

ANALYSIS METHOD OF SURFACES AND SECTIONS FOR LASER WELDS

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ABSTRACT Laser welding process is controlled by variation of power, welding speed and defocusing. There is a study of variations for melted area on the weld section and crater area obtained at the end of welding. In laser welding phase transformations occur as melting and vaporization. The study presents a method of comparing the two phase transformations. It shows two-dimensional effect of the phase transformation from correlation between the melted area on the weld section, generated by melting and solidified after welding, and crater area at piece surface obtain at end of welding process. A analyze the significance of linear and quadratic correlation formulas is made. It discusses the thermal phenomena present in laser welding.

KEYWORDS: Laser keyhole welding, metal melting, metal vaporization, thermal conduction

1. INTRODUCTION

In the study of phenomena that occur in laser welding is an important aspect is physical appearance. This is related to phase transformations, melting and vaporization. The uses of high laser intensities lead to the simultaneous presence of melting and vaporization in the keyhole welding regime. The conditions of occurrence of melting and vaporization related to the intensity of the laser beam are presented in work [1] and [2]. For keyhole laser welding system for the main effect is the melting material, but vaporization is the first effect occurs in the material. It will propose a comparative study of the effects of melting and vaporization. The molten weld area, measured on weld section was identified as a result of melting. As a result of vaporization was identified crater area which is obtained at the end of welding. Crater which is obtained at the end of welding is the result of vaporization and movement of melt. Crater area on the piece surface can be considered a direct effect of vaporization. Through this identification are associated phenomena of melting and vaporization with structures that can be identified in the final weld. The method of analysis is carried out by polynomial correlations formulas between weld melted area and crater area. Was watched the type of correlation obtained. This was a part of a comparative analysis between weld section and weld surface.

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 $\leq 0.16\%$). 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 100×130×10 mm for which were made between 5 and 8 welds, with a distance of over 10 mm between welds.

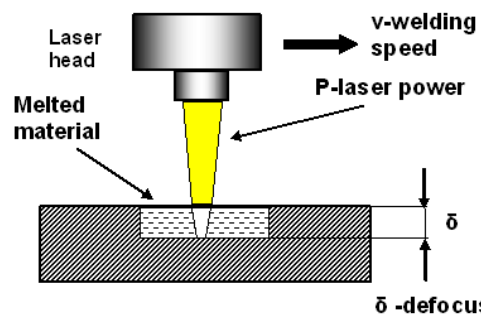


Fig. 1 Experimental parameters for welds

In experiments was varied the laser power, welding speed and distance between focal plane and piece surface (defocusing or defocusing depth, figure 1). Welds were cut in

the stable part of the weld near the place where welding process was stopped. Melted area was measured directly by its footprint. Crater area produced end welding process was measured indirectly using images of the crater.

Experimental plans contained classical experimental series. They have been used to link by functions the crater area and melted area under variation of all parameters or variation with maintenance some of them constant. Was been made a factorial experimental plan type 2^3 . Based on this was done on a hierarchy of parameters effects and interactions between parameters effects for crater area and melted area on weld section.

3. ANALYSIS OF CHANGES

In the following we perform a comparative analysis of the crater shape obtained at the end of the welding process and the molten weld section shape according to parameters variations.

