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Microstructural Changes During Laser Beam Welding of Austenitic Stainless Steel Sheets

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Abstract

The purpose of our study was to investigate the properties of welded joints formed by 1.5 mm thick plates with a diode laser beam equipment. The technological parameters influence the shape of the weld metal. In the heat affected zone no grain coarsening appeared. Increasing the welding speed, in case of similar laser power, the ferrite content of weld metal decreases. The hardness' of the streams are higher than that of base metal, but the highest values were measured in heat affected zones.

Keywords*: diode laser, austenitic stainless steel, welding, ferrite content.*

1. Introduction

One of the new technologies to be exploited in the 21st century is the increasingly available laser welding. Due to the velocity of the concentrated beam and its repetitive accuracy it stands out from other technologies [1–3]. Laser beam welding plays an increasingly important role in welded structures today due to the concentrated heat input and the high welding speed. Laser beam welding works with concentrated heat input, making it suitable for welding of high alloyed austenitic steels. Generally, the heat-affected zone is small, no grain coarsening is created, consequently the structure will have good mechanical properties and the corrosion properties will be favorable as well. In return for its advantages, laser welding requires accurate preparation before welding [1–5].

The properties of laser welding machines are extremely diverse compared to laser radiation sources. The radiation source determines the wavelength of the laser beam, which affects the absorption. For instance, the CO_2 laser with a wavelength of 10.6 μm is expected to have a low interaction time and deep beet-shaped melting, called keyhole welding. The other mode is heat conduction welding, where the energy of the laser beam reaches to deeper layers of the product from the surface by heat-conduction. This behavior is produced, for example, by the diode laser in this study with its 0.94 μm wavelength, which is called half-lens-shaped in the scientific literature.

The sources of the laser beam in the case of keyhole welding are the carbon dioxide laser and the Nd: YAG lasers. The welding speed is less than 12 m/min and the weldable plate thickness is less than 25 mm. Laser beam intensity is higher than 10^6 W/cm^2 in the case of steel welding. With this method can be welded unalloyed and high-alloyed steels, aluminium and its alloys, copper and its alloys, pairs of materials of different metals [4].

Typical radiation sources for the heat-conduction process are Nd: YAG lasers, fiber laser and diode laser. The intensity of the laser beam in the case of steels is less than 10^6 W/cm^2 [6]. According to the literature, this process is suitable for welding high-alloy steels as well. The weldable plate thickness without any filler material with a diode laser beam can be increased with laser beam power [6]. The laser beam processes are influenced by the focus point position as well as by the focus path parameters [7–9]. A common feature of laser beam methods is that the heat input and the heat transfer are influenced by the absorption and geometric conditions. As reported in the literature [10], the absorption of a laser beam in the case of a CO_2 laser is about 10 %, whereas with application of a diode laser it increases to 30 %. The roughness of the surface also influences significantly the absorption coefficient of the laser beam. The absorption coefficient varies between 4–80 % in the case of CO_2 laser beam treatments, but in case of the solid-state laser beam treatments it can reach 30 % even on polished surfaces [11]. The basic principle of a diode laser is same as all the other laser's, with an additional characteristic that the formation of the population inversion requires a particularly high current density, thus it is advisable to use the material, which is to be excited, with a minimum volume. It is advisable to organize several units into modules for the required performance. This is one of the favourable characteristics of the diode laser: the small laser beam source can be placed at the end of the robotic arm. Obviously, there is no consuming laser gas, and these two effects can result in significant cost savings and space requirements. Yet, the diode laser is rare in welding applications because of the energy density mentioned above.

2. Material and Testing

The 1.4404 austenitic corrosion-resistant steel selected for the experiment can be easily cold formed and is a weldable quality steel. This steel is also often used in the construction of chemical and textile structures because of its high resistance to aggressive media, its resistance to inter-crystalline corrosion up to 400 °C, and its low cost compared to other austenitic grades [12]. The purpose of our study was to investigate the properties of welded joints made of 1.5 mm thick plates with diode laser beam equipment. In case of LDL 130-3000 laser beam apparatus used, the energy distribution of the radiation source is very abundant, the focus is oval, 3 mm long and 1 mm transverse. The weld metal was protected by argon gas at a yield of 15 L/min on the crown side and 10 L/min on the root side. The nozzle was at an angle of 30° to the workpiece. During to laser beam welding, the temperature of the weld bath could be monitored on a monitor, which was always between 1400 °C and 1500 °C. When the laser beam stopped, the temperature of the seam decreased at high speed and the piece became quickly touchable.

