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Laser welding of butt joints of austenitic stainless steel AISI 321

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Manufacturing and processing

ABSTRACT

Purpose: of this paper: A study of an automated laser autogenous welding process of butt joints of austenitic stainless steel AISI 321 sheets 0.5 [mm] and 1.0 [mm] thick using a high power diode laser HPDL has been carried out.
Design/methodology/approach: Influence of basic parameters of laser welding on shape and quality of the butt joints and the range of optimal parameters of welding were determined.
Findings: It was showed that there is a wide range of laser autogenous welding parameters which ensures high quality joints of mechanical strength not lower than the strength of the base material (BM). The butt joints of austenitic steel AISI 321 sheets welded by the HPDL diode laser at optimal parameters are very high quality, without any internal imperfections and the structure and grain size of weld metal and HAZ is very small and also the HAZ is very narrow and the fusion zone is very regular.
Research limitations/implications: Studies of the weldability of stainless steels indicate that the basic influence on the quality of welded joints and reduction of thermal distortions has the heat input of welding, moreover the highest quality of welded joints of austenitic stainless steel sheets are ensured only by laser welding.
Practical implications: The technology of laser welding can be directly applied for welding of butt joints of austenitic steel AISI 321 sheets 0.5 and 1.0 [mm] thick.
Originality/value: Application of high power diode laser for welding of austenitic stainless steel AISI 321.
Keywords: Manufacturing and processing; Welding; Laser welding; AISI 321; HPDL

1. Introduction

Stainless steels of austenitic structure and chromium - nickel type are widely used for manufacturing of chemical installations, including stationary pressure tanks and tanks for transport of liquid and compressed gases, pipelines of high diameter in water power plants, for manufacturing of ships for transport of chemicals and installations of drilling rigs, etc. [1-5,12,14-17].

Austenitic stainless steels type 18-8 are well welded and the problem of hot cracking of welded joints is limited thanks to high metallurgical purity of steel and also consumables and applying minimal heat input of welding. Similarly reduction of carbon content in austenitic steels and consumables below 0,01[%] prevents the phenomenon of inter-grain corrosion of welded joints. The only problem is minimizing of thermal distortions during welding, especially in a case of welding of thin sheets, as a result of high thermal expansion of austenitic structure steel about 18x10-6 [1/K] and very low heat conductivity about 15,5 [W/mxK] [1,6,7-16,18].

Previous studies of the weldability of stainless steels indicate that the basic condition for ensuring high quality of welded joints and reducing thermal distortions to minimum is reducing the heat input of welding, moreover the highest quality of welded joints of austenitic stainless steel sheets are ensured only by laser welding [2,5,6,7,9].

2. Experimental

To determine the influence of parameters of laser welding without consumables by high power diode laser ROFIN DL 020 on a quality and a shape of butt joints of austenitic stainless steel AISI 321 sheets 0,5 [mm] and 1,0 [mm] thick, tests of bead – on plate welding and welding of the steel sheets were carried out at different power of the laser beam and different welding speed.

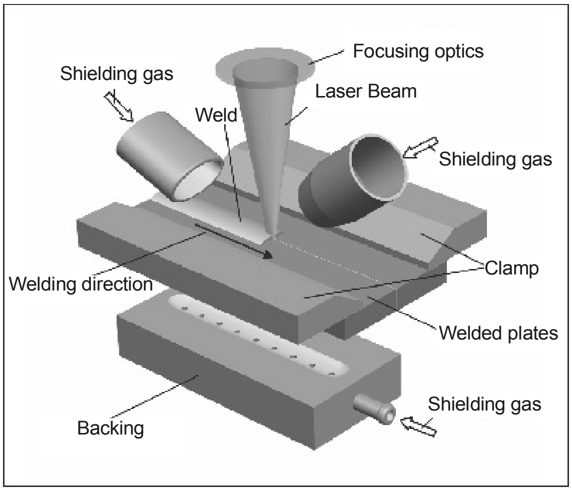

Fig. 1. A view of the device for mounting of welded joints with a copper backing plate

The experimental setup for test laser welding of austenitic stainless steel AISI 321 sheets was equipped with the high power diode laser (HPDL) manufactured by Rofin Sinar Laser and the positioning system ISEL Automation. A copper backing plate was used for formation of the weld root, which is recommended for welding of austenitic stainless steels because ensures narrow bead of the weld and low angle distortions of joints, thanks to intensive heat transfer, Fig. 1.