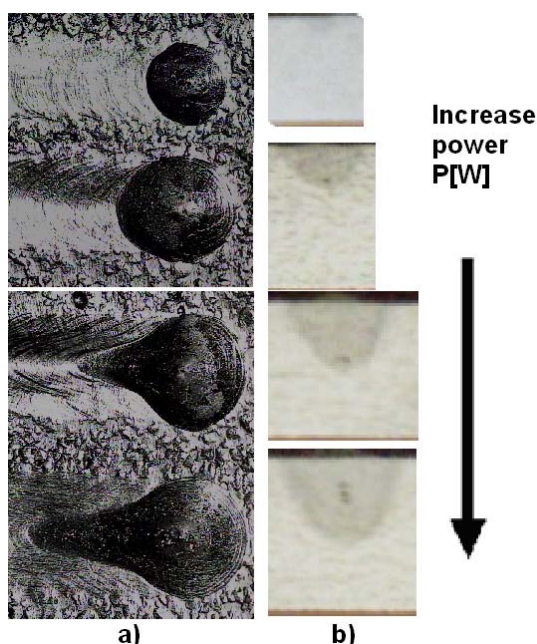


Fig. 2 Related images a) crater and b) weld melted area for power variation

Figure 2 shows that the crater shape changes with increasing laser power. It change from a circular to an oval and then to an elongated form like teardrop [3]. Crater area increase and is accompanied by increased weld ascent. Weld sectional area evolves from a hemispherical shape characteristic of conduction welding regime

under a specific oblong shape under keyhole welding regime. As a shape weld section can be compared with the back of the crater (to the welding, welding the opposite direction) shape. Section area, melted area and heat affected zone increases with power.

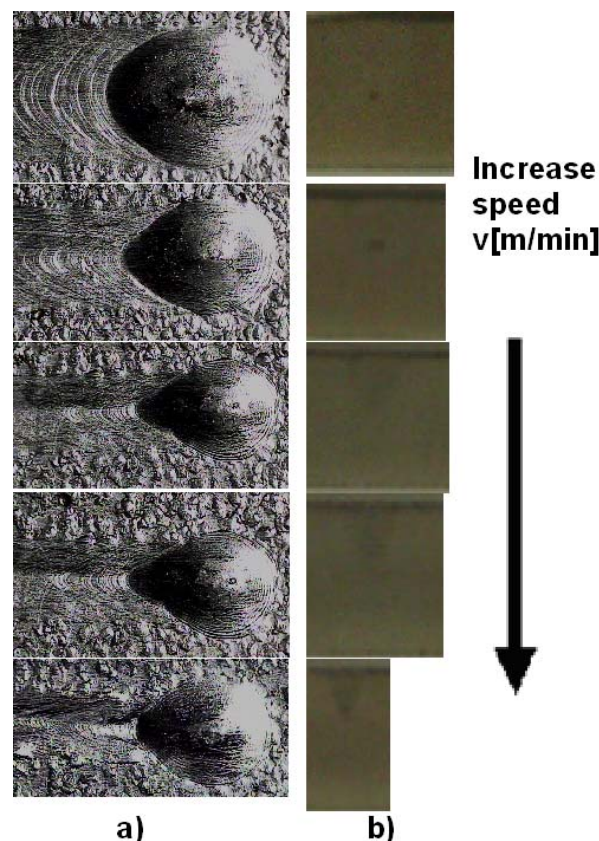


Fig. 3 Related images a) crater and b) weld melted area for speed variation

Figure 3 shows that with increasing welding speed crater retains the same shape but his area decrease. The same behavior has weld section. Increasing the welding speed decreases the weld section area but keep the same shape. Welds presented are in keyhole welding regime.

Figure 4 shows the defocusing effect for welds at same power (high value in experiments). Welds shows a keyhole welding regime. There is a decrease in crater elongation and weld penetration. This is due to lower laser intensity at piece surface.

In previous figures we see that main types of shapes for melted area on weld section and crater are given by laser power. Speed and defocusing have direct influence on the size of melted area and crater surface.

Interpretation of parameters influence on the melted area and the crater area based on measured values is shown in Pareto charts

(figures 5 and 6). They show direct effect of parameters (A), velocity (B) and defocusing (C) and also effects for interactions between them as products of these. For melted area AT figure 5 shows an increase with power and decreases with welding speed. Interaction between power and speed decreases melted area. Also the interaction between power, speed and defocusing decreases the melted area.

