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Corrosion Resistance of LASER Welded Joints of Stainless Steels

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Abstract— **The CO2 laser weldability of the 2304, 2404 and 304 type stainless steels is investigated in this work with special regards to the corrosion properties of the joints. An improvement in corrosion properties is found what is related to the welding speed, thus the heat input regarding the samples. Based on the results the laser welding seems to be more suitable for industrial applications in the case of duplex stainless steels.**

Index Terms— **LASER welding; duplex steel; corrosion resistance; austenitic steel**

I. Introduction

Stainless Steels are one of the most used materials in the industrial fields due to their unique properties as good strength, fatigue resistance and excellent corrosion properties [1-4,7]. Stainless Steels are alloys based on iron in majority and in minority they contain at least 12% chromium to prevent material from oxidation with thin film established on the surface and other alloying elements as Mn, Mo, and so on for better mechanical properties. The most widely used austenitic steels are chromium-nickel steels. These exhibit good resistivity against chemicals and atmospheric corrosion [8]. Also, the formability and ability to surface treatments makes these alloys suitable for scaled-up industrial applications.

The second group, which is called ferritic-austenitic steels or duplex steels, combines the benefits of ferritic and austenitic steels. The strength of duplex steels is almost the double of those austenitic grades, while the pitting corrosion resistance is almost the same [5,6].

Because in the industry the welding is necessary, the investigation of the weldability and corrosion properties of the formed welding seams has importance.

Experimental methods – Laser Welding

In the Table 1 one can see the chemical compositions and plate thicknesses of the investigated (duplex 2304, 2404 and austenitic 304) materials.

Table 1. Composition and thickness of the used materials.

International Steel No.		Thickness (mm)	Chemical Composition % by wt. Typical Values					
ASTM	EM		C	N	Cr	Ni	Mo	EW
2304	1.4362	2.5	0,02	0,10	23,0	4,8	0,3	24,63
2404	1.4662	2.0	0,02	0,27	24,0	3,6	1,6	24,49
304	1.4301	2.5	0,04	-	18,1	8,3	-	25,24

Trump TLF 5000 Turbo type CO_2 Laser welding equipment was used, the shielding gas was He, which flowed during the welding to remove the plasma. Different welding speeds were used for each material of the same thickness to provide as much beam penetration as possible, with minimum thermal distortion. For all welds, no filler metals were used. The parameters chosen and the properties of the joints are described in the Table 2.

II. Investigation of the Microstructure

All of the specimens were sectioned, grinded and polished up to 0.05 μm alumina powders and etched in the Kalling'2 (100 ml C_2H_6O + 100 ml HCl + 5 mg $CuCl_2$) solution to determine the general microstructure of the weld and Heat Affected Zones (HAZ). Behara (85 ml water + 15 ml HCl + 1g $K_2S_2O_5$) solution was used to change the ferrite color (darker) for better observations, while austenite (brighter) remained unchanged (see Figures 1 and 2). This established high contrast between phases allows a quantitative analysis.

Figure 1. Laser welded joints in different parameters. The 2404 duplex welded with power of a) 5200W, b) 3800W and c) 2000W, respectively. All the magnifications are 10x, scale bar 200 μm.

Table 2. Laser welding parameters (CW = Current Wave)

Sample		**P[W]**	**v [mm/s]**	**f [kHz]**	**Plate 1**	**Plate 2**	**Joint type**	**Gas Type**	**Flow Rate [l/mm]**	**Focal position [mm]**
Homogen samples pair										
L1	2304	5200	8000	CW	2304	2304	Narrow	He	7	0
L2	2304	3800	5000	CW	2304	2304	Middle	He	7	0
L3	2304	2000	2000	50	2304	2304	Wide	He	7	0
L4	2404	5200	6000	CW	2404	2404	Narrow	He	7	0
L5	2404	3800	7000	CW	2404	2404	Middle	He	7	0
L6	2404	2000	3000	50	2404	2404	Wide	He	7	0
L7	304	5200	8000	CW	304	304	Narrow	He	7	0
L8	304	3800	5500	CW	304	304	Middle	He	7	0
L9	304	2000	2500	50	304	304	Wide	He	7	0
Heterogen samples pair										
L10	2404-304	5200	7000	CW	304	2404	Narrow	He	7	0
L11	2404-304	3800	6250	CW	304	2404	Middle	He	7	0
L12	2404-304	2000	2750	50	304	2404	Wide	He	7	0