For metallographic examination, 10×30 mm samples were cut at 25 mm from the streams end. 2-2 specimens with 15×30 mm dimensions were prepared for corrosion testing from the central region of the seam. The ferrite content was measured by Fischer FMP30. Ferritescope using a magnetic induction type. The ferrite content of the welds at crown and root portion of the stream weld, and also the weld metal on metallographic prepared samples were measured. Our metallographic studies tested several etching materials. The γ and δ phases can be distinguished after etching with Kalling'2 reagent, but the austenitic structure of the base material became more visible after aqua regal etching. Microstructure of welded zone were studied on Neophot-2 type microscope.

Microhardness measurement was carried out with a load of 0.2 kg. Corrosion tests were performed according to ASTM G48 standard method B in 6 % $FeCl_3$ aqueous solution.

3.Results

We could create properly fusible seams with a 1000-1200 W power and a welding speed between 4–8 mm/s. Applying 1000 W the welding speed had to be 4–6 mm/s. Increasing the laser power from 1000 W to 1200 W when the welding speed was 6 mm/s the ratio of height to width decreased from H/D= 5/3 to 1/2 as can be seen in **Figure 1.**

The heat-affected zone of the seams is extremely narrow, almost indistinguishable by aqua regal etching, but etching with Kalling's reagent separates a narrow ferritic band at the edge of weld metal, which is narrower than the midline ferritic enrichment in the middle of the parent material plates, as shown in **Figure 2.** There was no grain coarsening in heat affected zone.

Consistent with the microscopic observations, the percentage of ferrite on the surface of the plates, measured with a ferrite microscope, was 0.01 % on average, while in the center line 0.3 %. After welding, the ferrite content of the weld metal increased. The ferrite content of the weld metal with the highest heat input exceeded 5 % when the measurements were executed on the crown part, but almost reached 4 % measured on the metallographically prepared samples (**Figure 3**).

The microhardness measurement data show a good agreement with the results measured with a ferrite scope. Samples with higher ferrite content have higher average hardness. The highest hardness was measured in the heat-affected zones, but nowhere exceeded 200 HV0.2. Welding with same laser power the highest hardness was measured at the lowest welding speed. (**Figure 4**).

a) b)

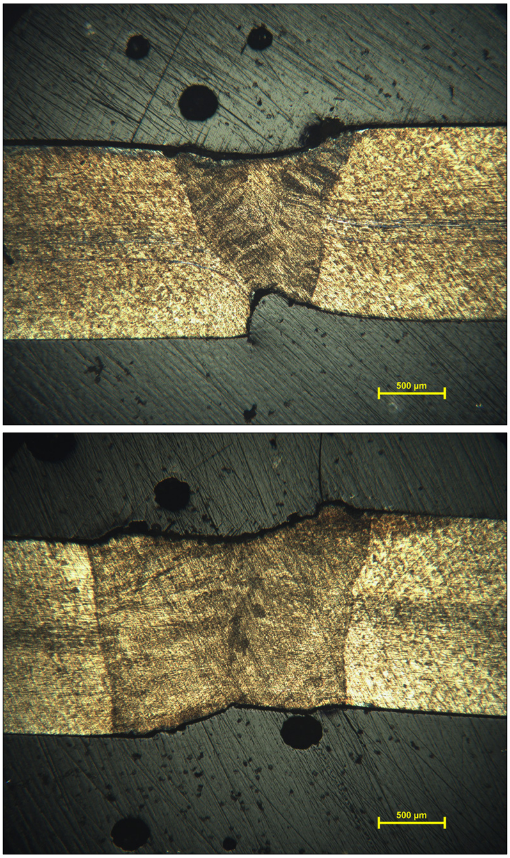

Figure 1. *Laser welding power effect on geometry of welding streams. v = 6 mm/s Kalling reagent a) P = 1000 W, b) P = 1200 W.*

Testing the resistance of the weld areas to pitting corrosion in a 6 % aqueous solution of $FeCl_3$ by soaking method showed little pitting corrosion after 24 hours, but after 72 hours several holes were observed in the vicinity of the joints, especially in samples with wider widths, as shown in Figure 5.

4. Conclusions

Austenitic stainless-steel sheets, with 1.5 mm thickness, were welded by diode laser welding equipment, at 1000–1200 W. Despite the fact that no filler material was used, the ferrite content of the weld metal in the crown part exceeded 3%, this was slightly lower in the sections. At the same plate thickness, using the same welding power, it can be shown that the ferrite content of the weld metals, measured with a ferritescope, decreases with increasing welding speed. It can be seen that the hardness of the seams increases compared to

a) b) c) d)

