LASER BEAM WELDING OF SUPERDUPLEX STAINLESS STEEL WITH POST-HEAT TREATMENT

Ladislav SCHWARZ, Tatiana VRTOCHOVÁ, Koloman ULRICH

Authors: ***Ladislav Schwarz, MSc. Eng., Tatiana Vrtochová, MSc. Eng., Koloman Ulrich, Profesor, PhD.***
Workplace: ***Department of Welding, Institution of Production Technologies, Faculty of Materials Science and Technology, Slovak University of Technology***
Address: ***ul. J. Bottu 25, 917 24 Trnava, Slovak Republic***
E-mail: ***ladislav.schwarz@stuba.sk, tatiana.vrtochova@stuba.sk, koloman.ulrich@stuba.sk***

Abstract

This paper investigates the structure and ferrite/austenite content of 2507 duplex stainless steels joints by laser welding. The quality of welded joints was assessed mainly metallographically (including optical microscopy). The results of ferrite content measurement in weld metal and in base metal show, that application of suitable post heat made possible to reduce the ferrite content in weld metal by 12 %. These results suggest that such a procedure leads to positive results.

Key words

duplex stainless steel, laser beam welding, welding parameters, ferrite and austenite contents

Introduction

Duplex stainless steels are very attractive constructional materials for service in aggressive environments and in many industry branches like petrochemical, chemical and paper, energy, gas fuel, power generations, marine transportations, etc. Such steels offer several advantages over the common austenitic stainless steels. The duplex grades are highly resistant to chloride stress corrosion cracking, have excellent pitting and crevice corrosion resistance and are about twice as strong as the common austenitic steels [1, 6]. The duplex stainless steel is two – phase steel with the structure composed of austenite and ferrite. Optimum austenite/ferrite proportion is 50 % [3]. The suitable structure is obtained by heat treatment at approximately 1050 to 1150 °C (*solution annealing*). The optimum ratio between both phases can be influenced by the welding processes. The duplex steels are normally weldable using welding procedures generally used for high alloyed steels. The experience with such comparatively new welding method like laser beam welding is still limited [4].

Characteristic of welding problem

Duplex stainless steels have an optimized content of individual components (*50 % ferrite - δ and 50 % austenite - α*) with precondition for desired austenite proportion and also desired mechanical and corrosive properties of weld. The iron-chromium-nickel ternary phase diagram is a roadmap of the metallurgical behavior of the duplex stainless steels (Fig. 2). Duplex steel solidifies from the melt first fully as ferrite and ferrite is later partially transformed to austenite towards temperature of 1 000 °C. For wrought alloys, the microstructure has morphology of laths of austenite in a ferrite matrix [5]. Essential parameters for welding duplex steels are therefore heat input, cooling rate.

Laser beam processes, which do not use filler metal, are not recommended since they provide welds with a high ferrite proportion, owing to low heat input and too fast cooling weld. Low heat input and too fast cooling rate may result in undesirable proportion of ferrite in weld and in the heat affected zone and in corresponding loss of toughness and corrosion resistance. Maximum average ferrite content should be within 40 to 50 %. Improvement may be achieved only by bulk annealing after welding at temperatures 1150 to 1050 °C, what however represents an undesired operation increasing the welding costs.

The effect of increasing nitrogen content is also shown in Fig. 2. Beneficial effect of nitrogen is that it raises the temperature at which the austenite begins to form from the ferrite. Therefore, even at relatively rapid cooling rates, the equilibrium level of austenite can almost be reached [2, 4].