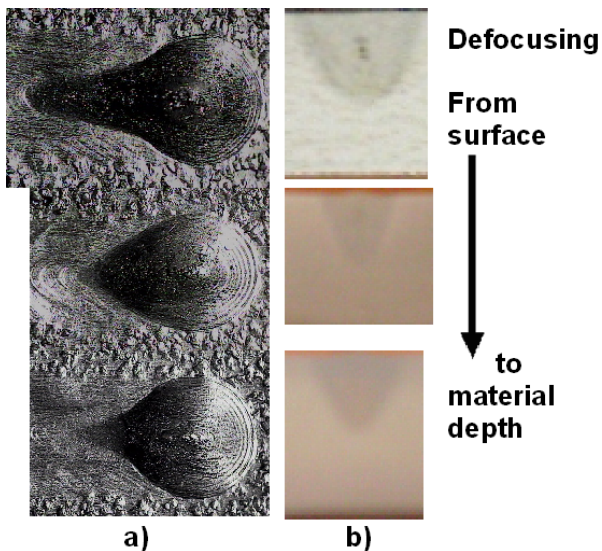


Fig. 4 Related images a) crater and b) weld melted area for defocusing variation

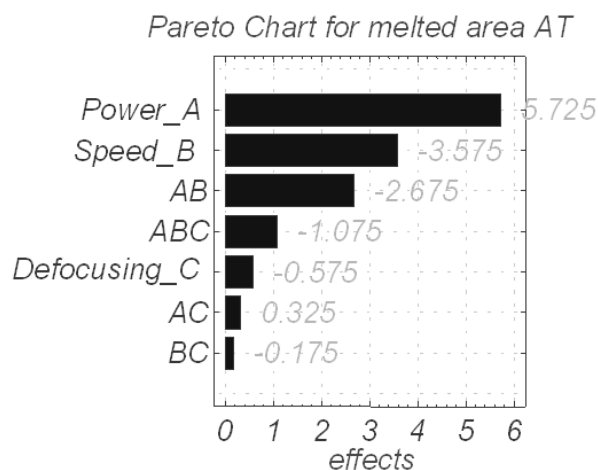


Fig. 5 Pareto chart for melted area

The overall effect of increasing the melted area due the power is lower than decreasing with defocusing and his interactions. The interaction of three factors of influence is stronger than the defocusing effect and its interaction with power and speed in part. This shows that defocusing is a influence factor with less importance in the control of melted area.

Figure 6 shows that the crater area increases sharply with power. Defocusing has a increase effect on crater area. But this is less. This is due by the fact that experimental plane containing the weld under the conduction and keyhole welding regime. Speed and defocusing led to the presence of individual effects (inclination of the keyhole front wall and multiple reflections increased coupling of energy between laser radiation and material). Opposite effect, decreasing the crater area is achieved by interaction between speed and defocusing and the interplay of three factors. This along with power generated increased shows the main effect that on the crater area is given by laser intensity. Although the defocusing effect is small but its interactions have a significant effect.

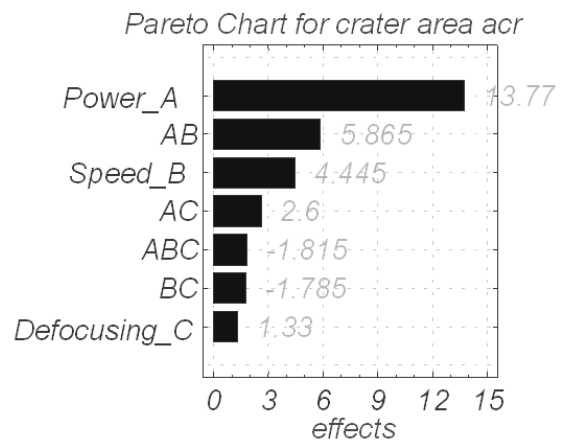


Fig. 6 Pareto chart for crater area

Of the previously shown result that the laser intensity, controlled mainly by power, is the main effect of both the molten weld area and the crater area. Defocusing effect is stronger on the crater area than the melted area.

4. CORRELATION FUNCTIONS

This paragraph has studied the correlation between the crater area $x = acr$ [mm²] and weld-sectional area $y = AT$ [mm²]. Both sizes are one area, a two-dimensional feature of weld. Sectional area can not be easily obtained because it requires cutting the weld. It is so interesting if it can be predicted by study of a similar size (one area) measured on the surface of weld.

