Acta Materialia Transylvanica 5/1. (2022) 35–38.
DOI: Hungarian: https://doi.org/10.33923/amt-2022-01-08
English: https://doi.org/10.33924/amt-2022-01-08

High Heat Input Welding of NSSC 2120 Type Lean Duplex Steel

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Abstract

Duplex stainless steels offer a high strength alternative to stainless steel, while providing excellent corrosion resistance, due to their dual-phase microstructure. This microstructure can be significantly influenced during welding, thus the maximum recommended heat input is usually 2.5 kJ/mm. In this research, we inspected the high heat input (3 kJ/mm) weldability of NSSC 2120 lean duplex stainless steel, which is designed and developed specifically for this purpose. The welds were evaluated by metallographic techniques and corrosion tests. It was found the NSSC 2120 grade can be welded with high heat input without deterioration in the phase balance and microstructure.

Keywords*: lean duplex stainless steel, electrochemical etching, microstructure.*

1. Introduction

Duplex stainless steels have high strength and excellent corrosion resistance due to their double (ferrite-austenitic) microstructure [1, 2]. However, the welding heat cycle can significantly influence the microstructure ratio, so the recommended heat input is usually no more than 2.5 kJ/mm [3]. During welding with a higher heat input, detrimental phase transformations and precipitations may appear in the ferrite phase [3].

The NSSC 2120 lean duplex was developed by the Japanese manufacturer for high heat input welding, primarily for submerged arc welding. According to the manufacturer's datasheet, no detrimental nitride precipitates appear in the heat-affected zone, which is particularly sensitive to phase transformation during high-heat welding [4]. In our research, welded seams were prepared with a heat input of 3 kJ/mm by the 135 welding process (GMAW) and were evaluated by metallographic methods and corrosion testing.

Table 1. *The chemical composition of NSSC 2120 lean duplex stainless steel, according to the manufacturer.*

C	Si	Mn	P	S
0.019	0.38	3.0	0.024	0.001
Ni	**Cr**	**Mo**	**Cu**	**N**
2.03	20.9	0.28	1.08	0.18

2. Materials and Methods

2.1. Base materials

For welding experiments, NSSC 2120 lean duplex plates (not standardized) with a thickness of 10 mm were used. The chemical composition of the base material according to the manufacturer's data sheet is shown in Table 1 .

2.2. Welding consumables

Two types of welding wires were used for the welding experiments, both Ø 1.2 mm size. The solid wire recommended for welding standard duplex steels was G 22 9 3 N L (22 % Cr, 9 % Ni, 3 % Mo) and the flux cored wire recommended for welding lean duplex steels was T 23 7 N L R M/C 3 (23 % Cr, 7 % Ni, rutile flux). The welding wires are hereinafter referred to as 2209 and 2304 (Avesta FCW-2D 2304), respectively, according to the manufacturer's designation.

2.3. Welding parameters

Welding experiments were performed using the 135 welding process (GMAW) using a Yaskawa welding robot and a Fronius TPS 400i Pulse power supply. The seams were welded by pulsed material transfer with the PMC Universal process version of the power source, which provides a uniform penetration depth. The heat input for wire 2209 was 3.05 kJ/mm with a thermal efficiency of 0.8, and for wire 2304 it was 2.99 kJ/mm. A gas mixture of M12 - ArC - 2.5 (argon + 2.5% CO_2) with a flow rate of 15 l/min was used as shielding gas in both cases.

2.4. Microstructural evaluation methods

The ferrite content of the welds was measured with a Fischer Feritscope FMP30 type ferrite scope. The weld geometry dimensions were measured on a metallographic sample with an Olympus SZX16 stereo microscope. The metallographic samples were prepared first by grinding to a grain size of 4000 and then by polishing with a 3 µm diamond suspension. Microstructural images were taken with an Olympus PMG3 optical microscope. Electrochemical etching was performed on samples prepared for metallographic examination. For oxalic acid etching, 10 g of reagent ($C_2O_4H_2$) was dissolved in 90 ml of distilled water, and etching was performed at 7 V for 15 seconds. For nitric acid electrochemical etching, 60 ml of nitric acid (HNO3) was mixed with 40 ml of distilled water, and etching was performed at 2 V for 20 seconds.

2.5. Corrosion testing methods

Corrosion tests were performed according to the ASTM 1084 standard [5] for lean duplex steels. The 25 × 50 mm samples were placed in a solution containing 55.1 g of ferrous chloride ($FeCl_3 \cdot 6H_2O$), 6.6 g of sodium nitrate ($NaNO_3$) and 600 ml of distilled water for 24 hours. the corrosion rate and the pitting corrosion behaviour were determined from the weight loss. The weight of the samples was measured on a Denver Instrument APX-200 with an accuracy of 0.1 mg.

3. Results and discussion

3.1. Results of the weld geometry measurements

The face width of the 2209 solid wire weld was 14.5 ± 0.6 mm and the face height was 4.1 ± 0.2 mm. The penetration depth measured on the cross-section was 5.4 mm and the weld cross section area was 84.1 mm^2. The form factor calculated by dividing the penetration depth by the face width was thus 0.37.

The seam welded with 2304 flux cored wire had a face width of 15.9 ± 0.6 mm and a face height of 3.3 ± 0.3 mm. The penetration depth measured on the cross-section was 3.2 mm and the weld cross section area was 60.1 mm^2. The form factor calculated by dividing the penetration depth by the face width was thus 0.19.