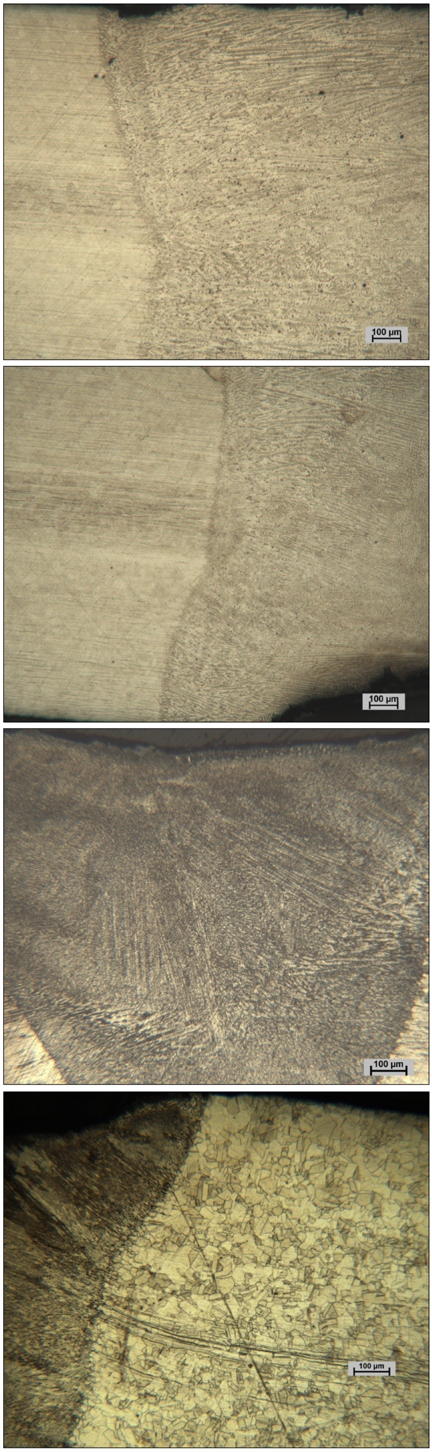

Figure 2. *Micrographs on weld metals zone a) 1200 W, 4 mm/s. Kalling reagent, b) 1200 W, 6 mm/s. Kalling reagent, c) 1200 W, 8 mm/s. Kalling reagent, d) 1000 W, 6 mm/s. aqua regal.*

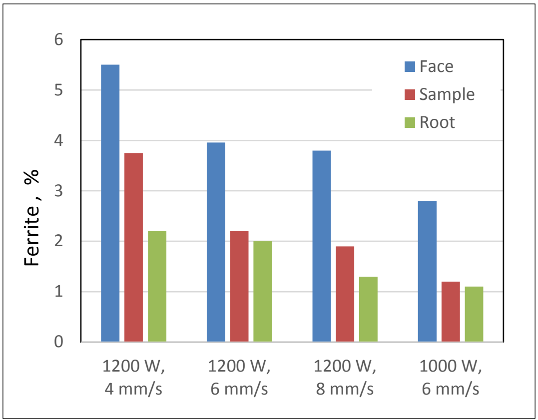

Figure 3. *Laser welding parameters effect on ferrite content of the weld metals.*

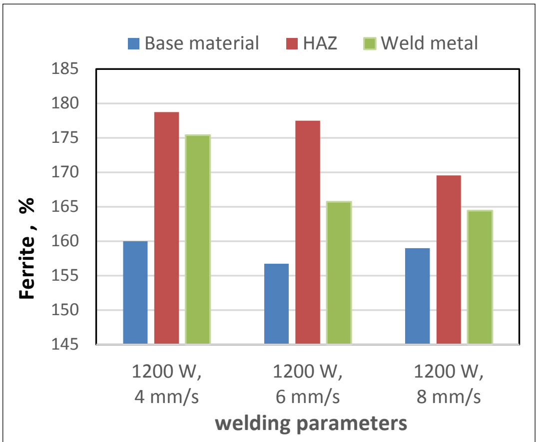

Figure 4. *Laser welding parameters effect on hardness after welding.*

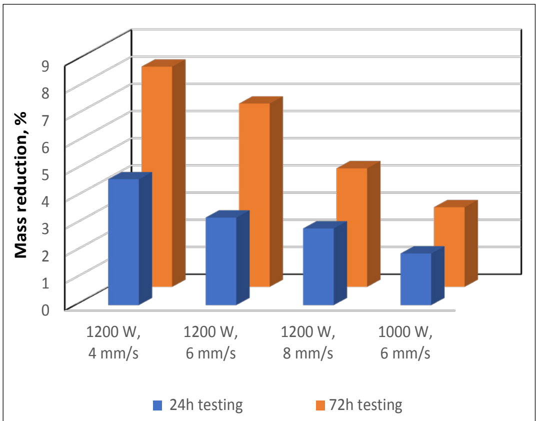

Figure 5. *Laser welding parameters effect on pitting corrosion.*

the base material at each welding speed, but the highest hardness was measured in the heat-affected zones, which can be related to the amount of delta ferrite.

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