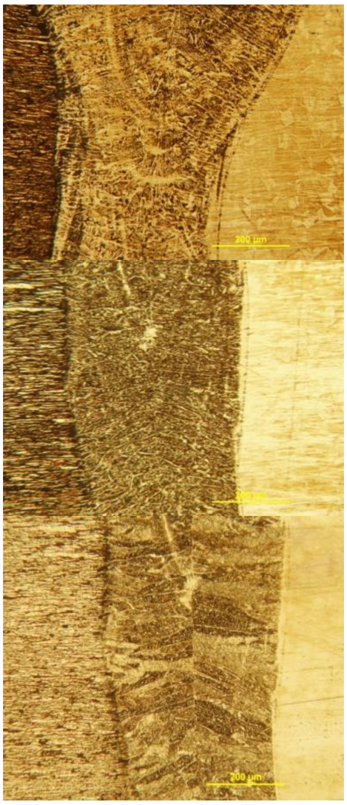

Figure 2. Laser welded joints in different parameters. The heterogeneous sample (2404-304) welded with power of a) 5200W, b) 3800W and c) 2000W, respectively. All the magnifications are 10x, scale bar 200 µm.

It is noted that the power difference in laser welding favors a deeper and wider seam-shape. For the 2404 duplex increased power caused an increase of the width of the weld bead. In the heterogeneous weld this difference was not as evident, though it can be observed difference in the weld seam shape.

III. Ferric Chloride Pitting Corrosion Test

Since the welding produced oxides on the surface, a pickling treatment was performed in order to get better performance of the tests. The samples were cut with water-cooled cutter to 10mmx20mm dimension pieces and joints were mechanically attached to them. The initial resistance testing of pitting and crevice corrosion was varied out in glass vessels containing 100g of $FeCl_3.6H_2O$ dissolved in 900 ml distilled water, as the ASTM G48 "A" practice provides. The total time of testing was 72 hours and the changes of masses were collected to the Table 3.

Table 3. Weight variation and mass lost in each time interval.

Sample	Initial (g)	24 hours	48 hours	72 hours	Mass lost (g/cm²)
L1	4.1971	4.0605	3.9872	3.927	0,13475
L2	4.2183	4.0742	3.9944	3.935	0,14130
L3	4.2268	4.0641	3.9926	3.926	0,15005
L4	2.9068	2.8659	2.8441	2.825	0,04055
L5	2.9036	2.8870	2.8637	2.819	0,04195
L6	2.9001	2.8429	2.8168	2.770	0,06475
L7	3.6773	3.5936	3.5501	3.513	0,08175
L8	3.6628	3.5921	3.5603	3.539	0,06160
L9	3.7027	3.6053	3.5590	3.518	0,09190
L10	3.2619	3.1691	3.1185	3.073	0,09410
L11	3.2708	3.1522	3.0980	3.058	0,10615
L12	3.2661	3.1679	3.1248	3.070	0,09775

As one can see from tabulated data of Table 3, the 2404 duplex steel (L4-L6) has the less mass lost. This is in connection with the high Mo content, which leads to increasing corrosion resistance.

The most surprising mass loss rate for the 2303 duplex stainless steel is followed by heterogeneous joint. This event is directly linked to the parameters of welding and the ferrite formation in the Heat Affected Zone.

With increasing power beam, the 2304 duplex steel becomes more susceptible for the pit corrosion. The holes in the weld and in the HAZ increased in depth and surface area, even in the crown.

For the duplex2404 was not noticed the same, even changing the conditions, as power or type of joint, the changes regarding the weld were not so significant.