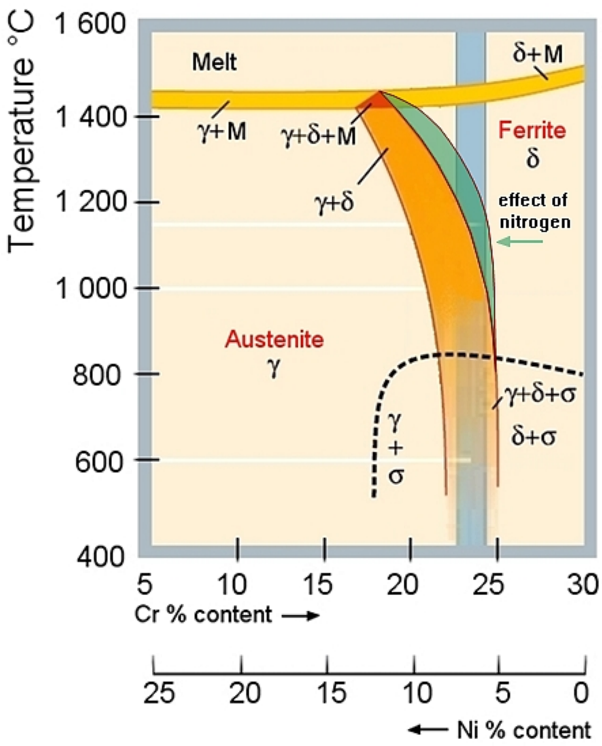

Fig. 1 *Ternary Fe – Cr – Ni phase diagram at 70 % Fe section*

Programme of experiments

All experiments were performed with material in form of a seamless tube without final forming and surface heat treatment, made of duplex steel type SANDVIK SAF 2507 with dimensions ø 42 x 3.5 x 500 (mm).

Sandvik SAF 2507 is a high alloy superduplex (*austenitic-ferritic*) stainless steel for service in highly corrosive conditions [4]. It is characterized by excellent resistance to stress corrosion cracking in chloride-bearing environments, excellent resistance to pitting and crevice corrosion, high resistance to general corrosion, very high mechanical strength, physical properties that offer design advantages, high resistance to erosion corrosion and corrosion fatigue and good weldability.

The chemical composition and mechanical properties of used steel are given in Tables 1 and 2.

CHEMICAL COMPOSITION OF SAF 2507 STEEL (%) Table 1

C max.	Si max.	Mn max.	P max.	S max.	Cr	Ni	Mo	N
0,030	0,8	1,2	0,035	0,015	25	7	4	0,3

MECHANICAL PROPERTIES OF SAF 2507 STEEL AT 20 °C, PIPES WITH WALL THICKNESS MAX. 20 mm Table 2

Yield point $R_{p0,2}$ (MPa) min.	$R_{p0,1}$ (MPa) min.	Tensile strength R_m (MPa)	Elongation A (%) min.	HRC hardness max.
550	640	800 – 1000	25	32

In order to guarantee a balanced ferrite/austenite ratio of the weld, heat treatment after welding, and solution annealing is recommended, what however represents an undesired operation increasing the welding costs.

Low heat input and rapid cooling (*laser beam welding*) rate may result in undesirable proportion of ferrite in weld and in the heat affected zone and in corresponding loss of toughness and corrosion resistance. Maximum average ferrite content should be within 40 to 50 %.

We tried to solve the mentioned drawbacks of beam welding duplex steels in the following way:

- by reducing the cooling rate applying the post-heat after welding by a defocused beam with several passes (*rotations*) along the weld zone,
- by application N_2 gas during welding and post-heat operation.

Welding was performed on Gas CO_2 laser machine Ferranti Photonics AF 8 with max. output 8 kW. With wave length 10.6 µm. The mentioned laser is of versatile type suitable for hardening, welding, thermal cutting and cladding. Welding tests were performed in form of penetration run into solid material with parameters given in Table 3. Fabrication of penetration runs was immediately followed with post-heat, performed with defocused beam with parameters given in Table 4.

PARAMETERS OF WELDING Table 3

Power	4,7 kW
Welding speed	15 $mm.s^{-1}$
Shielding gas	N_2 (*18 l/min*)
Thermal input	0,188 $kJ.mm^{-1}$
Defocusing	on surface (f = 0)

PARAMETERS OF POST HEAT Table 4

Power	4,7 kW
Speed of post heat	15 $mm.s^{-1}$
Shielding gas	N_2 (*18 l/min*)
Number of passes	3
Defocusing	f = + 20 mm

The results

The samples were subjected to metallographic structural (*macrostructure and microstructure*) analysis and ferrite content measurements. Microstructure of base metal, fusion zone and weld metal was examined.

