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Effect of Laser Beam Welding on the Microstructure of Duplex Stainless Steels.

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Abstract. This study addressed the evolution of microstructure across some duplex stainless steel joints welded by laser beam without and with applying additional materials. The chemical composition and the thickness of the parent material modify the welded joints profile also. Similar technological parameter results different macrostructure and ferrite content at different type of additional material. Pitting corrosion resistance were also studied.

Introduction

Duplex stainless steels have a significant competitive value among stainless steels because of its high strength and the lower content of Ni. Moreover, due to its high pitting corrosion resistance, design engineers prefer to utilize duplex stainless steels rather than austenitic stainless steels as enclosing and constructive assemblies where especially chloride attack is a significant problem. The advantageous characteristics of duplex stainless steels are guaranteed by a balanced austenite / delta-ferrite distribution with minimum possible amount of secondary phases in the microstructure. Welding may deteriorate the optimum microstructure of duplex stainless steels [1 - 4].

The mechanical and corrosion properties of stainless steels welds are highly dependent on microstructure. Microstructure is affected by welding parameters, especially in case of laser beam welding. The metallurgy of the as-welded duplex stainless steel is principally determined by the weld metal composition and the cooling rate. Fast cooling rates retain more of the ferrite and lead to a higher probability of precipitation of nitrides [5]. Steel composition affects greatly the austenite formation. High nickel and nitrogen levels allow austenite to form at higher temperatures. This is due to the fact that high nickel and nitrogen levels reduce Cr_{eq}/Ni_{eq} ratio at the time ferrite solvus temperature rises and austenite can form at higher temperatures. Other elements that assist austenite formation are manganese, carbon, vanadium and copper. Elements that stabilize ferrite phase are chrome, molybdenum and silicon respectively.[5-8]

Cooling rate has a significant effect on the ferrite-austenite ratio of the weld metal. Controlling heat input is an effective way to control ferrite content of weld. Heat input effects straight on the cooling rate of the weld and thereby on ferrite-austenite ratio. [8, 9]

The usage of laser beam welding has increased continuously over the last decades and the growth has been further intensified by the introduction of high power high-brightness lasers, such as the fiber and disk lasers. The properties which are normally considered as benefits when laser welding, the low heat input and the rapid cooling rate, which prevent distortion, are however, often seen as disadvantages when welding duplex steels because excessive ferrite contents in the HAZ and fusion zone may reduce the corrosion resistance and the ductility of the material [2,9,10]. The heat input of laser beam welding is mainly affected by three different factors: absorption, laser power, and welding speed. The heat input can be easily modified by regulating laser beam power or welding

speed. Increasing welding speed the heat input decreases and respectively increasing laser power increases heat input. Absorption is tied to the wavelength of laser beam and the welded material, but the effect of additional materials were not studied before. Usually (case of TIG welding, SAW, MMA welding, FCAW) microstructure of the welds is controlled by selection of proper filler metal [11]. There is only a few researches about filler materials effects in laser welding process.

Materials and processing

In this work the weld metals characteristics after laser beam welding of four different duplex stainless steels sheets with different thickness were studied. The used LDX 2101, 2205, 2304, LDX 2404 grade steels were produced at Outokumpu Works. The chemical composition and the thickness of the sheets is presented in *Table 1*. The samples (70x120 mm) were cut perpendicular to the surfaces by Stuers Discotom 6. To perform the butt joints no edge preparations were made.

Table 1. Chemical composition of the parent materials

Steel		Thick-	Chemical composition%										
Grade	EN No.	ness (mm)	C	Si	Mn	P	S	Cr	Ni	Mo	N	Cu	Fe
LDX 2101	1.4162	1.5	0.023	0.66	4.97	0.022	0.001	21.49	1.51	0.29	0.228	0.25	rest
2205	1.4462	1.5	0.019	0.37	1.42	0.022	0.001	22.4	5.8	3.16	0.177	-	rest
2304	1.4362	2.5	0.018	0.30	1.37	0.024	0.001	23.16	4.71	0.34	0.12	0.27	rest
2404	1.4662	3	0.025	0.36	3.00	0.022	0.001	23.92	3.66	-	0.279	-	rest
LDX 2101	1.4162	3	0.022	0.67	4.97	0.022	0.001	21.52	1.57	0.29	0.213	0.32	rest

The effect of the additional materials on the laser beam welded metals microstructure were studied also. As additional material high nickel content powder material (Metco41C from Sulzer Metco) and a conventional used wire for duplex stainless steels 22 9 3 NL with 0.8 mm diameter were used. Chemical compositions of additional materials are presented in *Table 2*. The applying speed of wire feed were dependent of the parent material thickness and chemical composition.

