U.P.B. Sci. Bull., Series D, Vol. 74, Iss. 3, 2012 ISSN 1454-2358

# LASER WELDING PARAMETERS INFLUENCE ON THE GEOMETRICAL ASPECT OF THE MELTED ZONE IN STAINLESS STEEL

Elena-Manuela STANCIU[1], Gabriel-Marius DUMITRU[2]
Adrian-Cătălin PĂVĂLACHE[3], Gabriel IACOBESCU[4]

*În această lucrare este prezentat efectul transferului termic prin conducție ce apare la sudarea cu laser, precum şi o serie de aspecte legate de influența parametrilor de sudare cu laser asupra geometriei sudurii în cazul componentelor subțiri utilizate în medii corozive. Experimentele au fost efectuate pe diverse piese din oțel inoxidabil AISI 304. Geometria zonei sudate a fost analizată prin microscopie optică, stabilindu-se corelația între extinderea zonei influențate termic pentru diferite valori ale parametrilor de sudare.*

*This paper presents the effect of heat transfer by conduction which occurs during laser welding, and a series of issues related to the influence of laser welding parameters on the weld geometry for thin components used in corrosive environments. Experiments were conducted on various samples of AISI 304 stainless steel. The geometry of the welded area was analyzed by means of optical microscopy setting a correlation between the heat affected zone extents and the welding parameters.*

**Keywords:** Nd:YAG laser, stainless steel, welding parameters

## 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 mechanism of direct heating involves absorption of the beam energy by the material surface and subsequent transfer of energy into the surrounding material by conduction. A hemispherical weld bead and heat affected zone is formed in a similar manner to conventional arc fusion welding processes. Conduction-limited welds, therefore, exhibit a low depth-to-width ratio (aspect

[1] Eng. University POLITEHNICA of Bucharest, Romania, Universidad Politécnica de Madrid, Spain, elena.manuela.stanciu@gmail.com
[2] Prof. Eng. University POLITEHNICA of Bucharest, Romania, gabriel.marius.dumitru@yahoo.com,
[3]Eng. University POLITEHNICA of Bucharest, Romania, Universidad Politécnica de Madrid, Spain, adrian.pavalache@gmail.com,
[4] Prof. Eng. University POLITEHNICA of Bucharest, Romania, gabiiacobescu@yahoo.com.

ratio), which is often required when limited penetration in the thickness direction is desired. Thermal cycles are rapid, resulting in a fine-grained weld bead with good mechanical properties. Spot welds are made by pulsing the laser beam to melt sufficient material to form the joint.

Continuous welds may be made by overlapping pulsed spot welds, or by using a continuous wave beam. The energy transmission mode of conduction welding is used with materials that transmit near infrared radiation, notably polymers. An absorbing ink is placed at the interface of a lap joint. The ink absorbs the laser beam energy, which is conducted into a limited thickness of surrounding material to form a molten interfacial film that solidifies as the welded joint.

Thick section lap joints can thus be made without melting the outer surfaces of the joint. Butt welds can be made by directing the energy towards the joint line at an angle through material at one side of the joint, or from one end if the material is highly transmissive [1].

## 2. Conduction effect

Conduction welding is possible when the absorbed energy is sufficient to melt the weld zone, but insufficient for vaporization and plasma formation. Conduction welding of steels and stainless steels at low power typically requires a relatively small focused spot (in the range of 250-300 μm) in order to obtain efficient coupling of the energy into the weld joint.

Conduction welding is a stable, low energy input process, which can be performed using a laser that does not need to have a high beam quality. A relatively low power, low cost laser can therefore be used. Providing that fusion can be obtained, the properties of weldable materials are relatively unimportant – hardness does not affect the process, and they do not need to conduct electricity, for example.