Metallographic studies were performed on all specimens of welded joints. Macrostructures of laser welded joints of stainless steel SAF 2507 are given in Fig.2. The macrostuctural observations have shown that all fabricated joints were without any apparent defects like cracks or pores. In case of some weld roots overrunning was observed.

Fig.2a shows the macrostructure of laser welded joints after welding. Observation of macrostructure has shown, that the width of the heat affected zone (*HAZ*) is relatively small, the weld consists of one layers and the weld root is not overrun. Characteristic surface and root of penetration runs of laser weld joint after application post heat by defocusing laser beam is shown in Fig.2b. Macrostructure show that the width of the heat affected zone is small, the weld consists of two layers and the weld root is slightly overrun. No inhomogeneities were found in the joint.

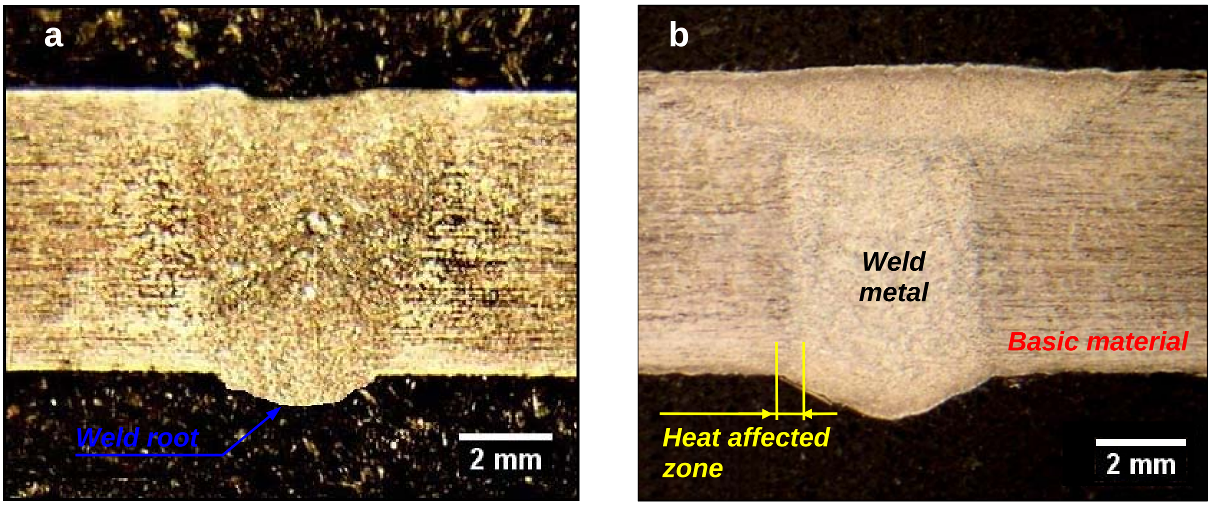

Fig. 2 *Macrostructures of laser welded joints*
a) after welding, b) after application post heat

Microstructural observations of welded joints were performed by use of optical microscopy. Microstructure of base metal (*BM*) is linear, what corresponds to tubular products. Bright particles in the photos represent austenite and the dark ones ferrite. Structural character of individual samples actually does not differ.

Fig.3 shows the microstructure of laser welded joints after welding without additional heat effect of weld metal (*WM*). Microstructure of base metal consists of ferrite with austenite islands. The fusion line is distinct, where the fused zone has polyhedral and acicular structure with finer grain than further in weld metal (Fig. 3a). Fusion zone between the weld and the base metal is contiguous, relatively plain and without any integrity defects. These facts point to the perfect metallurgic joint of the weld and the basic material.

Microstructure of weld metal is composed of ferrite and austenite is excluded on frontiers grains. (Fig. 3b). There are no non-integrity signs like cracks or poruses in the weld that would be visible to the naked eye.

