed and defocusing. Weld cross section was characterized by three sizes related with fused zone. These are measured or calculated surfaces values. Their variation by laser power, welding speed and their ratio linear energy was examined. Three particular values were considered for defocusing. We analyzed the effect of defocus on the molten zone.*

Keywords: *laser welding, steel, weld cross section, melted material*

1. INTRODUCTION

Experimental research in laser welding is an open field. Research on laser welding of steels have been presented in the works [1,2]. Laser irradiation produces metal melting for laser beam intensities of range 10^4-10^7 W/cm^2 and time of interaction between laser beam and material 10^{-3}-10^{-2} s [3]. In these conditions it is possible to achieve laser welding. The conditions of irradiation of the piece in the welding process is performed by varying the laser power, welding speed and defocus (or defocusing depth) [4].

Defocusing is the distance between focal plane and the workpiece surface, figure1. Negative values of defocus show the location of the focal plane below the surface of the workpiece. In such case, get a convergent radiation propagation in the interaction zone with the material. Focus within the piece has been applied in the experiments presented in the works [5,6]. The main part of the analysis refers to the study of welds cross sections [7].

Purpose of the paper is to conduct a comparative analysis of alternative ways to measure the weld area on the weld cross section. Evaluation of the laser beam parametres to obtain the necessary characteristics of melting material and weld quality is emphasized best by weld cross section area. Detailed study of it can be different. In this work it considers different ways of assessing it. Direct measurement of molten area MA is strictly linked by obtains melt. The area of this zone can be measured.

There are issues of demarcation between the melted and heat affected material and not melted. The interface between these areas is not smooth. Heat affected zone and melted zone after weld is visible on the photograph of weld cross section. This area A will be called heat affected zone area. Evaluation of the two areas together is a combination of the effect of thermal heating and melting of the material. This area can be assessed much better because it is larger than melted area and the interface between it and the material is smooth and unaffected by heat. In other situations it is necessary only a rough assessment of the penetration of the weld in material. This is done on only by measured melted zone width at the piece surface and depth of the weld. It is considered a form triangle form of weld cross section.It is associated with the melting.

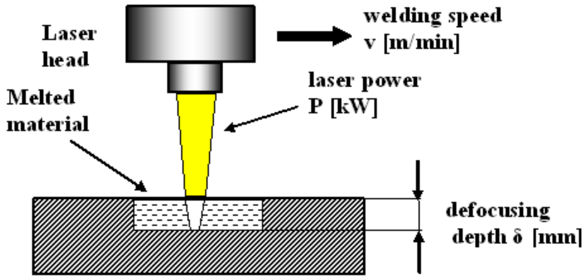

Fig. 1. Varied parameters in experiments

Triungiulare zone area is calculated and named as S. Sizes above can be used to evaluate weld in accordance with a specific purpose. On the other hand they show the particular effect of thermal phenomena. The area MA shows the effect of laser melting material. A area shows the cumulative effect of melting and heating the material and thus indicates the energy transmitted by laser to the material. S calculated area is a quick way to assess the weld cross section area. Areas A, S and MA on the weld cross section are presented in Figure 3.

For high penetration welds under keyhole welding regime the S area contains mostly melted zone area. All three areas analyzed are related to the molten weld zone. Part of the energy transmitted by the laser is used for maintenance of thermal phenomena that are unfavorable to achieve the weld. These are vaporization and melt movement.

2. EXPERIMENTAL PROCEDURE

The material used was steel Dillimax500 EN 10137. This is a fine grain steel with high elasticity limit elasticity $C \leq 0.16$.

The experiment consisted of fusion lines (welds) with the line length of 110mm on steel Dillimax500 plates with thickness 10mm. An industrial laser machine Nd: YAG Trumph Haas 3006D was used. It emits radiation with wavelength $\lambda = 1.06$ μm and have a maximum power of 3kW. Irradiation was performed in continuous regime. 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), figure 1. Welds are presented in figure 2

Fig. 2. Welds on steel plate a) Plate surface b) Cross-section for welds

Defocus change by lowering the focal plane inside the piece increases the laser spot on the piece surface. This decreases the laser beam intensity at the piece surface, but provides convergent laser radiation propagation in the interaction area. Values produced by the laser beam spot size on the workpiece surface are presented in the following table 1.