Two cylindrical nozzles for shielding gas were used for protection of the weld pool. One of the nozzles, which were 10,0 [mm] in diameter, was set along the axis of the joint at an angle 45[°] and the second one was set contrary to the welding direction at an angle 20[°], Fig. 1. Flow of shielding gas via the backing copper plate was applied for protection of the weld root against oxidation and the gas flow was set at 3 [l/min], Fig. 1. Higher flow of the shielding gas from a root side resulted in blowing up of the molten metal of the weld pool and lower shielding gas flow than 3 [l/min] resulted in surface oxidation of the weld root because of not sufficient protection.

To eliminate the influence of a changeable width of the joint gap on shape of the weld bead and penetration depth, the preliminary tests of welding were carried out by bead-on-pate welding of the austenitic steel AISI 321 sheets by the diode laser beam. Samples of size 100x50 [mm] for the study of laser bead-on-pate welding and welding of austenitic stainless steel were cut by guillotining and degreased by acetone prior to laser welding. The laser beam spot of size 1,8×6,8 [mm] was set along the welding direction and focused on the top surface of the welded sheets, Fig. 1.

Parameters of one-side laser welding of butt joints without consumables were set on the base of preliminary tests of bead-on-plate laser welding of austenitic steel AISI 321 sheets 0,5 [mm] and 1,0 [mm] thick. A proper shape of the weld bead and a full penetration of the weld bead at minimum distortions and maximum welding speed were the criterions of quality and selection of the range of optimal laser welding parameters.

An x-ray device ERESCO 200 MF was used for the tests of butt joints of austenitic steel AISI 321 sheets 0,5 [mm] and 1,0 [mm] thick welded by high power diode laser HPDL. The quality of joints was evaluated according to standard PN-EN 25817:1997.

The static tensile tests of the examined butt joints were carried out according to the standard PN-EN 895:1997, and the tests of transverse bending according to PN-EN 910:1999, Fig. 2.

Measurements of microharness of the butt joints of austenitic steel AISI 321 sheets 0,5 [mm] thick welded by the high power diode laser HPDL Rofin Sinar DL 020 were carried out by a microhardness tester Micro-Vickers 401 MVD manufactured by Wilson Wolpert according to the standard PN-EN 10431:2000, Fig. 3 and 4.

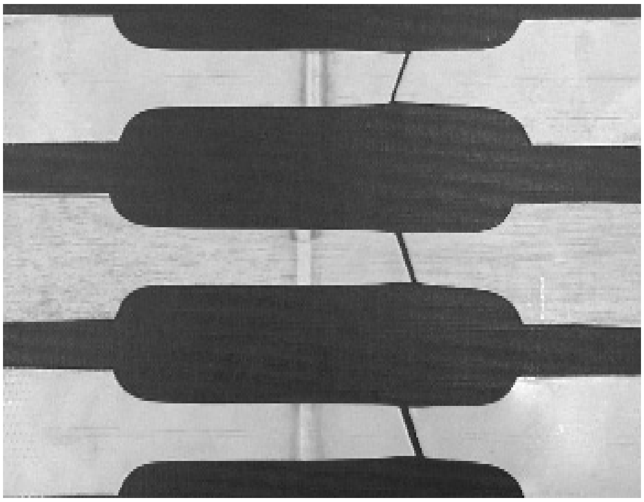

Fig. 2. A view of butt joints of austenitic steel AISI 321 sheets 1,0 [mm] thick welded by the high power diode laser HPDL ROFIN DL 020 after static tensile test. Broken in base material

3. Results

Preliminary tests of bead-on-plate welding of the austenitic steel AISI 321 sheets 0,5 [mm] and 1,0 [mm] thick by HPDL laser showed that the power of laser beam, at constant speed of laser welding, has a very strong influence on the bead shape and a penetration depth. Increase of the power of laser beam resulted in increasing of the width of beads and the penetration depth. The shape of the fusion zone is transformed from an elliptical shape to almost vertical and parallel sides. Increase of the laser power leads also to increase of the HAZ width. On the other hand, increase of the welding speed during bead-on-plate welding of the austenitic steel AISI 321 sheets by HPDL laser, at constant laser beam power, resulted in decreasing of the width of beads and also penetration depth. The shape of the fusion zone is transformed from a mushroom like shape to an elliptical shape.

