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KEYHOLE FORMATION DURING LASER WELDING

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Abstract: *In this paper a short description of the keyhole effect in case of laser welding is made. Several aspects of the proprieties of the keyhole and the influence over the weld bead are considerate. The geometry of the weld bead of austenitic stainless steel is also investigated.*
Key words: *Laser welding, keyhole, austenitic stainless steel*

1. INTRODUCTION

Laser beam welding is a welding technique used to join multiple pieces of metal through the use of a laser. The beam provides a concentrated heat source, allowing for narrow, deep welds and high welding rates. The process is frequently used in high volume applications, such as in the automotive industry.

An important mechanism in laser beam welding is the interaction of the laser beam with the material. This interaction mechanism is influenced by many parameters such as: the laser power *P*, the intensity distribution I of this power at the surface, the welding speed *v*, the material properties and the wavelength of the laser radiation λ.

2. KEHOLE EFFECT

In order to perform the welding process, the minimum energy needed is of 10^6 W/cm^2 where the diameter of the beamer represents 30% of the part thickness.

The diameter of the laser beam used for the welding process generally varies between 0.2…1 mm, with a reference value of 0.3 mm. For the geometry of the elements, usually the lap joint is used, and only seldom the add-on material. Lap welds melt a lot of metal to produce a small connection, but they have a much larger tolerance on position than butt welds (Pascu et al., 2009, a). As relative motion between the beam centerline and material occurs, the molten metal flows around from the front of the keyhole and solidifies at the back, forming a laser weld (Fig. 1). By traversing the beam relative to the workpiece, a narrow weld bead is formed with a high aspect ratio (depth/width), illustrated in Fig. 2. (John, 2005)

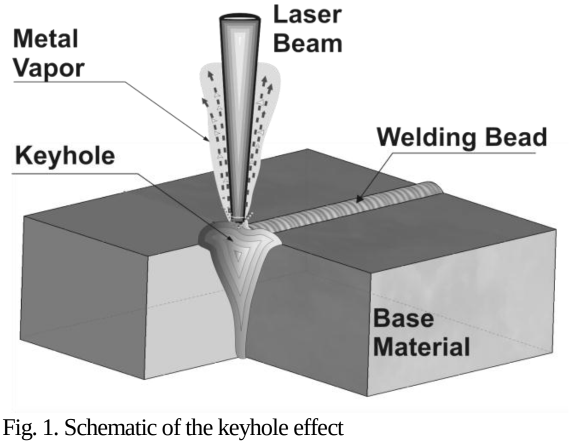

Fig. 1. Schematic of the keyhole effect

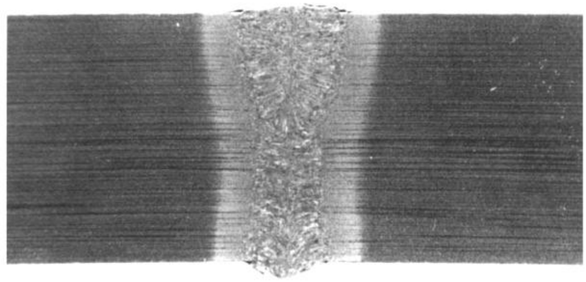
Fig. 2. Transverse section through a full penetration keyhole weld made in a carbon–manganese steel of thickness 6mm using an Nd: YAG laser beam

The keyhole phenomena induce in metal bath an irradiation effect wich will provide the energy needed to vaporize the base material. The heat transfer process at the interface between the solid-liquid phase involve beside the thermal conduction also the convection effect due to the movement of the melted metal into the metal bath. Only the vapour presence combinated with thermal conduction and convection effect will provide a deep penetration of the welding.In laser welding the keyhole effect produce two major consequences:

- The energetic transfer between the laser radiation and the material is higher becaude the laser radiation is propagated trough the keyhole channel and it is absorbed directly inside the material.
- The heat souce will generate sudden variation in time and space of the material themperature and powerfull evaporation will occure. The rapid vaporasion will generate an increasing pressure wich facilitate the process transformation of liquid metal into vapour.

The hot gas escaping from the keyhole forms a plasma or plume above the workpiece. The laser beam energy is absorbed on the walls of the keyhole (Vught, 2003). The keyhole effect allows welding procedures with deep diffusion due to the fact that the laser beam heat is well absorbed in a steamy medium. The reflectivity of the metal is only important until the keyhole weld begins. After forming the first drop of melted metal, the level of absorbed energy will increase because the metallic bath has a low reflection degree, causing the temperature to significantly increase up to the point where metal steams form (Pascu et al., 2009, b).

The laser beam is focused to produce an incident power at the surface of the material; power wich will initialize the vaporisation and the formation of the keyhole effect. Keyhole welding is dependant on focused spot power density (laser power and focused spot size), welding speed, material, melting temperature, material reflectivity, material conductivity, and the like. In general, CW keyhole welding of steels and stainless steels is possible above 600 watts. For materials such as aluminum and copper, keyhole welding is generally not possible in the CW range below 1000 Watts (Havrilla, 1999).