Table 1 The relationship between spot diameter and defocusing

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

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

In welding it is a standard size that characterizes the heat source. It shows the energy that is sent to the material per unit length traveled. It is calculated by the ratio between power and speed.

$$E_l = \frac{P}{v} \quad \text{[J/cm]} \qquad (1)$$

For welds made were analyzed following the welds. Have been measured weld width near the piece surface and the weld depth at weld center. These were used to calculate the area of a triangular area S. On the weld footprint were measured directly using graph paper area MA of molten zone and area A of heat affected zone that including melted zone MA.

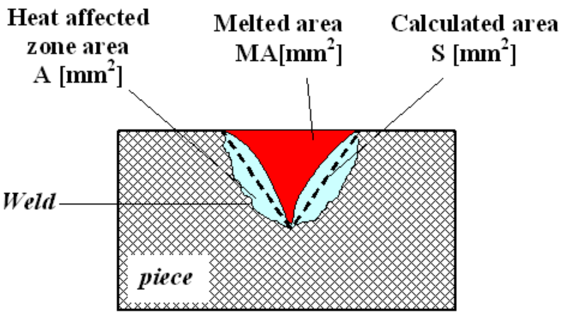

Fig. 3: Scheme variables measured on the weld cross-section

Production of melt the in material is given by the laser beam intensity at piece surface and interaction time between laser radiation and material. Values for these physical quantities are given, as general field, by the following: laser beam intensity 0.54×10^5 -10.61×10^5 [W/cm^2] and interaction time 24-480 ms.

The varied parameters laser power, welding speeds and defocusing have the following effects on molten zone dimensions:

- Laser power. Increasing the laser power produce increase the intensity on piece surface therefore melted material amount increases. From a certain value, intensity not too high melting material amount, favours material vaporization.

- Welding speed. Increases the welding speed decreases the interaction time between laser radiation and material. If the interaction time is less then the molten zone dimensions are smaller.

- Defocusing. Defocusing by lowering the focal plane within piece produce lower intensity at piece surface by increasing laser spot area at piece surface and from same issue will increase interaction time between laser and material. Table 1 shows the relationship between the values of spot diameter on the piece surface and defocusing.

Focus within piece associated with the presence of keyhole welding bath will increase the spread of radiation in keyhole and coupling of laser radiation and material. Defocusing may thus have different effects on melting material. You can not predetermine a clear trend of increasing or decreasing the molten zone. Defocusing effects will be analyzed based on experimental results.

3. VARIATIONS WITH LASER POWER

Figure 4 shows a linear increase of the melted area with the laser power. This trend is valid for all three values of defocusing. At low power defocusing $\delta = 0$ produce the largest weld melted area. At high power focus inside piece $\delta = -2\,mm$ produce higher values of weld melted area. It leads to a strong dependence on the laser beam intensity on the piece surface for melted area both by varying laser power and spot diameter on the workpiece surface.

Figure 5 shows a increase of heat affected zone area with the power for all three values of defocusing. The highest values for this area are obtained to focus at surface $\delta = 0$.It shows the increase of spaces between the regression straight lines with the increase of laser power.Increased laser power produce variations of laser beam intensity on the workpiece surface. These are highlighted for the isothermal curve vursection that separates the material unaffected by heat affected zone of weld.