Materials can be joined in a variety of geometries: wires, strips, thin sheets, or combinations of these. Because of the relatively large beam size, the tolerances for alignment and fit-up can be relatively large. The process is ideally suited to small component geometries, in which the weld bead is on the order of millimeters. Joints can be placed close to heat-sensitive components. Because of the stable welding conditions, the weld bead has a good visual appearance.

High temperature strength, reduced manufacturing time and simplified material separation at the end of the life cycle are also important process characteristics.

Consider now the case of a laser beam traversing the surface at a rate $v$, as illustrated in Fig.1 [5,6]. At any point in the material, transient heat flow is experienced, i.e. the temperature field changes with time. The power density is then no longer unique in determining the processing mechanism – the heating time must also be considered.

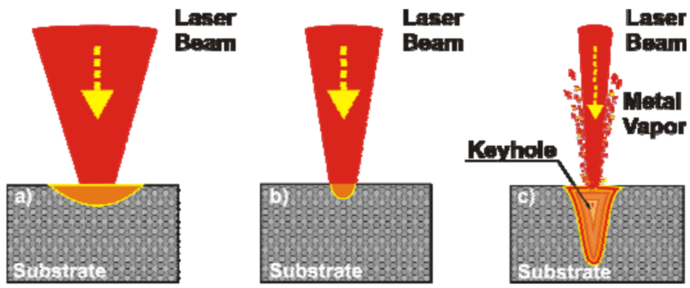



Fig.1. The effect of power density on the interaction mechanism between a laser beam and a large block of material under steady state conditions (a- surface heading, b- surface melting, c- surface vaporization – keyholing).

The heating time can be approximated by the beam interaction time, τ:

$$\tau = \frac{2r_B}{v} \tag{1}$$

τ clearly influence the processing mechanism, but we do not yet know the exact form of the relationship[1]

However, if conduction welding is used to join thicker sections, the energy input per unit length of weld is relatively high, resulting in a large weld bead and high levels of distortion [4].

This type of welding occurs at relatively low laser beam intensity ($I < 10^{10}$ W/ $m^2$). The laser energy is absorbed by Fresnel absorption at the surface of the workpiece and can be described by an absorption coefficient *A*, indicating the fraction of absorbed laser power $P_A = A \cdot P$. For steel at the melting temperature ($T_m$ = 1800 K) the absorption coefficient is of the order of A = 0.4 for Nd:YAG laser radiation.

The rest of the laser energy is reflected. For metal the laser energy is absorbed in a thin layer (~ 40 nm) at the surface of the workpiece where it is converted into heat. The absorbed energy is transported into the depths of the material by means of heat conduction and fluid convection, hence the name conduction mode welding. In conduction mode welding the weld geometry is shallow and wide, as indicated in Fig. 2, and only low welding speeds can be achieved (v < 40 mm/s) [2].

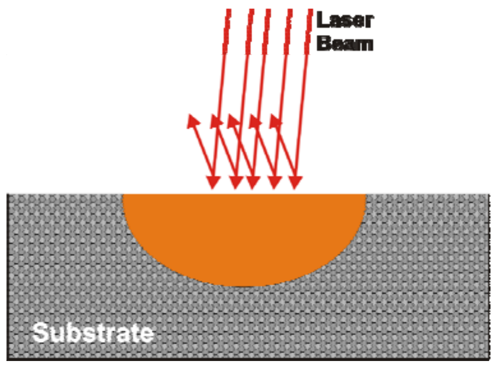



Fig. 2. Diagram of the laser material interaction phenomena of typical welding mode

### 3. Materials

Austenitic stainless steels chemical composition contain 18–25% Cr, 8–20% Ni, and up to 0.2% C. The most common contain 18% Cr and 9–10%Ni. The solidified microstructure comprises austenite or a dual phase austenite–ferrite mixture. A ferrite content between 3 and 8 vol.% endows the steel with good resistance to solidification cracking.

However, ferrite may be preferentially attacked in some corrosive environments, and may transform to the brittle sigma phase if exposed to temperatures in the range 540–930ºC. Ferrite is also detrimental to fracture toughness in cryogenic environments.