Correlation study was carried out using a) all experimental data (varying power, speed and defocusing), b) for series of same

defocusing characterized (varying the power and speed) c) the series at constant speed (varying the power) d) series at constant power (varying the speed). It was intended to use some types of simple correlations. If there is a linear correlation can be said that the two areas have a similar way of training. Was studied the correlation coefficient for each of the cases discussed above. For each case presents the significance of variables, the formula of correlation and correlation coefficient.

a) Correlations function between the melted area and the crater area using all measurements. It is given by the following relation:

$$y = 0.499 \cdot x + 0.223 \quad R^2 = 0.51 \quad (1)$$

Obtained correlation is weak. It looks like that, in cases of the arbitrary variation of process parameters, the two quantities are not correlated.

b) Correlation functions between the melted area and the crater area for the experimental series characterized by the same defocusing. Were obtained the following results:

For defocusing $\delta = 0$ mm

$$y = 0.802x + 0.184 \quad R^2 = 0.75 \quad (2)$$

For defocusing $\delta = -2$ mm

$$y = 0.013x^2 + 0.459x - 0.921 \quad R^2 = 0.96 \quad (3)$$

For defocusing $\delta = -4$ mm

$$y = 0.047x^2 - 0.253x + 0.545 \quad R^2 = 0.91 \quad (4)$$

It notes that the same defocusing conditions between the two sizes are a correlation. Correlation coefficient increases for the series which focus within the piece.

Although it is quadratic correlation is observed that the magnitude coefficient of the 2 degree term is small in comparison with that of the 1 degree term. This means a phenomenological similarity of the production of the two surfaces.

c) Correlation functions between the molten area and the crater area at constant speed. Were obtained the following results:

For speed $v = 0.6$ m/min, and defocusing $\delta = 0$ mm :

$$y = 0.098x^2 + 1.731x - 0.424 \quad R^2 = 0.48 \quad (5)$$

For speed $v = 0.6$ m/min and defocusing $\delta = -2$ mm :

$$y = 0.757x - 1.668 \quad R^2 = 0.94 \quad (6)$$

For speed $v = 0.6$ m/min and defocusing $\delta = -4$ mm

$$y = 0.028x^2 + 0.05x + 0.266 \quad R^2 = 0.85 \quad (7)$$

It shows that for focus on the surface the two quantities are not correlated. On weld section (melted area) increasing power has a specific effect is a transition of a shape from semicircle to oblong as they transition from conduction regime to regime keyhole. This progress is expected. Crater area is affected by melt flow. This produces a less predictable effect. With the power level increase become more difficult to have a correlation between crater area and melted area. This explains why the correlation for focusing in depth is better than to focus on the surface. For these cases the intensity decreases.

d) Correlation functions between the melted area and the crater area at the same power. Were obtained the following results:

For power $P = 2$ kW, and defocusing $\delta = 0$ mm:

$$y = 0.989x - 2.86 \quad R^2 = 0.96 \quad (8)$$

For power $P = 2$ kW, and defocusing $\delta = -2$ mm:

$$y = 0.863x - 3.671 \quad R^2 = 0.96 \quad (9)$$

For power $P = 2$ kW, and defocusing $\delta = -4$ mm

$$y = 1.08x - 7.468 \quad R^2 = 0.96 \quad (10)$$

It is noted that the use of constant power is obtained for all cases formulas with linear correlation and high correlation coefficient.

There is a linear or nearly linear correlation between the melted area on section and crater area where the intensity (directly dependent on power) is low. Also good correlations are obtained when the speed is kept constant. No good correlations are obtained when the power is high. One can say that the correlation between the two quantities is linear. It is confirmed that the emergence of two areas the same way to obtain. They appear both due to a combination of melting and vaporization phenomena. This type of correlation indicates that two types of surfaces are obtained by similar processes.

5. DISCUSSIONS

The following will present a discussion of the thermal phenomena involved in laser processing. Theory of heat is the main tool in the quantitative study of phenomena that occur in laser irradiation of materials. In the following we present the main aspects of the theory of heat applied in the study of laser welding.

