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Influence of electrical Field on Pulsed Laser beam welding of Stainless Steel (304)

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Abstract

Pulsed laser beam welding experiment were carried out on stainless steel (SUS 304), using vertical and horizontal electric fields of different intensities to study its effectiveness on the welding process, regarding depth and weld quality. Pulsed Nd: YAG laser emitting 10 ms pulses in the TEM_{00} mode at 1.06 μm wave length was employed, microstructure of welded zone and defect were investigated using optical and scanning electron microscopes. Tensile test and microhardness measurements were carried out to evaluate the weld quality. Welding by this method increased the efficiency tremendously and a depth increase of 85 % was achieved.

1. Introduction

Different methods have been recently reported to enhance the pulsed laser beam welding of stainless steel alloys under different operating parameters such as beam focusing, pulse duration, polarization, power density, welding speed, pulses repetition rate, shielding gasses,...etc.[1,2,3].

In the present work, a new technique has been developed to achieve deep and efficient Nd:YAG pulsed laser beam welding of stainless steel (SUS 304) with constant energy (10J-12J), while applying a variable vertical or horizontal electric field to the specimen. The external electric field is exerted vertically opposite to the laser beam direction and horizontally perpendicular to the laser beam direction.

1.1. Principle and process parameter

In both the mentioned cases the strength of the field will force the free electrons of the specimen to migrate toward the opposite direction of the field, and then reduce the electrical conductivity of the surface to a certain value that satisfies the condition:

$$f \ll \frac{\sigma}{2\pi\zeta\zeta_0} \tag{1}$$

in order to insure heavy absorption of the laser beam by the metal [4]. Here, f is the frequency of the laser beam $(H_z)\sigma$ is the electrical conductivity of the metal (s/m): and $\zeta\zeta_0$ are the electrical permittivity of metal and vacuum, respectively (F/m). The reduction of electrical conductivity σ will help to increase the skin depth δ (μm), which is defined as [4]

$$\delta = (\pi \sigma f \mu \mu_0)^{-1/2} \tag{2}$$

where $\mu\mu_0$ are the magnetic permeability of metal and vacuum, respectively (H/m). The electric field amplitude of the laser beam diminishes over a distance δ, and most of the laser heating occurs within a small multiple of this distance [5], Therefore, applying external electric field can improve the absorption at the specimen surface and increasing the propagation distance of the laser beam inside the metal. Moreover, it has been proved that the absorptivity of the metal is proportional to the square root of its electrical resistivity (Ωcm) [6]. However, the enhancement of welding could be attributed to the increase of energy stored in the electric field of the laser beam in association with that of the external electric field, and may be attributed to the increased absorptivity of the specimen. Additionally, applying an electric field can help reduce the attenuation of the laser beam caused by the plasma over the welded zone which is presumed to scatter the beam and defocus it [7].

The electric field, with the aid of shielding gasses like argon and nitrogen, increase the laser-metal coupling by enhancing the surface absorption. This process thus allows a large increase of welding depth. A comparison between welding with and without electric field under different conditions is shown by a number of diagrams and photographs in this paper.

2. Experimental Details

10 ms pulsed Nd: YAG laser in the TEM_{00} mode was used to weld two pieces of (SUS 304) under the effect of the electric field in different positions as indicated in A, B and C in Figure 1. A positive objective lens of 8 cm focal length was used to focus the laser beam 1 mm below the surface of the specimen. Welding is performed each time at incremented values of the electricfield under various conditions. The electric field is controlled by a variable de voltage (0.5kv-10kv) source. Two kinds of shielding gasses (nitrogen and argon) have been used separately at the same flow rate and jet angle to control the throwing power and to diminish the likelihood of a spark which could occur between the parallel plates of the electric field. The output energy of the laser beam was 10.5 J with nitrogen and 11.5 J with argon. Cross section area of the welded zone have been investigated using optical and scanning electron microscopes, and tensile test and microhardeness have been carried out.

3. Experimental Results and Discussion

Examination ofthe cross sectional area of different welded zones shows that pulsed laser beam welding is greatly affected by the electric field. Comparing to welds performed without external electric field, welds carried out with the arrangement shown in Figure 1a without shielding gas exhibited a 75% increase in weld depth; with the arrangement in Figure 2b and 1c and using nitrogen shielding gas, weld depth increased 73% and 78%, respectively. For each case the laser pulse energy was 10.5 J. Theeffect ofthe external electric field on the depth for each case is shown in Figures 2, 3 and 4.