Austenitic stainless steels can only be hardened by mechanical working. They possess high corrosion resistance, particularly to pitting caused by chlorides. They can be cleaned easily, are easy to fabricate, have a good appearance, are non-magnetic, and have good toughness and ductility at low temperatures.

Of the stainless steels in use today 80–90% is of the austenitic type. They are used when corrosion resistance and toughness are the primary requirements, e.g. in car wheel covers, wagons, fasteners, chemical and food processing equipment, heat exchangers, oven liners, aircraft exhaust manifolds and pressure vessels. They are suitable candidates for laser cutting and welding [1].

The temperature microstructure of the fusion zone of austenitic stainless steels is dependent both on the solidification behaviour and subsequent solid-state transformations. All stainless steels solidify with either ferrite or austenite as the primary phase. The austenitic stainless steels may solidify as primary ferrite or primary austenite, depending on the specific composition.

Small changes in composition within a given alloy system may promote a shift from primary ferrite to primary austenite. The composition range of many austenitic stainless steels is broad enough that both solidification modes are possible. Following solidification, additional transformations can occur in the solid state upon cooling to temperature. These transformations are most important in alloys undergoing primary ferrite solidification, since most of the ferrite will transform to austenite [3].

### 4. Experimental procedure

For issuing of welding tests it was used an equipment comprising a laser source Nd:YAG with continuous wavelength and a 6-axis welding robot type ABB. To study the thermal effects on thermal expansion of the heat affected zone, the power and welding speed were varied successively.

To fulfill tests samples of AISI 304 stainless steel plates were used having a thickness of 0.5 mm. Samples were remelted using a laser spot size constant value. At a low power density (229.299 KV/cm$^2$) penetration test was not carried out, only a penetration of 0.22 mm. Values of welding procedure and experimental results are presented in Table 1.

From the analysis of experimental results, it can be noticed that the penetration value is directly proportional to the laser power density and seam width is inversely proportional to the power density.

In Table 1 are presented the values of welding parameters and values of penetration and width remelted seams. The appearance of each molten area of seams in cross section is presented in Fig. 3.

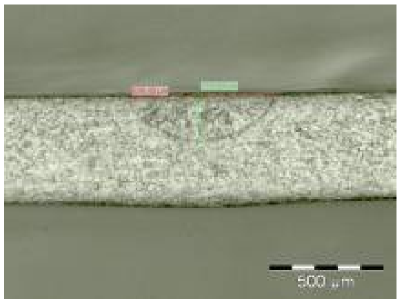
*Table 1*

**Laser welding parameters and experimental results**

| **Sample** | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| **Laser Power [W]** | 450 | 550 | 900 | 900 |
| **Welding Speed [mm/s]** | 25 | 25 | 80 | 60 |
| **Spot diameter [mm]** | 0,5 | 0,5 | 0,5 | 0,5 |
| **Power density [ kW/cm$^2$]** | 229.299 | 280.255 | 458.599 | 458.599 |
| **Penetration [µm]** | 220 | 390 | 577 | 507 |
| **Width [µm]** | 640 | 814 | Top - 801<br>Bottom -293 | Top - 918<br>Bottom -732 |

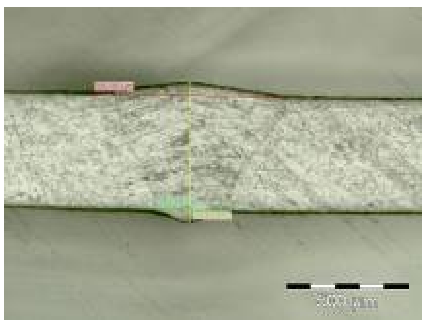
Diameter of laser beam is one of the most important characteristics of the welding system, because it determinates the default value of power density and penetration molten area.