Laser beam and electrons beam are thermal sources that are capable of high heat flux density. These heat flux densities held laser processing such as welding, drilling, cutting and milling laser.

Processing of materials subject to such machining a large class is a metal. Absorption of laser radiation in material produces a heat source in it. This generates material heating and phase change (melting and vaporization), physical phenomena that can be called by thermal nature. Another category of mechanical phenomena that occur are material ablation (broken solid state), the melt movement and vapor movement. These phenomena can be described as thermo-mechanical because the driving force generates them is represented by a temperature gradient). To these are added, to ceramics and polymeric materials, the chemical decomposition and at high heat flux density material ionization. The heat flux densities mentioned all these phenomena occur almost simultaneously, their spatial and temporal delineation very difficult to realize.

The phenomenon of thermal heating of the material is first taking place and its production is subject to all other phenomena. Heating can be described by applying the heat equation. This is an equality between the heat received by a unit volume, heat stored, and transferred from it. From the results of the heat equation is retained the surface temperature. All phenomena that follows the heating can be considered as phase transformation and characterized by size called latent heat. There are three phase transformations which can be classified as thermal phenomena: heating the material at a constant temperature difference, the melting material, and material vaporization. There is a combination of these types of events defining the full phase transformation. Thus all the phenomena that occur from heating the material to its vaporization can be characterized by a single value of latent heat.

The mechanical phenomena, chemical decomposition, break solid state, melt and vapor movement is related to it being interpreted as phase transformations. On the theory to address separately the two types of thermal phenomena: the heating and phase transformation. In laser material processing there are a few questions related to phase transformations that occur and the effect actually produced on the material (eg: extension of molten zone). Process control is done by adjusting the two parameters: laser intensity I , (a part of this is absorbed in material and can be described as a heat flux density) and interaction time. Although experimental conditions can be varied ultimately in these physical size makes issues about effect of laser radiation. Laser intensity determines what events occur during the interaction between laser and material and gives the spread of phenomena. The first predictions will be based on heat flux density that they will be followed by those related to the time of interaction.

To get an overview of phenomena that occur have to change the approach to problems. Usually thermal phenomena are considered in order of their development over time: heating, melting, vaporization.

This approach, however, is incomplete because the order phases transformation is not clear default (can take place sublimation of solid material), and on the other hand can not consider phenomena related to melt and vapor movement and possible chemical reactions taking place.

The alternative to this approach is the consideration of a single phase transformation characterized by a single latent heat L . This will include the sum of latent heats at constant temperature for heating, melting, vaporization, melt and vapor movement and possible chemical reactions taking place. This phase transformations will be put directly related to heat flux density q generated by the laser beam. This phase transformation is characterized by a constant temperature produced in the material. This is the temperature which can generate by laser material, in a meaningful way. It will not be associated with a particular time and the positioning of the surface for heat source. This approach provides flexibility in designing the thermal phenomena that occur for a particular process. The proposed method

considers a single full latent heat for a process of irradiation.

Formulation of thermal problems only on heating leads to distorted picture of phase transformations. So the idea is that for a given radiation first heats the material, then melt, melt moves, then melted material is vaporized and there is a vapor movement. Between the occurrences of each phase transformation is a period of time. This is true but the times that make the difference between them is 100 times smaller than the real interaction time. In this situation the full phase transformation thermal phenomena consider all phenomena simultaneously without distinguishing between times of their occurrence.

The simultaneous consideration of thermal phenomena contains the idea of conditioning (eg: the material will be uniformly heated to melting temperature before they melt) and on the other hand the idea of simultaneity (eg: once melt is produced it moves).

6. CONCLUSIONS

In this paper was studied the crater area which is obtained at the end of welding and molten area of the weld. They are considered as separate effects of the phenomena of vaporization and respectively melting. It was shown that the laser intensity on the surface of the piece is the main effect on the two areas. It was shown that the between of the

two areas are linear correlations. The term of second degree is small. The type of linear correlation shown similar effects of melting and vaporization, as phase transformations. Good correlations were obtained for the situation where defocusing remains constant. There is a general discussion about thermal phenomena in laser welding.

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