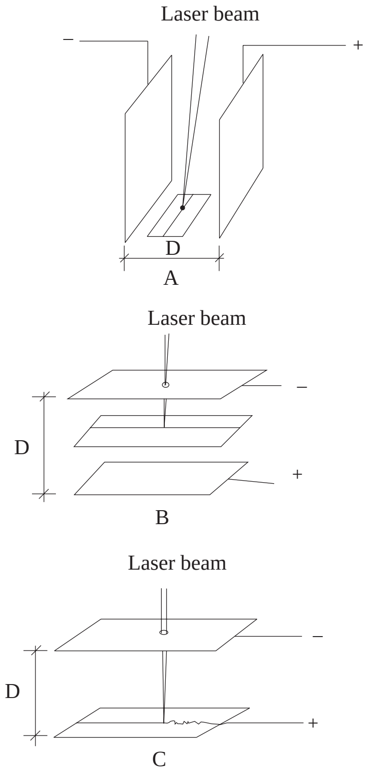

Figure 1. Shown the arrangement used in jelding process A) electric field is horizontal to the specimen. B) electric field is vertical to the specimen in opposite direction of laser beam. C) electric field is vertical to the specimen in opposite direction of laser beam but the specimen is the anode.

Metallugraphic examination of welded specimens showed that:

1. Arrangement (A) was associated with a defect-free weld zone, with the welded zones found to be a little bitwide than welds produced in arrangemet (B) and (C) due to the sideways effect of electric field.
2. Welded zone due to both arrangement (B) and (C) is associated with hot cracks and porosities, as shown in Figures 5 and 6.

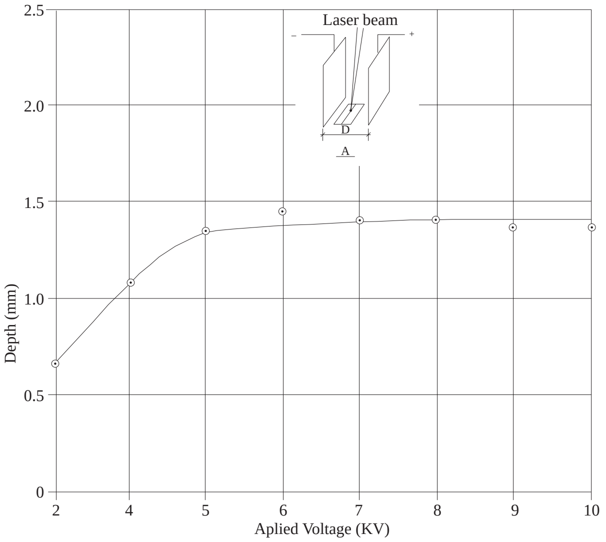

Figure 2. The effect of the applied electric field on weld depth using arrangement (A) without shielding gas at 10.5 J.

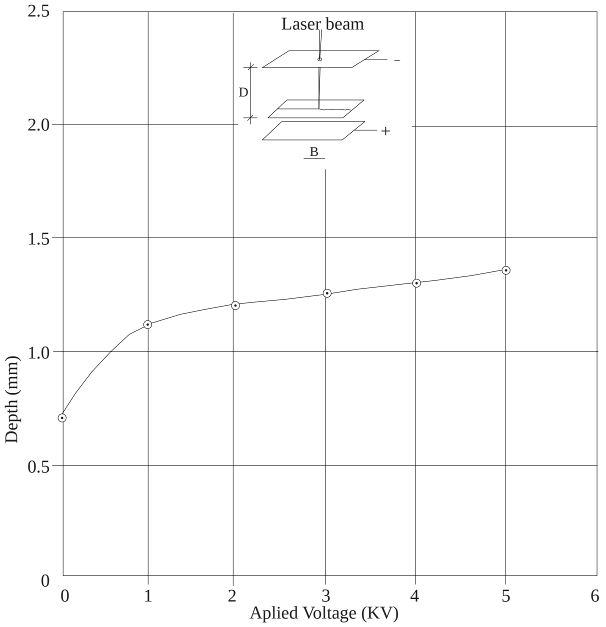

Figure 3. The effect of the applied electric field on weld depth using arrangement (B) without shielding gas at 10.5 J.