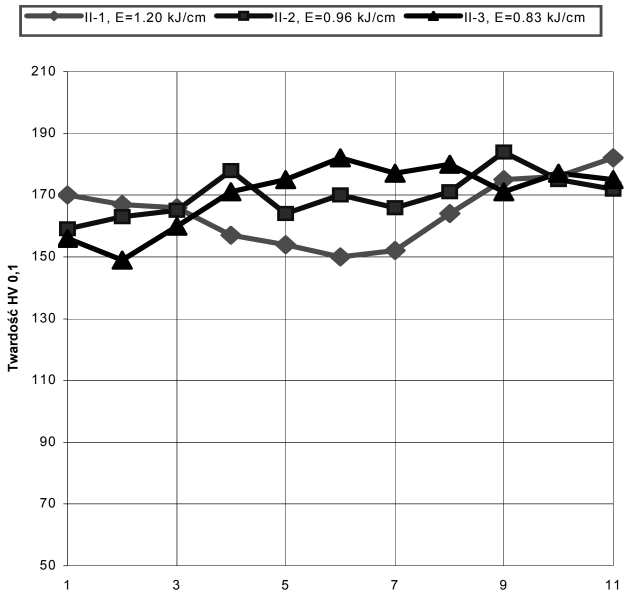

Fig. 3. Microhardness distribution on the crosssection of the butt joints of austenitic steel AISI 321 sheets 0,5 [mm] thick welded by the high power diode laser HPDL

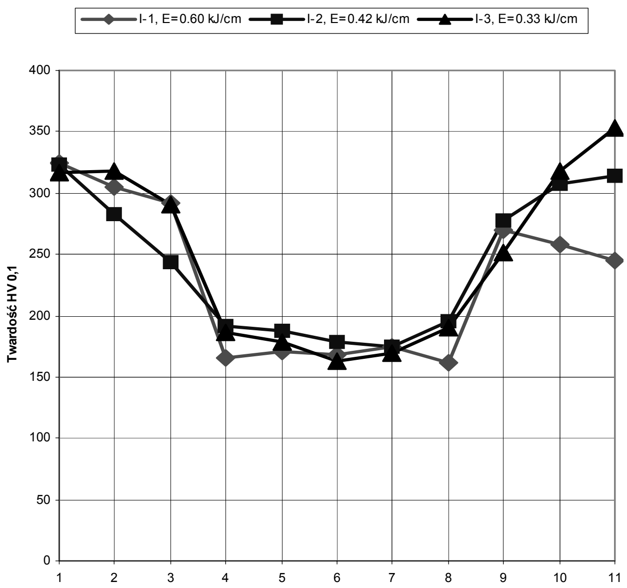

Fig. 4. Microhardness distribution on the cross-section of the butt joints of austenitic steel AISI 321 sheets 1,0 [mm] thick welded by the high power diode laser HPDL

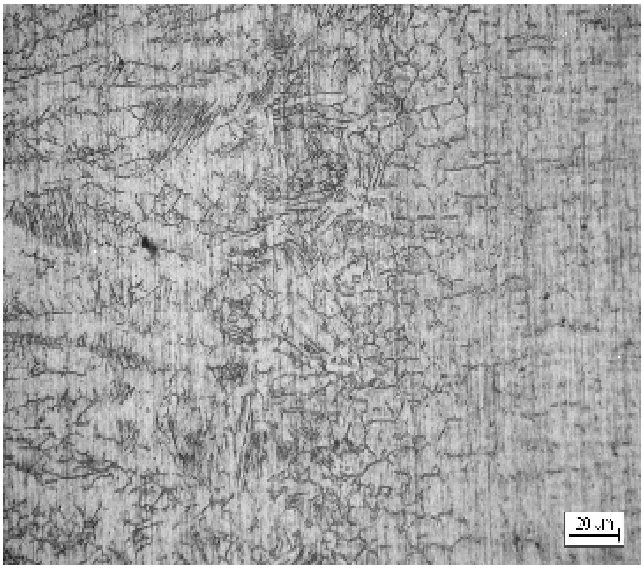

Fig. 5. Microstructure of butt joints of austenitic steel AISI 321 sheets 0,5 [mm] thick welded by the high power diode laser HPDL ROFIN DL 020 at laser power 0,6 [kW] and welding speed 0,6 [m/min]; (from left) weld metal, very narrow heat affected zone and austenitic structure of the base material, etched by iron chloride $FeCl_3$, magnification 200x