The main characteristic of the laser welding is the quick solidification of the metal bath. During this cooling, the material contracts, creating tensile stresses in the fusion zone. When using short welding intervals (5 ms), the welding belt might crack. It is possible the laser influenced areas of high-alloyed steel, turn into martensite with major drawbacks for the welding. These drawbacks can be avoided by increasing the welding intervals or by a local preheating procedure. Another wide spread method used for obtaining high quality welding results consists in using the shield gas for preventing the oxidation of the metal bath (Pascu et al., 2009).

3. EXPERIMENTAL PROCEDURE

The study is concerned to analyze the welding behaviour of stainless steel 304. Austenitic Cr-Ni stainless steel has a good corrosion resistance, high ductility, excellent drawing, forming, and spinning properties. Essentially non-magnetic, becomes slightly magnetic when cold worked. Low carbon content means less carbide precipitation in the heat-affected zone during welding and a lower susceptibility to intergranular corrosion. For the achievement of the welding tests, a 3,3 kW Nd:Yag continous wave laser was used as a thermal source together with an ABB 6-axes robot and a coaxial cladding unit made by Rofin. The welding parameters were varied in order to study the geometry and the manner in which a weld bead is constituted. The penetration depth in laser welding is proportional to the power density of the laser beam and is incident function between the focal spot size and its power. The values of the welding regime used for the experiments are presented in table 1.

Sample code	Spot diameter [mm]	Laser power [W]	Power density [W/cm^2]	Welding speed [mm/s]
1.1.	0,5	700	356,688	20
1.2.	0,5	900	458,599	40
1.3.	0,5	1100	560,51	60

Tab. 1. Welding parameters for the test pieces

4. RESULTS AND COMMENTS

All the samples were prepared for analises using grit paper, alumina and chemical etched with royal water in a molar ratio of 1:3.

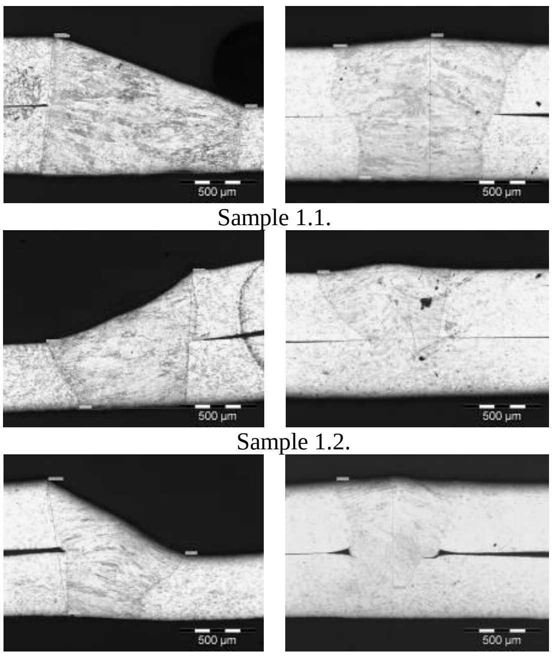

Fig. 3. Section of welding tracks; left: fillet, right: overlapp

The behavior of the weld bead in case of fillet and overlapp welding is clarly visible in figure 3. The speed has an major influence over the penetration and the width of the weld. Even so the power used at sample1.1 is smaller the width of the bead is higher and a full penetration was achived. Also at sample 1.1 a strait idealy geometry of the bead was obtined. In case of a higher speed at sample 1.2 and 1.3 a smaller width of the weld can be observed and also only a partial penetration was achived. The penetration of the overlap samples is proportionally inverse with the laser power and the welding speed. The penetration is lineary decreasing if the welding speed is higher. Also the width of welding bead is smaller in case of a hight speed. In table 2 are presented the values of the penetration and width of the analised samples.

Sample code	Penetration [µm]		Width [µm]	
	fillet	overlap	fillet	overlap
1.1.	-	928	1280	1310
1.2.	-	730	705	880
1.3.	-	732	482	852

Tab. 2. Aspects highlighted in the case of the welded samples

5. CONCLUSION

The irradiation of the metal bath is influenced by the convergent or divergent propagation of the laser beam. In case of Nd: YAG laser the absorbtion take place trough the Fresnel reflection wich appears at the top of the metal bath and inside the keyhole. During the formation and evolution of the keyhole the laser beam irradiate the front wall of the keyhole and the position of the beam became relatively ofaxiss with the keyhole channel. Also as welding speed increases the process becomes successively more dominated by direct absorption at the keyhole walls.

The quantity of absorbed energy trough Fresnel reflection depends on the incident angle of the radiation over the metal bath. This study will provide the necessary data for the further research in wich the behaviour of black and withe welding will be investigated.

6. ACKNOWLEDGEMENTS

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