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Welding imperfections of submerged arc welded duplex steel joints in aspects of the welding heat input

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Abstract: An influence of the heat input submerged arc welding of duplex steel UNS S31803 on kind and quantity of welded butt joints defects has been determined. Defects were identified by a radiographic method. As a defectiveness rate it was taken the ratio of quantity negative test results RN to complete radiographic test RC. Analysis of welding heat input influence on mechanical properties of test joints using heat input from 2,5 to 4,0 kJ/mm. For analysis of welding heat input influence on creation of welding imperfections, there were executed welding of sheet of thickness 10 – 32 mm using two ranges of the welding heat input: up to 2,5 kJ/mm and up to 3 kJ/mm. It was shown that submerged arc welding of duplex steel with the heat input from 2,5 kJ/mm up to 4,0 kJ/mm has no negative influence on mechanical properties of the joints. Experiment showed, that welding with heat input up to 3,0 kJ/mm reduces welding defects of joints, e.g. slugs, lack of a joint penetration for plates of thickness of 10 – 23 mm, as well as sticks, cracks, and the thoroughly decrease of other defects existence. Usage larger welding heat input provides the best joints quality, what decreases the joints control and repair costs.

Keywords: Technological sciences, Mechanical engineering, Welding

1. INTRODUCTION

Submerged arc welding of steels demanding limited heat input of welding, e.g. high-strength steels, austenitic steels, austenitic-ferritic steels require a such selection of parameters, which are a compromise between welding efficiency and joint quality [1 - 3]. Basic parameters of submerged arc welding are: arc current kind, intensity, and voltage, speed of welding, wire diameter, length of wire extension, thickness and width of welding flux layer and inclination angle of an electrode or a welded joint. Edge preparation has essential influence on quality of welding (Fig. 1).

2. EXPERIMENT

In the first stage of tests of duplex steel submerged arc welding, an analysis of the filler metal consumption in different variants of welding has been done with usage of the guidelines presented in literature [4 - 6] and of the recommendations of the filler metals suppliers. On account of mechanical properties and corrosion resistance, of welds main limitation of welding process of duplex steel is quantity of heat input - HI [7 - 9]. Plates subjected to welding are prepared according to Fig. 1, with $\alpha = 80^{o}$, h = 6 mm, d = 0 ÷ 0.5 mm, $t_1 = t_2 + (2 \div 3)$ mm, using two limits of the welding heat input: up to 2,5 kJ/mm, and up to 3 kJ/mm. Duplex steel UNS S31803 was used as a parent material. Welding of the test plates was carried out with the usage Avesta welding parent

materials: wire ø 3,2 mm grade 2205, and a flux material - Flux 805 – with alkalinity ~1.7 [10]. The welding heat input was calculated according to the equation (1).

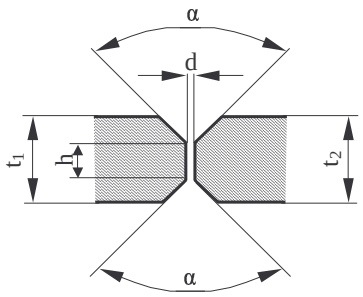

Figure 1. Scheme of a joint preparation of submerged arc welding according to weld materials producer recommendations; width of a root face - h = 3 ÷ 8 mm, groove angle - α = 60 ÷ 100 °, root face gap - d = 0 ÷ 0,5 mm, total thickness of plates - t_1, t_2 mm

$$HI[kJ/mm] = \eta * \frac{I[A]*U[V]}{Vsp[mm/s]*1000} \quad (1)$$

where: HI – welding heat input, η – coefficient of welding efficiency, I – welding current intensity, U – welding voltage, Vsp- speed of welding

Chemical composition and mechanical properties of the parent material - steel UNS S31803 and the additional materials - combination of welding wire 2205/flux 805 are presented in Tables 1, and 2. Welding processes have been made with the max welding linear energy: HI ≤ 2.5; HI ≤ 3.0; HI ≤ 3.5; HI ≤ 4.0.