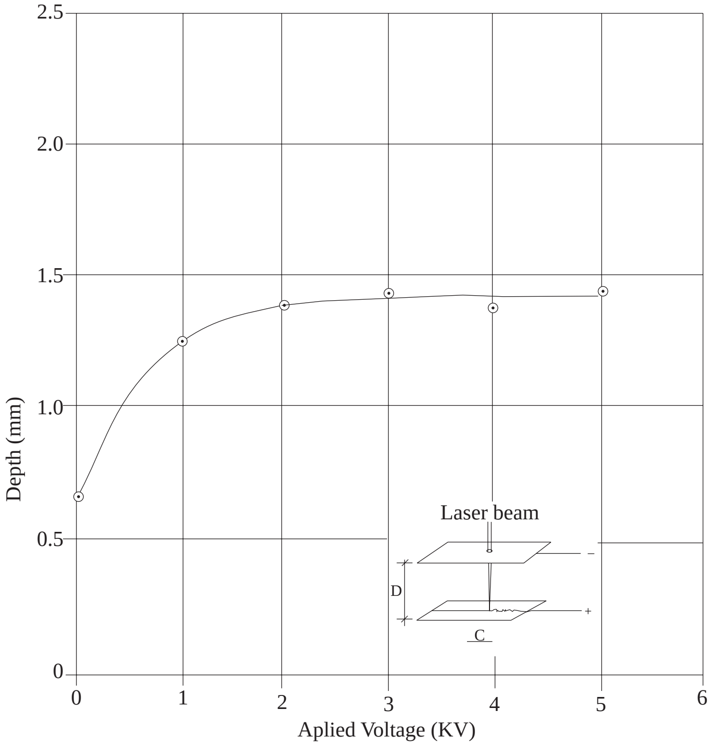

Figure 4. The effect of the applied electric field on weld depth using arrangement (C) with nitrogen as a shielding gas at 10.5 J.

Figure 5. Scanning electron micrographs of hot cracks in welded zone.

Figure 6. Scanning electron micrographs of porosities in weided zone.

Using argon as a shield gas allows higher laser beam energy to be used, because it is associated with higher ionization potential, as was the case for arrangement (c) in which deep and defect free weld were achieved, as illustrated in Figure 7. Microphotographs showing examples of such welds whose weld depths increased (up to 85%) with electric field intensity, can be viewed in Figure 8.

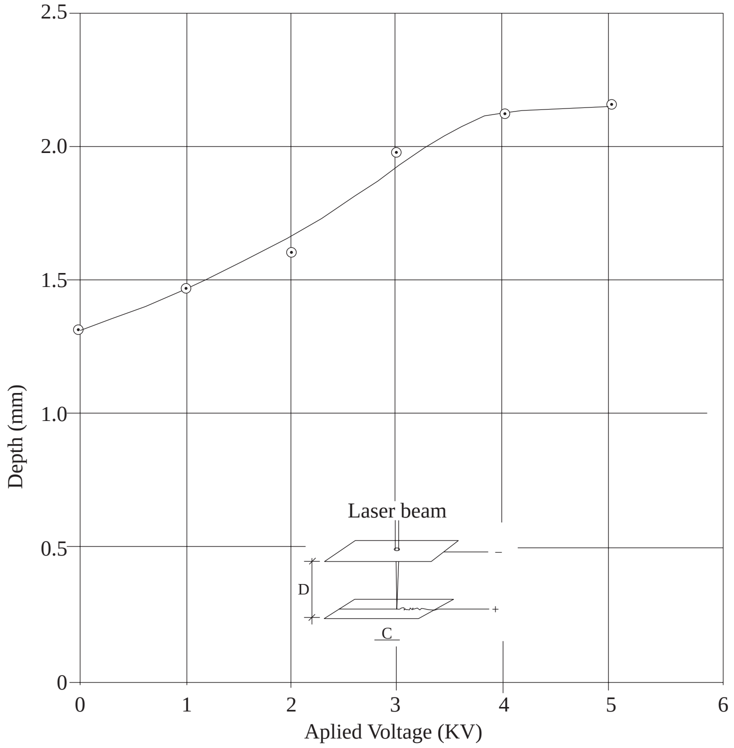

Figure 7. The effect of the applied electric field on weld depth using arrangement (C) with argon as a shielding gas at 11.5 J.

In all the above cases there is an optimum field value at which the weld depth can reach its maximum value for a certain laser beam energy.

Microhardness was measured at three depths (Figure 9). Hardness profiles showed that the maximum hardness developed in the fusion zone and there was a step hardness gradient in the heat affected zone (HAZ). A tensile test shows that the failure was in the parent metal and the laser weld was stronger than the parent metal but showed good ductility. Figure 10 shows the stress strain carves for the base and welded specimen.

From these results it is clear that the use of an electric field has a fundamental effect in enhancing pulsed laser beam welding by increasing the absorptivity of the metal or by increasing the energy of the laser beam in association with the external electric field to improve the effectiveness of the laser energy within the metals.