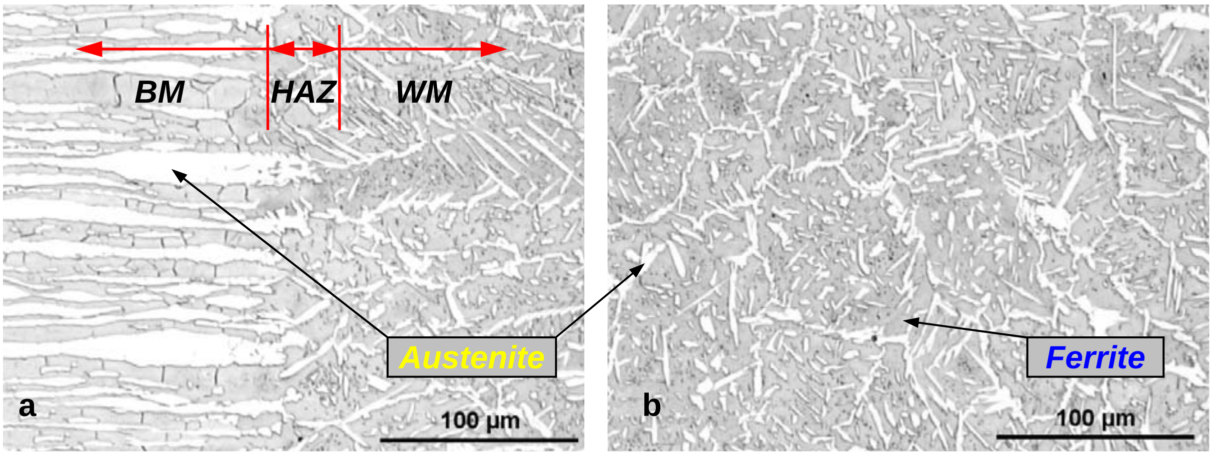

Fig. 3 *Microstructure of welded joint after welding without post heat*
a) HAZ between the base metal and the weld metal, b) weld metal

Fig. 4 shows the microstructure of laser welded joints after welding with additional post heat of weld metal (*WM*).

The fusion line is distinct, where the fused zone has polyhedral and acicular structure with finer grain than further in weld metal (Fig. 4a). Fusion zone between the weld and the base metal is without any integrity defects. These facts point to the good metallurgic joint of the weld and the basic material.

The matrix of weld is formed of ferrite and austenite forms a network along the grain boundaries (Fig. 4b). Austenite is excluded on frontiers grains the ferritic grains in form of massive particles. Structure coarsening was observed in the upper part of weld. Typical columnar ferrite grains can be observed along the boundaries with excluded austenite, which had partially dendritic character and in some zones also acicular morphology was observed. There are no non-integrity signs like cracks or poruses in the weld and his surroundings.

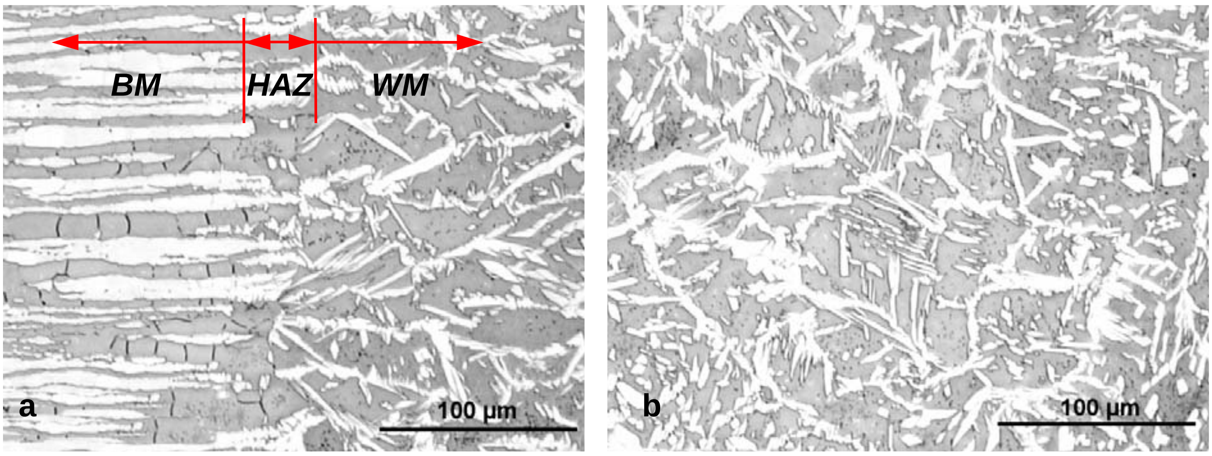

Fig. 4 *Microstructure of welded joint with post heat*
a) HAZ between the base metal and the weld metal, b) weld metal

Measurement of ferrite proportion was performed according to ASTM E 562 standard test, which specifies the ferrite amount in percentual content of ferrite. The test is evaluated on the basis of counting the points of pervading the selected phase within the grid. Ferrite content in these samples is shown in Table 5.