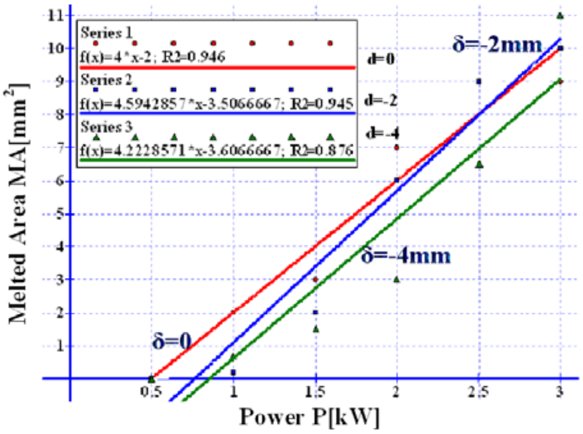

Fig.4 Weld melted area depending on the laser power at welding speed v=0,6 m/min

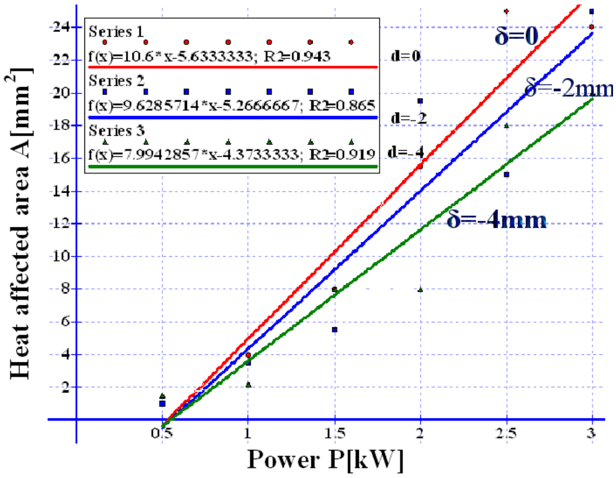

Fig.5 Weld heat affected zone area depending on the laser power at welding speed v=0,6 m/min

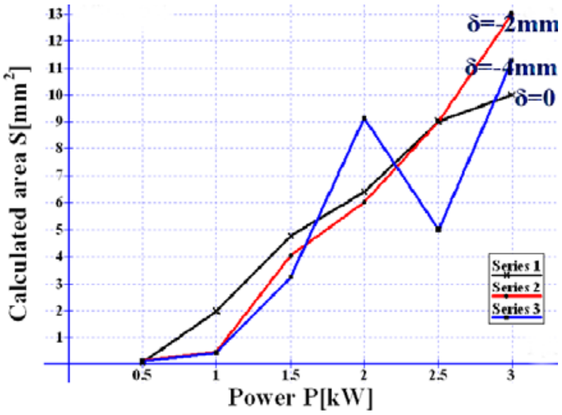

Fig. 6 Weld calculated area depending on the laser power at welding speed v=0,6 m/min

Figure 6 shows the variation with laser power for the calculated area S. There is an increase in S area with power for three values of defocusing. Higher values are for S are obtaned for focus to the surface $\delta = 0$ and for focusing in deep $\delta = -2\,mm$ variation are in a similar manner to the MA. Focusing inside piece $\delta = -4\,mm$ to produce instability in the melt zone area. These put out statements such as increased focus within the piece weld calculated area.

It is noted that experimental series where power was varied shows the same variation type for analyzed sizes MA, A and S and the three defocusing values.This increase is linear, the regression lines slopes close for the three values of areas analyzed.

4. VARIATIONS WITH WELDING SPEED

Figure 7 shows the variation for melt area MA with welding speed.

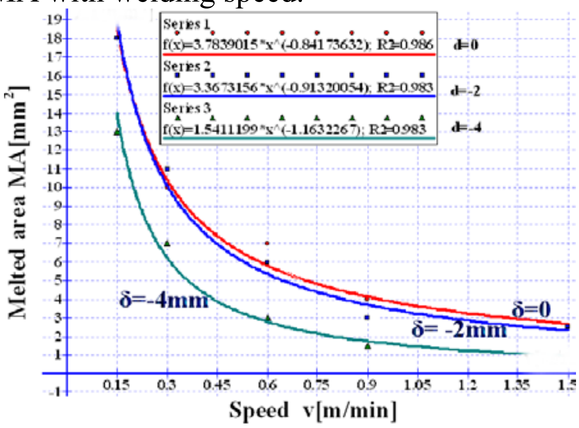

Fig. 7 Weld melted area depending on the welding speed at laser power P=2kW

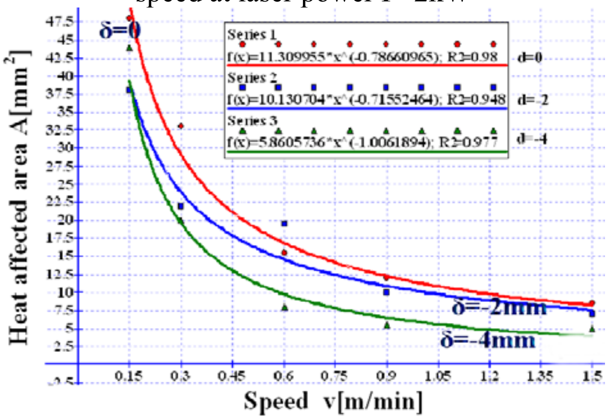

Fig. 8 Weld heat affected zone area depending on the welding speed at laser power P=2kW