Table 2. Chemical composition of the additional materials

Additional material	Chemical composition%						
	Cr	Ni	Mo	Si	N	C	Fe
Metco 41C powder	17	12	2.5	2.3	-	0.03	rest
22 9 3 LN	22.5	8.5	3.0	0.5	0.15	0.02	rest

To realize this work, a diode pumped Nd:YAG Rofin DY 027 laser was used. The applied power was 2500W. The powder feeding was performed applying the self-feeding Sultzer Metco apparatus, the wire feeding were on the front of laser beam (Fig. 1). Both the shielding gas and root gases were argon, which has no effect on the austenite/ ferrite ratio in molten metal.
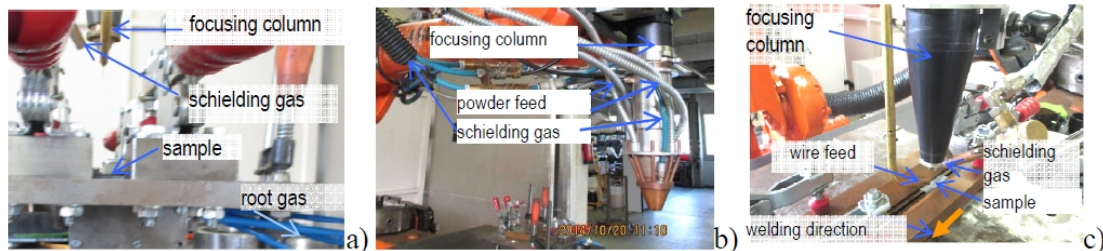

Fig 1. Instalation for this work
a) arreangement of the experiment b) head of powder additioner concentric with laser power column c) wire position in front of laser beam

Welded joints were visually inspected and samples were sectioned transverse to the welding direction, mechanically grinded and polished to 0.05 μm alumina powders. Microstructural features of the different regions of the welded joint were characterized by conventional metallographic

practices using. Kalling'2 reagent, which attack ferrite and slightly attack austenite. For quantitative analysis of the microstructure (austenite / delta-ferrite distribution) Beraha'2 reagent was used which is a colour etching material. Beraha'2 reagent composed from 85 ml water, 15 ml HCl and 1 g $K_2S_2O_5$ colours ferrite but not austenite. It provides a sufficiently high contrast of the ferrite and austenite phases.

The weld depth to width ratio (D/W) is an important quality criteria in welding, which is determined by the heat transport mode in the molten pool. The best way to study this ratio is the study the metallographic prepared specimens by stereomicroscope. The microstructure and phases in the weld line were analyzed by optical microscopy with Olympus SZX16 stereomicroscope and Olympus PMG3 inverse microscope. Quantitative faze analysis were made by J Microvision1.2.7 image analysis software.

The laser beam welding technology influence on the corrosion resistance were studied also. The samples with 10mm x 25mm sizes were put separately into glasses containing 100g of ferric chloride hexahydrate ($FeCl_3$ x $6H_2O$) in 900 ml of distilled water, according to ASTM G48.

Results and discussion

Macrostructures. Applying 1500 mm/min laser beam speed good joint were obtained both autogenously welding and welding with filler materials at sheets with 1.5 mm thickness. The focus point was on surface of the sheets in each case. The chemical composition of the base materials effects the weld metal characteristics, and the heat affected zones. These effects are well distinguishable at macrographs of heterogeneous welding *(Fig. 2. a, b)*. Applying additional material the characteristics of weld metals differs even if the welding speed and the base materials are the same *(Fig. 2. c, d, e)*.
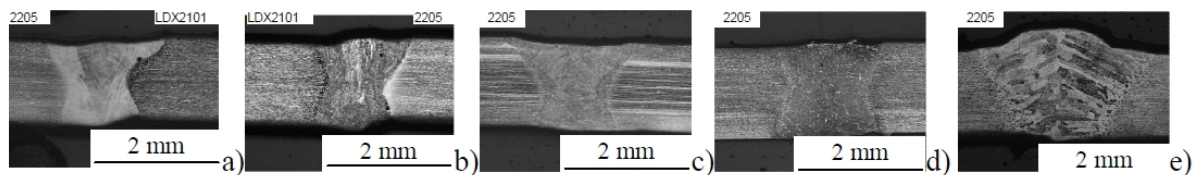