The austenitic 304 seemed to be more sensible to the pitting corrosion in the wide joint type. Nonetheless the corrosion, the surface area of the holes was lower that in the case of 2304. Ordering the joints in a corrosion ranking from the best to worst: 2404, 304 and 2304.

The heterogeneous weld presented good performance and good corrosion pit resistance. The pit holes were hardly noticeable. Moreover, a new phenomenon was observed in the 304side. The holes position showed a new kind of corrosion behavior that was not found in the literature before. One can find holes in dendritic arrangement. The number of these holes was higher in the root part of the welding (see Figure 3 and 4.)

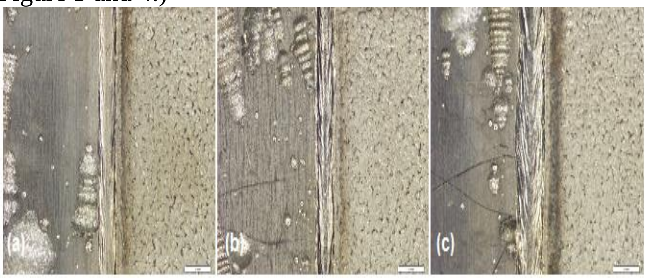

Figure 3. Crown of the heterogeneous welded 2404-304 joints displaced as narrow in 5200W(a), middle in 3800W(b) and wide in 2000W(c)

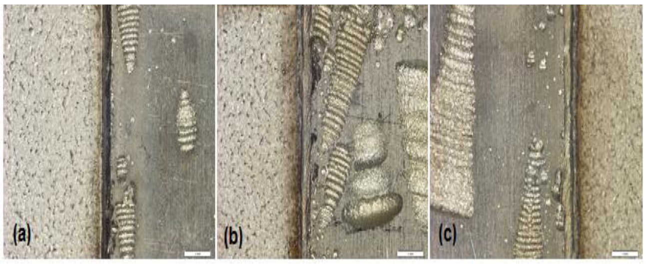

Figure 4. Crown of the heterogeneous welded 2404-304 joints displaced as narrow in 5200W(a), middle in 3800W(b) and wide in 2000W(c)

According to the literature there is hydrogen grouping in carbon steels in acidic environment [6]. The corrosion morphology in that case is similar like in the case of our investigation (heterogeneous weld)

IV. Electrochemical Corrosion Test

During electrochemical measurements, performed with Zahner IM6 potentiostat, we used the three-electrode cell. The working electrode was the sample; platinum net and Ag/AgCl/KCl$_{sat}$ electrodes were used as counter and reference electrode, respectively. The potentiodynamic polarization curves were recorded with 5 mV/s scanning rate. The electrolyte was 0.5 M NaCl solution for all experiments. The resulted data calculated from Tafel curves (Figure 5.) can be seen in Table 4.

Table 4. Corrosion rates (mm/Y) of the laser welded samples

Sample	Parameter (mV)	B (V)	i_{corr}(μA/cm^2)	CR (mm/Y)
L1	5	57,702	8,222	0,0153
L1	50	-158,437	8,777	0,016
L2	5	-37,885	1,533	0,003
L2	50	26,180	1,055	0,002
L3	5	114,425	2,5	0,005
L3	50	-165,852	3,933	0,007
L4	5	137,924	3,45	0,006
L4	50	-94,354	8,388	0,016
L5	5	178,008	2,322	0,004
L5	50	-105,609	4,927	0,009
L6	5	175,578	2,95	0,005
L6	50	-21,806	4,716	0,009
L7	5	-138,281	2,916	0,005
L7	50	-33,766	20,388	0,038
L8	5	-431,201	5,611	0,0106
L8	50	-48,304	15,222	0,029
L9	5	-253,733	1,766	0,003
L9	50	-234,014	2,977	0,006
L10	5	-2821,320	1,427	0,003
L10	50	-197,795	3,488	0,006
L11	5	170,346	1,172	0,002
L11	50	-105,221	2,538	0,005
L12	5	387,729	2,777	0,005
L12	50	-96,101	8,611	0,016