FERRITE CONTENT IN WELDED JOINTS Table 5

Sample	Point of measurement	Min. ferrite content (%)	Max. ferrite content (%)	Average ferrite content (%)	
				In given point	*Total*
Without post heat	Weld surface	52	78	64	**64**
	Weld centre	48	72	61	
	Weld root	56	68	67	
With post heat	Weld surface	40	72	52	**52**
	Weld centre	28	68	47	
	Weld root	44	64	57	

Ferrite content is high in no treated weld joints. In thermal treated joint the ferrite content is on limit. The ferrite % in weld metal was in all cases higher than in the base metal. Generally the content of ferrite > 70 % is considered as high. Ferrite content in all weld metals of tested variants is highest in the root zone of penetration runs compared to surface and centre of penetration depth. Whereby the penetration run with 3 rotations of post-heat has average ferrite content 52 %, what is very favorable and corresponds to requirements for base metal.

Conclusion

The welded joints were fabricated by CO_2 laser Feranti Photonics type AF8 in the First Welding Company Inc. in Bratislava.

Based on the experiments performed on laser beam welded joints fabricated in duplex stainless steel type SAF 2507, the following can be stated:

The structure of reference weld metal consisted of columnar ferrite grains with austenite precipitated on the grain boundaries. In specimens welded with post heat application, the grain refining and precipitation of austenite also inside ferritic particles occurred. A coarsened structure was observed on the surface of weld, caused by multiple laser beam passing during the post heat of weld. In no case the defects like cracks or pores were observed.

The results of ferrite content measurement in weld metal and in base metal performed according to ASTM E 562 show, that application of suitable post heat made possible to reduce the ferrite content in weld metal even by 12 %.

Based on the results of experimental activities it may be concluded that the CO_2 laser is suitable for welding of the duplex stainless steel type 2507 with application of post heat process by defocused laser beam immediately after welding.

Acknowledgement

This paper was supported under projects APVT-20-011004, APVT-20-020904, VMSP-P-0008-07

References:

[1] LIPPOLD, J. C., KOTECKI, D. J. *Welding Metallurgy and Weldability of Stainless Steels*. New Jersey: WILEY-INTERSCIENCE, 2005. 357 p. ISBN 0-471-47379-0

[2] HRIVŇÁK, I. Dual-Phase Stainless Steels – material of pipelines for aggressive media. In: *Corrosion of Underground Structures 2003. Proceedings of the 13th International Conference Corrosion of underground structures 2003*, 27 and 28 may 2003. Košice: technical University in Košice, 2003, p. 54-59. ISBN 80-7099-251-4

[3] KOLENIČ, F., IŽDINSKÁ, Z., FODREK, P. Influence of EB Welding Parameters on Properties of Welded Joints in Duplex steel type SAF 2205. In *60th Annual Assembly and International Conference: Proceedings of the IIW International Conference Welding and Materials*. Technical, Economic and Ecological Aspects. 01-08 July 2007 Dubrovnik & Cavtat. Croatia, Zagreb: Croatian welding society, 2007. p. 1-13. ISBN 978-953-7518-00-4

[4] KOLENIČ, F., KŘEČEK, I., DŘIMAL, D. Prospects in Laser Welding of Duplex Steels. In *Welder*, 2008, vol. 5, no. 3, p. 7 – 11.

[5] SCHWARZ, L., VRTOCHOVÁ, T. Study of solidification and structural modifications of duplex and superduplex steels. In *Welder*, 2010, vol. 7, no. 1, p. 7 – 10.

[6] Available on internet: < www.stainless-steel-world.net >