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The influence of welding heat input on submerged arc welded duplex steel joints imperfections

Jerzy Nowacki*, Paweł Rybicki

Technical University of Szczecin, Al. Piastow 19, 70-310 Szczecin, Poland

Abstract

The influence of the heat input submerged arc welding (SAW) of duplex steel UNS S31803 on kind and quantity of welded butt joints defects has been determined. Defects were identified by a radiographic method. For the defectiveness rate in the ratio of quantity negative test results RN to complete radiographic test RC were taken. Radiograms have been classified on the base of Polish and European Standards. The mechanical properties of the joints and value of ferrite share test have been done. 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 and up to 3 kJ/mm. It was shown that submerged arc welding of duplex steel with the heat input from 2.5 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. slags, 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 of larger welding heat input provides the best joints quality, what decreases the joints control and repair costs.

Keywords: Submerged arc welding; Welding heat input; Butt joints defects; Duplex steel welding; Radiographic test

1. Introduction

Submerged arc welding of steels demanding limited heat input of welding, e.g. high-strength steels, austenitic steels, austenitic–ferritic steels require 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, 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).

Selection of welding parameters is for:

- ensure high operating properties of the joint,
- low wear of filler metal on the joint,
- repeatability of quality of the welds at an acceptable level in term of welding imperfections.

That means lack of imperfections, which exclude possibilities of making usage of a welded product at assumed costs. According to the position in welding, imperfections can be divided into [4,5]:

- external (exposed) going out or situated outside a weld bead,
- internal (hidden) situated inside a weld bead.

According to the causes of forming welding, imperfections can be divided into:

- welding imperfections that are a result of an improper welding or improper technological conditions of welding—discrepancy of shape and surface, discrepancy in weld penetration, incomplete fusion, non-metallic solid inclusions or metallic inclusions;
- metallurgical imperfections—cracks or micro-cracks, gas voids, voids resulting from shrinkage, segregation of chemical composition, unfavourable structural changes in heat-affected zone;

* Corresponding author. Tel.: +48 91 449 47 51; fax: +48 91 449 43 56.
E-mail address: jnowacki@ps.pl (J. Nowacki).

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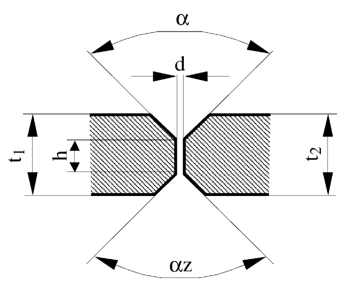

Fig. 1. Scheme of a joint preparation of submerged arc welding according to weld materials producer recommendations. Width of a root face: $h = 3$–8 mm, groove angle: $\alpha = 60$–100°, root face gap: $d = 0$–0.5 mm, total thickness (mm) of plates: t_1, t_2.

- welding imperfections as a result of the product designing errors—excessive stress concentration, e.g. as a result of welds concentration in highly loaded construction junctions.

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 [6] and of the recommendations of the filler metals suppliers.

On account of the mechanical properties and corrosion resistance, of welds the main limitation of welding process of duplex steel is the quantity of heat input (HI) [7–9]. Plates subjected to welding are prepared according to Fig. 1, with $\alpha = 80^\circ$, $h = 6$ mm, $d = 0$–0.5 mm, $t_1 = t_2 + (2$–$3)$ 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 Ø3.2 mm grade 2205, and a flux material – Flux 805 – with alkalinity ∼1.7 [10]. The welding heat input was calculated according to the following equation:

$$\mathrm{HI}\,(\mathrm{kJ/mm}) = \eta \frac{I\,(\mathrm{A})\,U\,(\mathrm{V})}{V_{\mathrm{sp}}\,(\mathrm{mm/s}) \times 1000} \tag{1}$$

where HI is the welding heat input, η the coefficient of welding efficiency, I the welding current intensity, U the welding voltage, V_{sp} the speed of welding.

The 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 maximal welding linear energy: HI ≤ 2.5 kJ/mm, HI ≤ 3.0 kJ/mm, HI ≤ 3.5 kJ/mm, HI ≤ 4.0.

Mechanical tests of the joints: bend test of the root and face (minimal specified angle 120°; mandrel diameter 5× thickness of the plate), R_m (tension test), KV (notched-bar impact test) and HV5 (hardness test) tests have been made according to Det Norske Veritas Rules. Corrosion tests have been made according to DNV Rules Pt.2 Ch.3 Sec.2 D200—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—according to ASTM E562 Specification.

The influence of the heat input of duplex steel submerged arc welding on type and quantity of welding imperfections of butt joints have been determined by means of X-ray tests. In this order the 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:

$$W\,(\%) = \frac{\mathrm{RN} \times 100}{\mathrm{RC}} \tag{2}$$

where W (%) is the percentage index of welds defectiveness, RN the quantity of radiographs with negative result, RC the complete quantity of radiographs.

Radiographs were classified basing on PN-12517 Standard—Non-destructive Examination of Welds, Radiographic Examination of Welded Joints, Acceptance Levels. Required Acceptance Level B according to PN-EN

Table 1
Results of the test of chemical composition and mechanical properties of the parent material used in the experiment

Chemical composition of the steel UNS S31803, average values (%)	
C	0.03
Si	0.9
Mn	1.8
P	0.025
S	0.015
Cr	22.1
Ni	5.2
Mo	2.9
N	0.17
PREN[a]	≥34
Mechanical properties, average values	
R_e (N/mm^2)	590
R_m (N/mm^2)	780
KV −20 °C (J)	170

[a] PREN: Pitting Resistance Equivalent Number; PREN = 3.3 Cr (%) + Mo (%) + 16 N (%); PREN minimal value, required according to international standards for planned constructions of chemical tankers is 34.

Table 2
Catalogue chemical composition and mechanical properties of the filler materials—welding wire 2205/flux 805 [10]

Chemical composition, average values (%)	
C	0.02
Si	0.6
Mn	1.1
Cr	23.0
Ni	8.5
Mo	3.0
Mechanical properties, average values	
R_e (N/mm^2)	590
R_m (N/mm^2)	800
A5 (%)	28
KV +20 °C (J)	90
KV −40 °C (J)	70