Fig.2. Effects of parent materials and additional materials on weld metals characteristics at samples with 1.5 mm thickness; $v_{laser\ beam}$ = 1500 mm/min; Beraha'2 reagent;
a) 2205-LDX2101 heterogenic autogenously welding. b) 2205-LDX2101 heterogenic welding with 15 g/min powder addition c) 2205 autogenously welding d) 2205 sheets welded with 15 g/min powder addition e) 2205 sheets welding with wire addition , v_{wire} = 1000 m/min

Applying additional materials the welding speed had to be reduced at samples with 2.5 -3 mm thickness. Good square butt welding joint appeared when the focus plane was right at the at surface both autogenously welding and laser beam welding with powder applying at each thickness, but no in case of laser welding by wire addition. El-Batahgy et al. [12] demonstrated in case of 2205 duplex stainless steel plat that applying defocusing and modifying the laser welding speed can change welded joints profile. At our 2.5- 3 mm thickness samples positive results (good welding joins) were obtained with defocusing plane of laser beam to 4-6 mm under surface, applying 350- 500 mm/ min laser beam welding speed and 1000 mm/min wire addition speed *(Fig 3. -4)*.
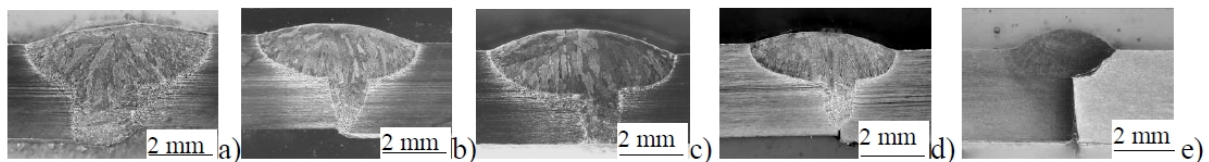

Fig. 3. Defocusing level and laser beam speed effect on the macrostructure of welded join applying 22 9 3 LN welding wire , v_{wire} = 1000 m/min, at sheets with 3 mm, Kalling'2reagent
a) 2404 sample d_f = 4 mm, v_{laser} = 350 mm/min b) 2404 sample d_f = 6mm v_{laser} = 350 mm/min
c) 2404 sample, d_f = 6 mm, v_{laser} = 400 mm/min d) 2404 sample d_f = 6mm, v_{laser} = 500 mm/min
e) 2404-LDX2101 sample d_f = 10 mm, v_{laser} = 400 mm/min

The most acceptable welding profile on the transversal section of 2404 duplex steels samples with 3 mm thickness the 4 mm defocusing level combined with 350 mm/min laser beam speed has been produced during welding with 22 9 3 LN wire. In case of 2304 samples the best weld depth to width ratio was obtained with 4 mm defocusing level combined with 500 mm/min for laser beam speed *(Fig. 4)* in case of laser beam welding combined with wire adding .

In case of similar welding procedures the fusion zone width decrease with increasing welding speed at same material *(Fig. 4)*.
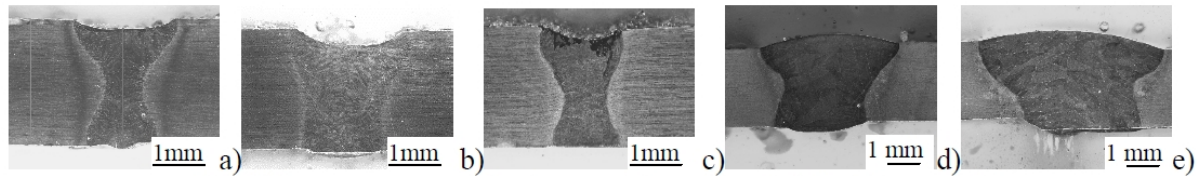

Fig. 4. Stereomacrographs about weld metals at 2304/ 2.5 m samples
a) $v_{laser\ beam}$ = 1800 mm/min b) $v_{laser\ beam}$ = 750 mm/min c) v_{powder} = 14 g/mm
+ $v_{laser\ beam}$ = 900 mm/min d) v_{wire} = 1000 mm/min + $v_{laser\ beam}$ = 500 mm/min
e) v_{wire} = 1000 m/min+ $v_{laser\ beam}$ = 350 mm/min

Microstructure. All duplex stainless steels solidify as primary ferritic solidification mode and austenite forms by solid state transformation. Ferrite phase is stable in elevated temperatures and this temperature is dependent on steel composition. When temperature drops below ferrite solvus temperature ferrite begins to transform to austenite. The nature of ferrite-austenite transformation is dependent on steel composition, additional material if exist and cooling rate. This transformation ultimately determines ferrite-austenite balance in the final weld metal. Heat input effects straight on the cooling rate of the weld and there by on ferrite-austenite ratio. The heat inputs can be modified by welding speed, focus point of laser beam and by additional materials. Pekkarien et al. observed that when solidification and cooling rate are high austenite formation can decrease [9].