Using values of welding parameters shown in Table 1, an adequate penetration for P3 and P4 samples was obtained or only an incomplete penetration area for P1 and P2 samples. Compared with the other samples, P4 shows a higher widht heat affected zone.



P1

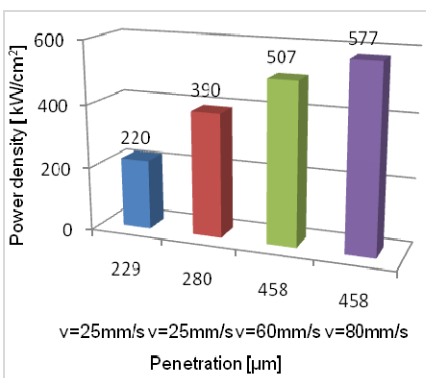
P2



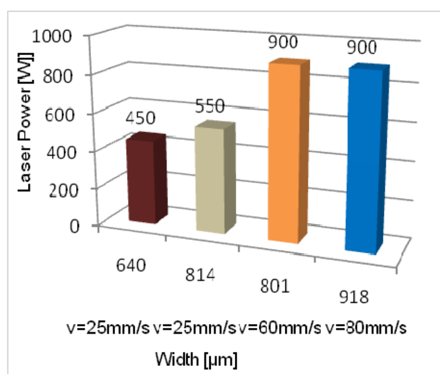
P3

P4

Fig. 3. The appearence of each molten area of seams in cross section




a)




b)

Fig. 4. Penetration and width as a function of power density

## 6. Conclusion

This research showed that the welding process using Nd: YAG laser is an effective method to achieve high performance in terms of welded joints with a high quality, made of stainless steel.

The data collected form these experiments are presented in Fig. 4, where penetration and width as function of power density is presented.

It can be observed that the penetration is higher at high power values even if the speed is also increased.

The clad width is increased with the increase of power. As expected, the weld penetration and width depend on power and speed welding process.

The research shows that a good penetration has been obtained using the optimum welding parameters applied for samples P3 and P4, which were processed using a laser power value of 900W and welding speed of 60 and respectively 80 mm/s.

**Acknowledgements**

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/6/1.5/S/16.

The authors wish to thank all members of Centro Láser-Universidad Politécnica de Madrid, for their assistance in smooth conducting of experiments and carrying out the study.

## R E F E R E N C E S

[1] *C. I. John*, Laser Processing of Engineering Materials*,* Elsevier, ISBN 0 7506 6079 1, pp. 327-338, 2005

[2] *F.A. van Vught*, Weld Pool Control in Nd:YAG Laser Welding, S. Postma, Enschede, the Netherlands Printed by Oc, ISBN 90-77172-05-X, pp.6-7 , 2003

[3] *J.C.Lippold, D.J. KOTECKI*, Welding Metallurgy and Weldability of Stainless Steel, A Wiley-Interscience publication, ISBN 0-47 1-47379-0, 2005

[4] *D. Havrilla*, Laser Welding Design and Process Fundamentals and troubleshooting Guideline, 2nd Printing, pp.78-79,1999

[5] *Elena-Manuela Stanciu, Adrian Catalin Pavalache, Gabriel-Marius Dumitru, Octavian G.Dontu, Daniel Besnea, Ion Mihai Vasile*, Mechanism of keyhole formation in laser welding, The Romanian Review Precision Mechanics, Optics & Mechatronics, 2010 (20), No. 38, p171-176, ISSN-1584-5982

[6] *Elena-Manuela Stanciu, Gabriel-Marius Dumitru, Adrian Catalin Pavalache, Alexandru Pascu, Apostol Georgeta, Dan Petre,* Keyhole formation during laser welding, Annals of DAAAM for 2010 & Proceedings of 21th DAAAM of the 21st International Symposium,volume 21, No.1, ISSN: 1726-9679, ISBN: 789-3-901509-73-5, ISBN: 789-3-901509-73-5, p1087-1088.