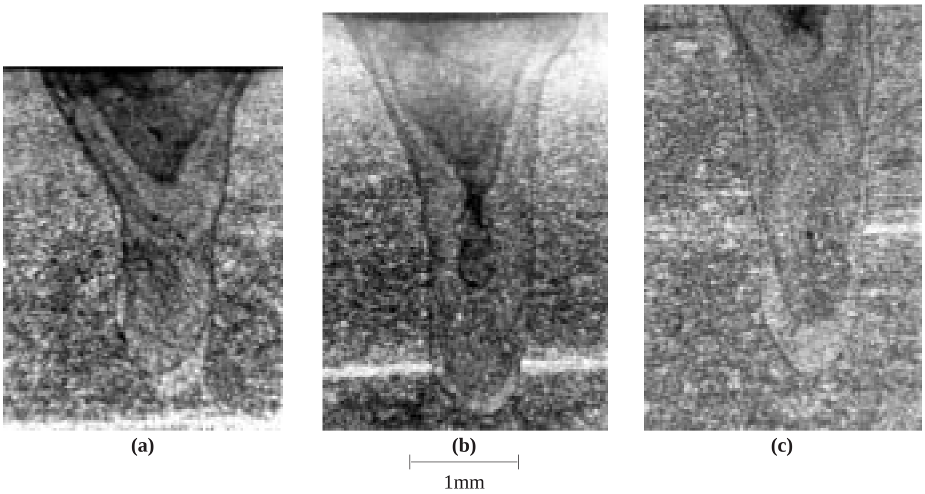

Figure 8. Microphotographs to show the defect free weld dept increase with electric field intensity increase (a) without electric field (b) with electric field caused by 3kv and (c) with electric field caused by 5kv.

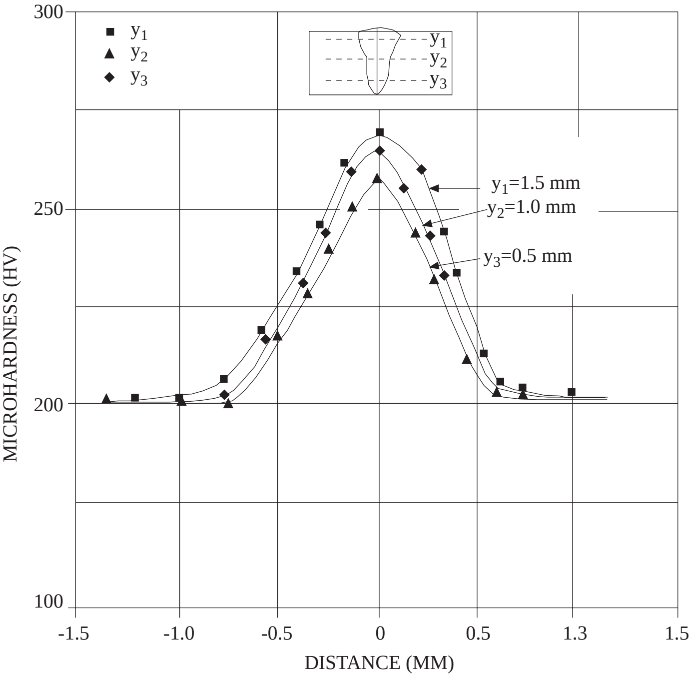

Figure 9. Transvers microhardness of welded zone of (SUS 304) using arrangement (C) with argon as a shielding gas at 11.5 J.

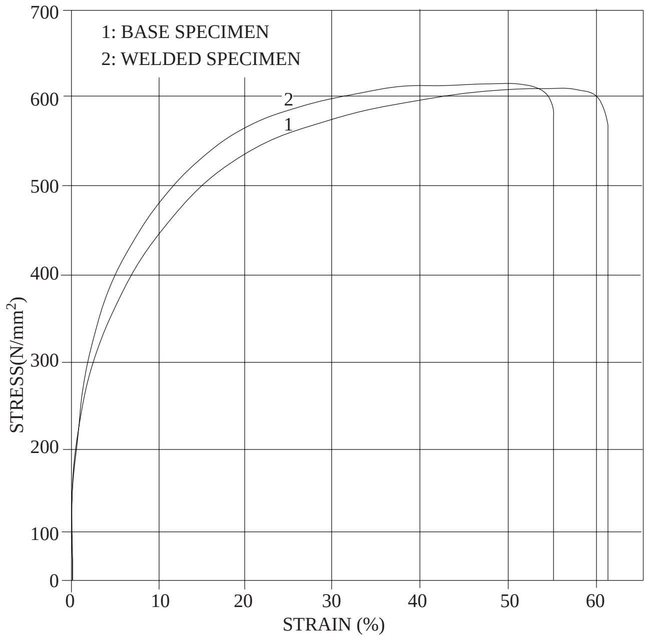

Figure 10. Stress-strain curves of base and welded specimen

4. Conclusion

Pulsed Nd: YAG laser beam weld depth is greatly affected by external electric fields with or without shielding gasses, in horizontal or vertical arrangements. From the results it could be concluded that:

1. The weld depth increases with increase in electric field intensity.
2. There is an optimum value of the field at which the weld depth reaches a maximum value.
3. Proper arrangement and shielding gas could enhance the weld together with the electric field.

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