There is a logarithmic decrease in the melted area with the welding speed for three values of defocusing. Higher values for melted area MA were obtained for the focus to the surface $\delta = 0$ and inside piece $\delta = -2\,mm$. For experimental series with speed variation does not varied the laser beam intensity on the piece surface. Effect of focus within the piece area is rendered more powerful at lower welding speed.

Figure 8 shows the variation of heat affected zone area A with welding speed. There is a logarithmic decrease of A area with welding speed. It is noted that the focus within the piece at $\delta = -2\,mm$ has an effect close to the focus $\delta = -4\,mm$ at the beginning of the experimental field and close to the $\delta = 0$ at the end of experimental field .This indicates an efficient transfer of heat in the material provided by the focus is inside the piece and welding speed is high. This trend is more being evidenced by a isothermal at temperature lower than melting temperature.

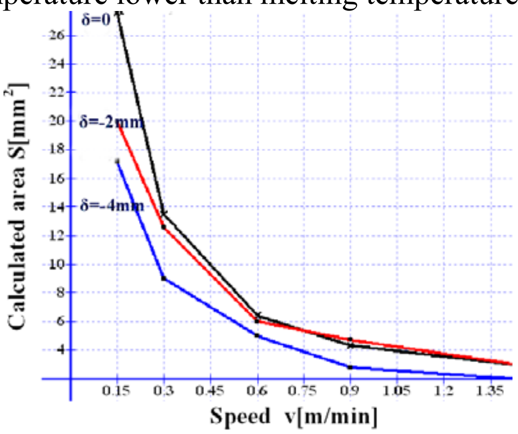

Fig 9 Weld calculeted area depending on the welding speed at laser power P=2kW

Figure 9 shows the variation of calculated area S with the welding speed. There is a tendency to decrease the sectional weld calculated area with welding speed. The highest values are obtained for the focus to the surface $\delta = 0$ and inside the piece.

The variations are similar to those produced for the size MA. For the three values analyzed MA, A and S there is a similar behavior in terms of variation of welding speed. This is the type of logarithmic decrease.

5. VARIATIONS WITH LINEAR ENERGY

Figure 10 shows a linear increase in the area of the weld molten zone with linear energy. Aria MA is higher to focus on the surface $\delta = 0$ and in piece deep $\delta = -2\,mm$. For these cases the laser beam intensity was higher compared to that of $\delta = -4\,mm$

Figure 11 shows a linear increase for area A with the linear energy. In this case the effect of high intensity at the surface is much stronger. It looks like that with decreasing temperature obtained isotherm of material structure change given the effect of main heat source represented by the laser beam becomes more pronounced.

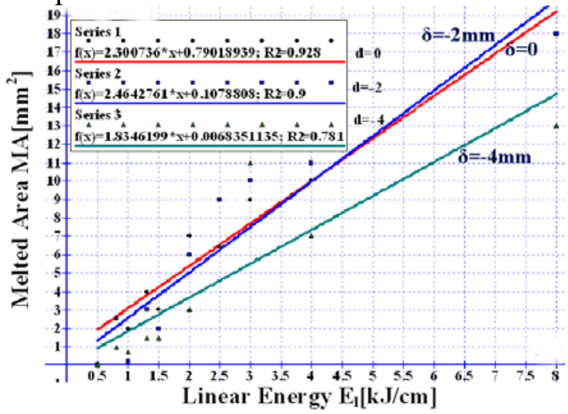

Fig. 10 Weld melted area depending on linear energy

Figure 12 shows a linear increase of the calculated S area with linear energy. It is noted that the increase complies with most of part the experimental field order intensities at piece surface. Higher values are obtained for the laser focus at the workpiece surface $\delta = 0$.