Table 1.
Chemical composition and mechanical properties of the parent material - steel UNS S31803

Chemical composition of the steel UNS S31803, average values [%]								
C	Si	Mn	P	S	Cr	Ni	Mo	N
0.03	0.9	1.8	0.025	0.015	22.1	5.2	2.9	0.17
Mechanical properties, average values								
Re [N/mm^2]		Rm [N/mm^2]			KV -20^{o}C [J]			
590		780			170			

Table 2.
Chemical composition and mechanical properties of the additional materials - combination welding wire2205/flux 805 [10]

Chemical composition, average values [%]					
C	Si	Mn	Cr	Ni	Mo
0.02	0.6	1.1	23.0	8.5	3.0
Mechanical properties, average values					
Re [N/mm^2]	Rm [N/mm^2]	A5 [%]	KV +20^{o}C [J]	KV -40^{o}C [J]	
590	800	28	90	70	

Mechanical tests of the joints: bend test of the root and face (min specified angle 120º; mandrel diameter 5 x thickness of the plate), Rm, KV and HRC tests have been made according to Det Norske Veritas Rules [13] Corrosion tests have been made according to

DNV Rules Pt.2 Ch.3 Sec.2 – D-200 – Method of Examination and ASTM G48-76 Method A). Ferrite share has been made according to DNV Rules Pt.2 Ch.3 Sec.2 D203 – acc. to ASTM E562 Specification. An influence of the heat input of duplex steel submerged arc welding on a type and quantity of welding imperfections of butt joints have been determined by means of X-Ray tests. In this order ratio of quantity of radiographs with the negative results – RN to the complete quantity of radiographs RC was established as index of the welds defectiveness RC. Radiographs were classified basing on PN-12517 and PN-EN 25817 – Arc-Welded Joints in Steel – Guidance on Quality Levels for Imperfections. In the second stage of the experiment joints of the plates 10 metres long were done according to established edge preparation and thickness: 10 ÷ 15; 16 ÷ 21; 22 ÷ 27; 28 ÷ 32 mm. Fraction index of the welding imperfections types occurring in joints WR in relation to the complete quantity of X-ray testing was determined. Submerged welds of duplex steel were subject to the visual and X-Ray examinations on the basis of criteria and requirements of Polish – European Standards. Welds should meet criteria of quality level B according to PN-EN 25817 [12, 13, 14]. Tests were carried out by X-rays apparatus Baltospot Ceram 235.

$$W = \frac{RN \times 100}{RC}[\%] \quad (2) \qquad WN = \frac{RW \times 100}{RN}[\%] \quad (3) \qquad WR = \frac{RW \times 100}{RC}[\%] \quad (4)$$

where: W [%] – percentage index of welds defectiveness, RN [pcs.] – quantity of tests with negative result, RC [pcs.] – complete quantity of radiographs, RW – quantity of radiographs with a specific type of weld imperfection.

3. RESULTS

The mechanical properties test results are presented in Tables 3 – 5. The weld shape and imperfection (Table 6) test results are presented in and Figures 2 – 6.

Table. 3.
Results of Rm of tested plate of 26 mm thickness

Heat input HI [kJ/mm]	Rm Average value [MPa]	Fracture place
HI ≤ 2,5	690	Fracture in the parent material
HI ≤ 3,0	750	Fracture in the parent material
HI ≤ 3,5	747	Fracture in the parent material
HI ≤ 4,0	744	Fracture in the parent material

Table 4.
KV of tested plate of 26 mm thickness

Heat input HI [kJ/mm]	Average value of KV [J] for notch localization			
	Weld metal	Fusion line FL	HAZ FL + 2 mm	HAZ FL + 5 mm
HI ≤ 2,5	120	90	105	119
HI ≤ 3,0	115	135	220	200
HI ≤ 3,5	80	148	160	148
HI ≤ 4,0	78	155	218	184

Results of the X-Ray tests of welds made with a usage of maximum hit input HI ≤ 2.5; HI ≤ 3.0; HI ≤ 3.5; HI ≤ 4.0kJ/mm proved lack of the negative influence of this l hit input value on duplex steel joints quality. Results of the mechanical properties tests of joints fulfil the requirements regarding duplex steel joints [13]. Next the tests with usage of two heat input values: HI ≤ 2.5 and HI ≤ 3.0kJ/mm have been carried out in production conditions. It was affirm the lack of inadmissible welding imperfection in the joints.