As we can see in *Fig.4* the ratio of the weld depth to width increase with welding speed. Studying the microstructures in high resolution it was observed that the grain shape (roundness) is modified by cooling rate. Decreasing of leaser beam speed the roundness of the solidified grain increase and the quantity of fine dispersed austenite island (light) inside of grains ferritic (darken) matrix increase *(Fig. 5)*. In ferrite content were no significant difference *(Fig.7.a)*.
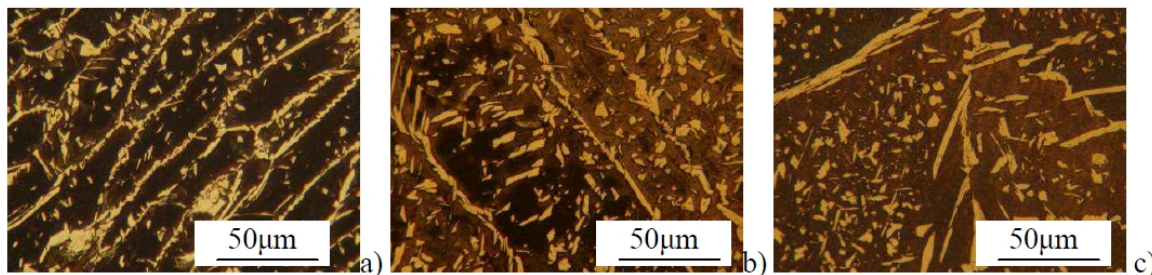

Fig. 5. Laser beam speed effect on the microstructure of weld metal at LDX2101/ 1.5 samples after autogeneous welding Beraha'2 reagent N = 500×
a) $v_{laser\ beam}$ = 3000 mm/min b) $v_{laser\ beam}$ = 1500 mm/min c) $v_{laser\ beam}$ = 750 mm/min

The effect of additional material on weld metal and on heat affected zone at same material and similar welding condition is presented in *Fig.6*. Austenite appears on grain boundaries and inside of grains as islands in ferritic matrix. The heat affected zones were narrow in each cases. The weld metals of samples welded with powder addition are inhomogeneous. The face of these samples contain more austenite, compared to the centre of the weld metal *(Fig. 2 b), d); Fig. 4. c)* and *Fig. 6 b)*. Quantitative analysis of the microstructures were effectuated on several micrographs recorded in high resolution, after etching the metallograficaly prepared samples with Beraha'2 reagent. At each samples ten number of image from characteristic weld metals were analyzed. The quantitative analysis results are presented in *Fig. 7*.
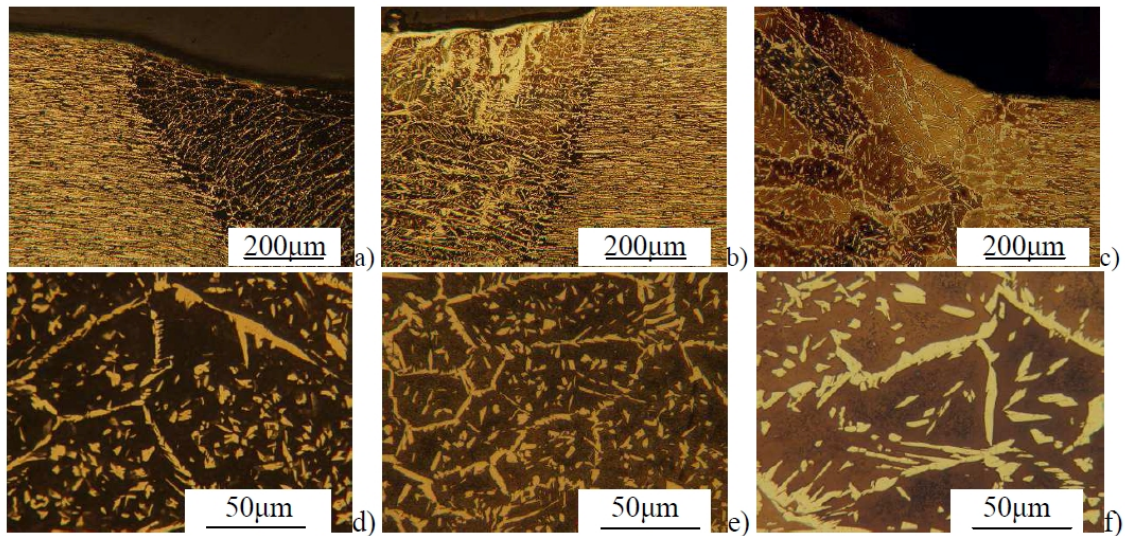
Fig. 6. Effects of additional materials on weld metals and heat affected zone at LDX2101 samples with 1.5 mm thickness, v $_{laser\ beam}$ = 1500 mm/min; Beraha'2 reagent; a)HAZ autogenously welding N = 100× b) HAZ powder addition v$_{powder}$ = 14 g/mm, N = 100× c) HAZ wire addition v$_{wire}$ = 1000 m/min, N = 100× d) autogenously welding N = 500× e) powder addition, v$_{powder}$ = 14 g/mm N = 500× f) wire addition, v$_{wire}$ = 1000 m/min, N = 500×
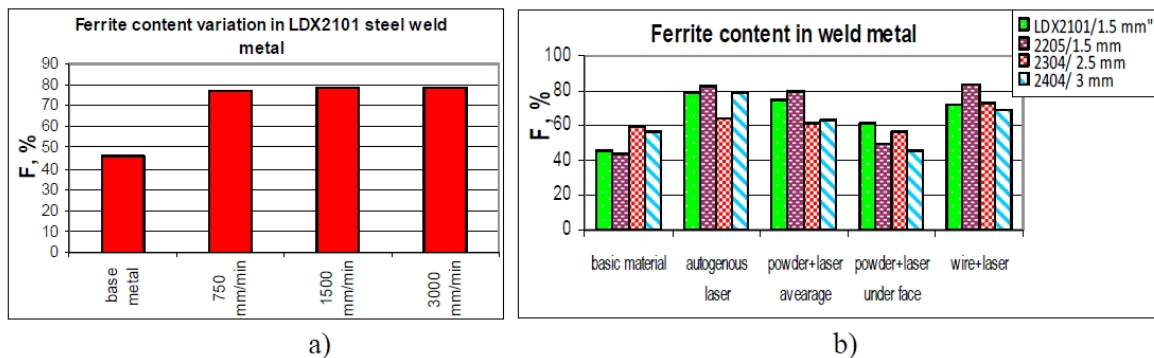