All three types of areas considered to show the same type of linear increase. The slopes of regression straight lines are close. Thus all three sizes can be used to characterize the weld cross section MA is less sensitive to the value of laser intensity on the surface while maintaining the high values.

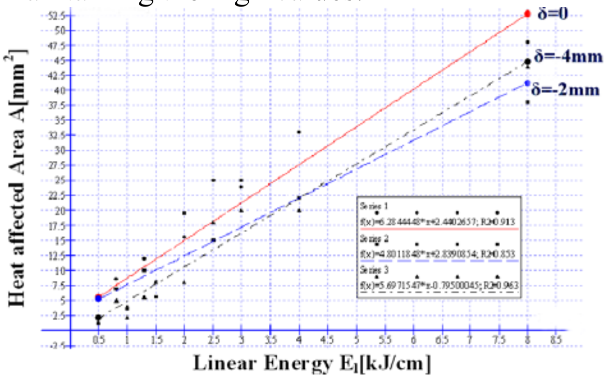

Fig.11 Weld heat affected zone area depending on linear energy

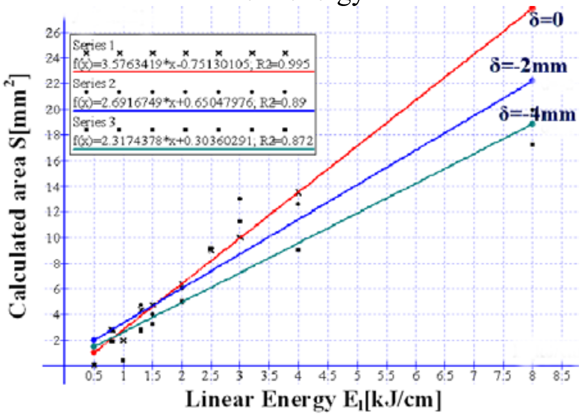

Fig. 12 Weld calculated area depending on linear energy

Contrary A is less sensitive to low values of laser intensity on the piece surface. S area has a average size effect compared with the two sizes discussed above. This has a balancing effect for the three defocus values, respecting the laser intensity decreases

3. CONCLUSIONS

The paper addressed three different ways to treat the cross-section area for welds. It was shown that the variation of the three areas expressed in way similar parameters effects. Selection between these sizes to characterize the weld cross section will be according to a particular purpose. Highest thermal effects are obtained for the laser beam focus on the workpiece surface $\delta = 0$. In this case the laser beam intensity at the workpiece surface was maximum. Generally considered the areas decrease with the focus within the piece and from that with the laser beam intensity to the workpiece surface.Defocusing at present has a closer effect to the $\delta = 0$ when the size is associated with production of the melt. It shows that for $\delta = -2\,mm$ the increasing amount of melt is produced. It is recommended to use defocus for making welded joints

REFERENCES

1. Jose Roberto Berretta, Wagner de Rossi, Maurıcio David Martins das Neves, Ivan Alves de Almeida, Nilson Dias Vieira Junior *Pulsed Nd:YAG laser welding of AISI 304 to AISI 420 stainless steels*, Optics and Lasers in Engineering 45 (2007) p:960–966..
2. M. Schmidt, A. Otto, C. Kageler, *Analysis of YAG laser lap-welding of zinc coated steel sheets*, CIRP Annals - Manufacturing Technology 57 (2008) p:213–216.
3. John C. Ion *Laser Processing of Engineering Materials Principles, Procedure and Industrial Application* Elsevier 2005 .
4. Tom Kugler and Mohammed Naeem *Material Processing With Super-Modulation* ICALEO 2002..
5. Cheolhee Kim, Junghak Kim, Hyunsik Lim, Jeonghan Kim, *Investigation of laser remote welding using disc laser journal of materials processing technology* 201 (2008) p:521–525.
6. Xiu-Bo Liu, Ming Pang, Zhen-Guo Zhang, Wei-Jian Ning, Cai-Yun Zheng, Gang Yu *Characteristics of deep penetration laser welding of dissimilar metal Ni-based cast superalloy K418 and alloy steel 42CrMo*, Optics and Lasers in Engineering 45(2007) p:929–934..
7. W.J.Han, J.G.Byeon, K.S. Park, *Welding characteristics..*, Journal of Materials Processing Technology 113(2001) p:234-236.