In the range of optimal parameters of laser welding of butt joints of austenitic steel AISI 321 sheets 0,5 [mm] thick by the diode laser ROFIN DL 020, with a rectangular shape of the laser beam spot of size 1,8×6,8 [mm] focused on the top surface of a welded sheet, the width of joint's face is below 2,0 [mm] and the width of joint's root is below 1,8 [mm]. In the case of butt joints of austenitic steel AISI 321 sheets 1,0 [mm] thick the width of joint's face is below 2,4 [mm] and width of joint's root is below 2,3 [mm].

On the base of visual examinations of butt joints of austenitic steel AISI 321 sheets 0,5 and 1,0 [mm] thick welded by the high power diode laser in a range of optimal parameters it was showed that the surface of joint's face and root is flat, smooth and with no undercuts and the height of reinforcement is minimal and the thermal distortions are neglectable.

The analysis of macro and microstructure of butt joints of austenitic steel AISI 321 sheets 0,5 and 1,0 [mm] thick laser welded at optimal parameters showed that the shape of the fusion zone is regular and symmetric and also the width of the heat affected zone is very narrow. In the heat affected zone grain size is significantly smaller than the gain size of base material, Fig. 5.

Results of the mechanical testing confirmed the high quality of laser welded joints. The tensile strength of butt joints of austenitic steel AISI 321 sheets 1,0 [mm] thick is not lower than the tensile strength of the base material, because all testing samples were broken in the base material, Fig. 5. In the case of butt joints of austenitic steel AISI 321 sheets 0,5 [mm] the samples after tensile test were broken in weld region, Fig. 2. However those steel sheets were delivered as cold rolled, so the structure of the base material was highly strengthen by strain hardening. During laser welding of the butt joints of austenitic steel AISI 321 sheets 0,5 [mm] a recrystallization of the weld metal occurs, that is the reason of lower mechanical properties of welded joints compared with the base material (730 MPa). The bending tests from the weld face and the root side of laser welded butt joints of austenitic steel AISI 321 sheets showed a high plasticity of the joints of 0,5 as well as 1,0 [mm] thick sheets. In the case of every tested sample, no cracks and tears were observed even at maximum angle of bending 180[°].

Measurements of microhardness on the cross-section of the diode laser welded joints of austenitic steel AISI 321 sheets 0,5 [mm] thick showed that there is a significant hardness drop in the weld metal to 160÷170 HV0,1 as well as in heat affected zone to 160÷190 HV0,1 compared with the base material 320÷350 HV0,1, which was delivered as strain hardened after cold rolling, Fig. 3. In the case of butt joints 1,0 [mm] thick, there were no significant changes of microhardness in the weld metal as well as in the HAZ and the microhardness was in a range 150÷180 HV0,1, Fig. 4.

On the base of x-ray analysis, it was proved that all the butt joints of austenitic steel AISI 321 sheets 0,5 [mm] and 1,0 [mm] thick welded by the diode laser at optimal parameters fulfill criterions of the quality level B (sharp requirements) according to standard PN-EN 25817:1997.

4. Summary

The study of the welding process of butt joints of austenitic steel AISI 321 sheets 0,5 [mm] and 1,0 [mm] thick by the high power diode laser HPDL showed that it is possible to produce high quality joints in a wide range of laser welding parameters without consumables, Fig. 2 to 5.

The width of butt joints of austenitic steel AISI 321 sheets 0,5 [mm] thick laser welded at optimal parameters is below 2,0 [mm] and in a case of butt joints of sheets 1,0 [mm] thick the width of joints is below 2,4 [mm]. The surfaces of laser welded joints are flat, smooth and with no undercuts and the height of the weld reinforcement is minimal .

The butt joints of austenitic steel AISI 321 sheets welded by the diode laser at optimal parameters are very high quality, without any internal imperfections and the structure and grain size of weld metal and HAZ is very small and also the HAZ is very narrow and the fusion zone is very regular, Fig. 5. The mechanical properties of laser welded butt joints of austenitic steel AISI 321 sheets are not lower than the properties of the base material.

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