Fig 7. Welding parameters effect on ferrite content in weld metal
a) laser beam speed effect on autogenously welded LDX2101/1.5 samples b) summary of ferrite content modifications

Corrosion resistance Ferric-chloride test revealed how the laser beam welding technology influences the corrosion resistance according to ASTM G48. The weight changing was measured after 24h, 48h and 72h. In *Fig. 8* the mass loss measured after 72 hours are presented. Studying the corrosion behaviour of the weld joints it was observed the additional materials increase the corrosion resistance. At all metals the less mass loss were produced at joints which were done by 22 9 3 NL wire addition and the most mass loss were observed

Fig. 8. Corrosion mass loss of welded samples with different welding material addition

at autogenously laser beam welding with exception of LDX2101 lean duplex samples, where the most mass loss was measured at welding with Metco 41C powder. There is the possibility of a galvanic reaction (dissimilar metal).
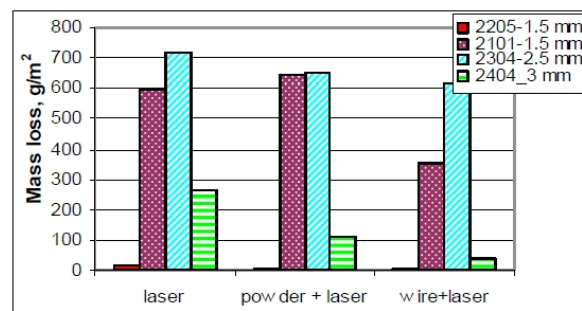
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The most resistant samples were the laser welded sheets with high Ni and Mo content. The mass loss of 2205 autogenously welded sample was 15.85 g/ m^2, the sample obtained after Metco 41C powder addition loss 6.22 g/ m^2 after 72 hours in room temperature, and only 3.58 g/ m^2 loss the sample welded with wire addition.

Summary

Four types of duplex stainless steels weld metals were studied. The sheets thickness were 1.5-3 mm. Laser welding with argon shielding gas with and without additional materials were studied.
The chemical composition of the base materials affects the weld metal characteristics.
The weld depth to width ratio changed with the change in laser beam welding speed and defocused distance, depending on the material. At same material and thickness the fusion zone width and area decrease with increasing welding speed in case of similar welding procedure.
In characteristically microstructure of weld metals the ferrite content are higher than in basic materials.
After corrosion test the less mass loss were observed at samples which were welded by wire addition at same material. The less sensitive for corrosion is the 2205 standard duplex steel, and less resistance present the LDX2101 lean duplex steel.

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