Table 5.
HV5 of tested plate of 26 mm thickness

HV5						
Heat input HI [kJ/mm]	Parent material		Weld metal		HAZ	
	min	max	min	max	min	max
HI ≤ 2,5	235	261	248	269	244	273
HI ≤ 3,0	233	272	255	284	238	277
HI ≤ 3,5	237	248	263	290	241	269
HI ≤ 4,0	240	262	259	288	254	281

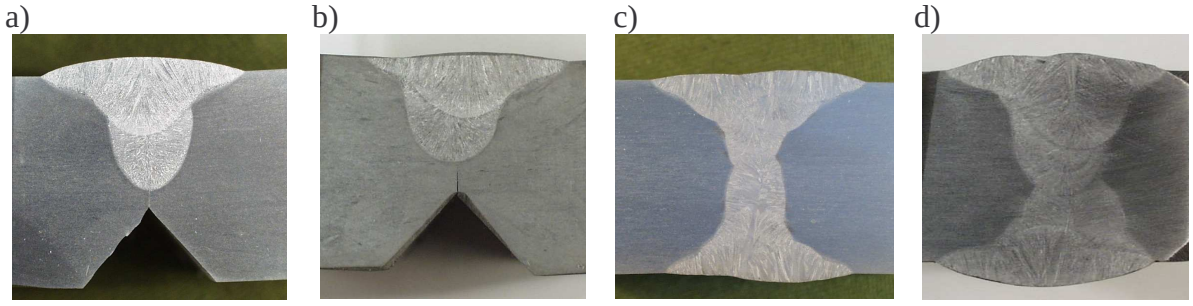

Figure 2. Shape of the weld bead of plate of 26 mm thickness; a) HI ≤ 2.5kJ/mm , b) HI ≤ 3.0kJ/mm; plate of 30 mm thickness; a) HI ≤ 2.5 kJ/mm , b) HI ≤ 3.0kJ/mm

Types of weld imperfections found as the tests result are presented in Table 7. The experiment proved, that assumed welding heat input up to 2,5 kJ/mm while submerged arc welding with above mentioned edge preparation led to occurrence of many inadmissible welding imperfections. Application of welding heat input of about HI = 3 kJ/mm caused radical decrease in welds defectiveness. Table 8 represents percentage occurrence index of kinds of welding imperfections in a joint WN calculated according to e.g.. 1.

Table 6.
Types of welding imperfection found in the test

Type	Marking
gas cavity	2011
slag inclusion	3012
linear slag	3011
lack of side fusion	4011
lack of joint penetration in two-sided weld	402
longitudinal crack in weld	1011
root and face undercut	5011/ 5012

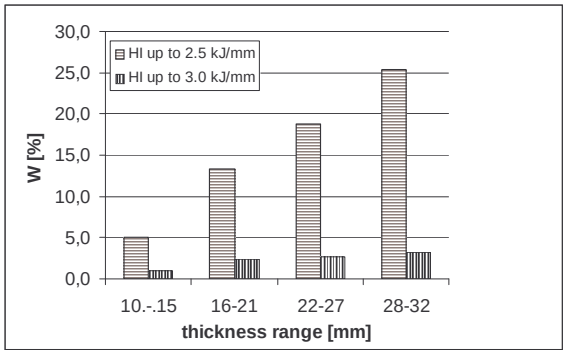

Figure 3. Fraction of welding imperfections W – acc. to equation 2 in X-rays testing for HI ≤ 2.5 kJ/mm and HI ≤ 3.0 kJ/mm

The tests proved that welding with heat input up to 3.0 kJ/mm reduced welding imperfections occurring in joints, e.g. slag, lack of joint penetration, and for plates of 10 - 23 mm thickness - incomplete fusion and cracks, as well as decreased radically occurrence of other welding imperfections. On the base of the tests results it can be stated, that in terms of the duplex steel welding quality higher heat input improves quality of welds. It has an important influence on costs of repair. The problem is limitation of quantity of heat introduced into the weld causing a necessity to use many operations to ensure high quality of the joints and the following of basic principles of duplex steel welding process, as: stable welding parameters, proper wire feeding, correct weld shape, correct assembly of elements to be joint, lack of contamination like dust, point, oil and humidity, minimizing of welding stresses.