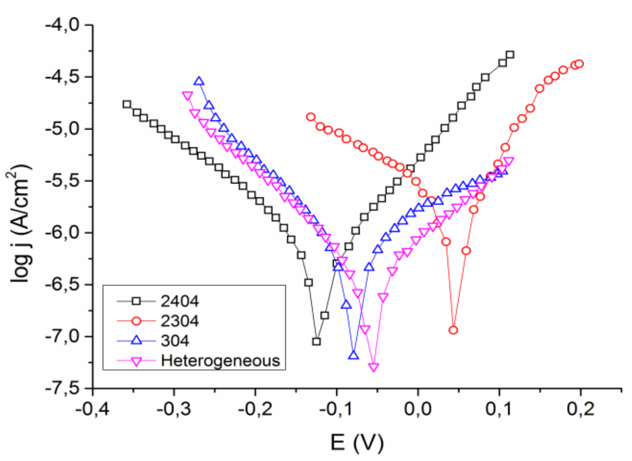

Figure 5. Potentiodynamic curves on different laser welded samples after 72 h immersion in NaCl (0.5 M) solution. The scanning rate was 5mV/s.

An important factor in galvanic corrosion is effect of the ratio of the cathodic and anodic areas. An unfavorable area ratio consists of a large cathode and a small anode.

For a given current flow in the galvanic cell, a smaller anode results in a greater current density and hence a greater corrosion rate [9]. On the basis of the results of individual polarization curves of homogen samples pair, it was found that the cathodic branch of Tafel curves implies kinetic control of cathodic reaction while the anodic branches refer mainly to mixed kinetic and diffusion controlled processes for anodic dissolution. It can be mention that significantly difference was not observed between the homogen and heterogen welded samples. It was found that the polarization curve for 2304 steel pair weld sample showed much positive than the other homogeny or heterogen samples. The positive shift of corrosion potentials accompanied by a decrease of corrosion currents indicates that the tendency to corrosion of 2304 steel pair weld sample

V. Conclusions

- The ferrite content in both weld metal and HAZ was relatively higher compared to the base metal. This has been confirmed using energy dispersive X-ray (EDX) spectrometry also. Concentrations of Cr and Mn in ferrite phase was higher, while Ni concentration was lower than in austenitic phase. The austenite content formed during cooling was depended on cooling rate. The higher the laser power and/or the lower welding speed, the coarser was the dendritic structure due to decreasing cooling rate. However, the effect of laser power was relatively less than that of welding speed.
- Corrosion rate of homogeneous welded joint were almost the same in the case of 2404 and 304 couple samples and for the 2304 sample was considerably lower.
- The improvement in corrosion properties of laser beam welded joints made using helium as a shielding gas is related to improvement in ferrite-austenite balance, in both weld metal and heat affected zone, as has been reported by other research works.

References

[1] Lula, R. A., J. G. Parr, and A. Hanson. "Stainless Steel, American Society for Metals." Metals Park, Ohio (1986).
[2] Beddoes, Jonathan, and J. Gordon Parr. "Introduction to stainless steels, 3." (1999).
[3] Peckner, Donald, and Irving Melvin Bernstein. "Handbook of stainless steels." McGraw-Hill Book Co., New York. 1977,(Chapters paged separately) (1977).
[4] Gardner, Leroy. "The use of stainless steel in structures." Progress in Structural Engineering and Materials 7.2 (2005): 45-55.
[5] Gardner, L., and N. R. Baddoo. "Fire testing and design of stainless steel structures." Journal of Constructional Steel Research 62.6 (2006): 532-543.
[6] Olivares-Ramirez, J. M., et al. "Studies on the hydrogen evolution reaction on different stainless steels." International Journal of Hydrogen Energy 32.15 (2007): 3170-3173.
[7] Davis, Joseph R., ed. Stainless steels. ASM international, 1994.
[8] Caplan, D., and M. Cohen. "High Temperature Oxidation of Chromium-Nickel Steels." Corrosion 15.3 (1959): 57-62.
[9] Fontana MG, Greene ND. Corrosion engineering. New York: McGraw-Hill (1967) 28-48.

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