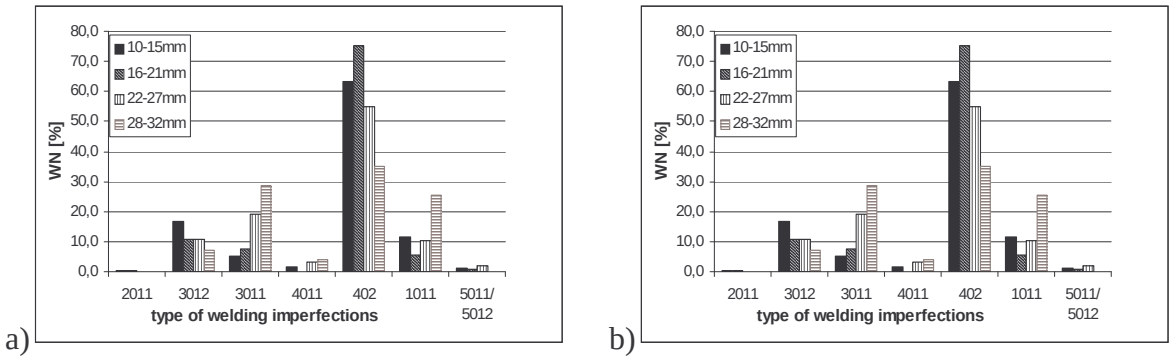

Figure. 4. Fraction of welding imperfections in X-rays testing with negative result WN – acc. to equation 3 for a) HI ≤ 2.5kJ/mm, b) HI ≤ 3.0 kJ/mm

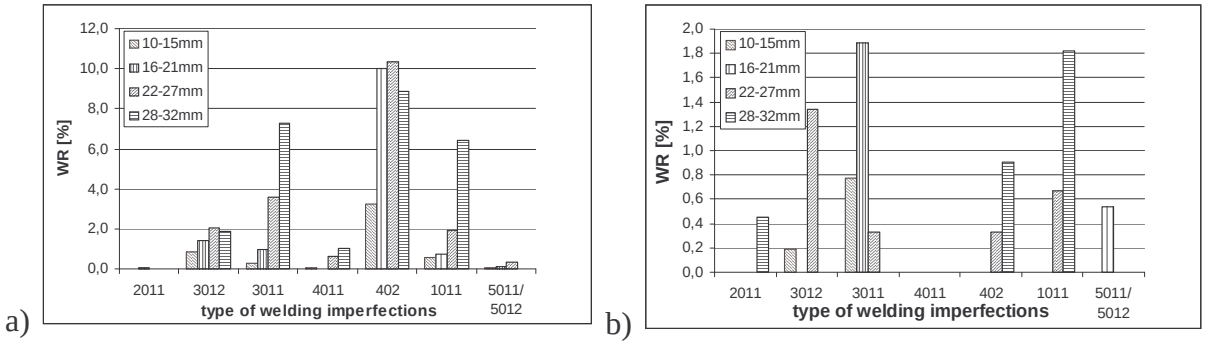

Figure. 5. Fraction of welding imperfections in X-rays testing with negative result WR – acc. to equation 4, for a) HI ≤ 2.5kJ/mm, b) HI ≤ 3.0 kJ/mm

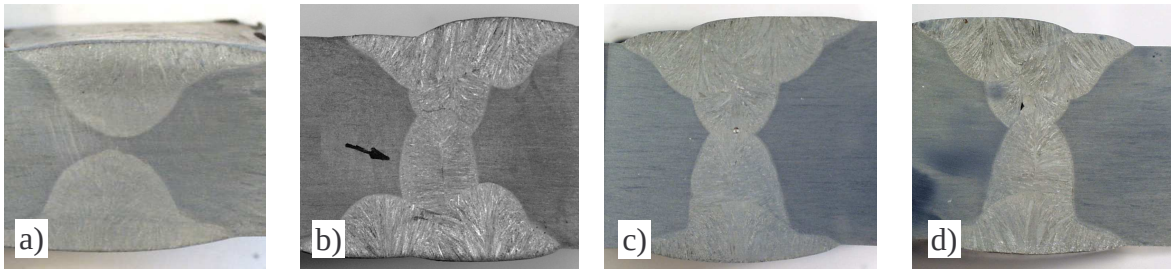

Figure. 6. Macroscopic image of a weld with a) lack of joint penetration, b) crack, c) pinhole, d) slag

4. CONCLUSION

Increase of the welding heat input in submerged arc welding of duplex steel results in decrease of occurrence and size of welding imperfections with regard to a quantity and length of imperfections. Increase of the welding heat input improves of the weld shape coefficient and decreases possibility of cracks creation. Mechanical tests of joints welded with maximal hit input HI ≤ 2,5; HI ≤ 3,0; HI ≤ 3,5; HI ≤ 4,0kJ/mm fulfilled requirements for duplex steel acc. to Det Norske Veritas Rulesand showed, that there was no negative influence of hit input increase on welds quality, in considered hit input range, on mechanical properties of joints. As a result of the tests, it can be stated that increase of plate thickness increases weld defectiveness of duplex steel. Increase of welding hit input reduces occurrence of inadmissible welding imperfections in joints, what reduces costs of testing and repairs.

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