The results show that although the heat input was roughly the same (~ 3 kJ/mm in both cases), a much smaller weld volume was deposited in the case of the flux cored wire, which is due to the presence of many slag-forming materials in the flux with the same wire diameter, which is not included in the volume of the weld metal.

3.2. Results of the microstructural evaluations

The ferrite content measured with a ferrite scope was 40.5±5.5 % for the weld metal welded with 2209 solid wire. For the 2304 flux cored wire, this value was 41.5±6.8 %. The values correspond to the ferrite content specified in MSZ EN ISO 17781 [6] (minimum 30 % and maximum 70 %), therefore NSSC 2120 can be welded well in terms of phase ratio with high heat input and the use of both wires.

Oxalic acid electrochemical etching can be used to detect carbides and nitrides in ferrite according to ASTM A1084 standard [5] Carbide and nitride precipitates appear as a dark area after etching, for the proportions of which the standard contains comparative images. The images after oxalic acid etching are shown in **Figure 1** for solid wire 2209 and in **Figure 2** for flux cored wire 2304.

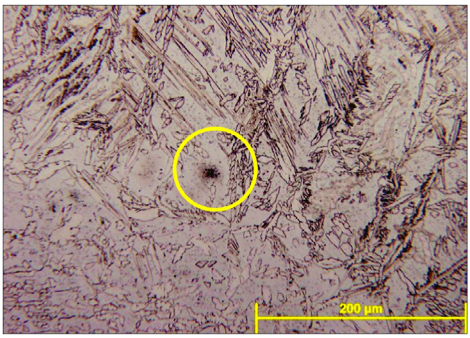

Figure 1. *Weld metal welded with 2209 wire and heat affected zone after oxalic acid electrochemical etching. A sign indicating nitride precipitation in the heat zone is shown in a black circle.*

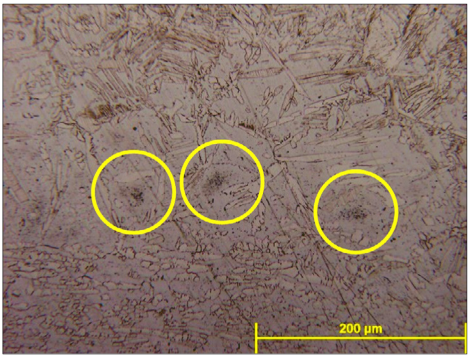

Figure 2. *Weld metal welded with 2304 wire and heat affected zone after oxalic acid electrochemical etching. A sign indicating nitride precipitation in the heat zone is shown in a black circle.*

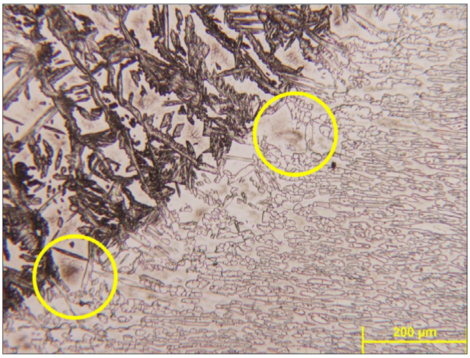

Figure 3. *Weld metal welded with 2209 wire and heat affected zone after nitric acid electrochemical etching. A sign indicating nitride precipitation in the heat zone is shown in a yellow circle.*

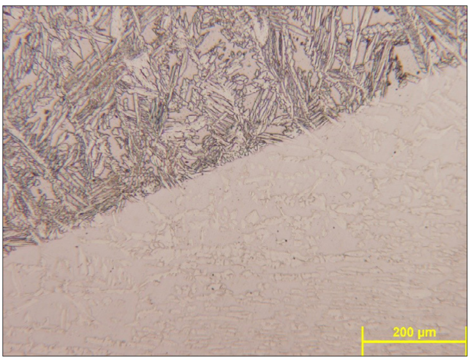

Figure 4. *Weld metal welded with 2304 wire and heat affected zone after nitric acid electrochemical etching. No signs of nitride precipitations.*

Minimal signs of carbide or nitride precipitation were found during etching (circled in the figures) and are abundant in the appropriate category according to the referenced standard. The electrochemical etching with nitric acid for the detection of various intermetallic phases and nitride precipitations was performed according to the ASTM E407 standard [7]. The images following nitric acid etching are shown in Figure 3. for solid wire 2209 and Figure 4 for flux cored wire 2304. Minimal signs of nitride precipitation were found during etching (circled in the figures), which are also compliant according to the referenced standard.

Based on the microstructure evaluation, it can be stated that the NSSC 2120 grade can be welded well with a heat input of 3 kJ/mm according to the manufacturer's recommendations, and the heat zone is less sensitive to the formation of detrimental secondary phases.

3.3. Results of the corrosion testing

The results of the corrosion test are shown in Table 2. The corrosion rate was 0.64 g/m^2 for solid wire 2209 and 0.72 g/m2 for flux cored wire 2304, which corresponds to the maximum 4 g/m^2 for welds, according to the MSZ EN ISO 17781 standard.

Table 2. *Results of the corrosion testing*

	2209 wire	2304 wire
Weight before test	61,0167 g	59,8156 g
Weight after 24 hours	61,0159 g	59,8147 g
Weight loss	0,0008 g	0,0009 g

4. Conclusions

In our research, we investigated the weldability of NSSC 2120 lean duplex steel with high heat input. Gas metal arc welding experiments were performed with a heat input of 3 kJ/mm, using solid wires of 2209 and a flux cored wire of 2304. Based on the evaluation of the welds, it can be stated that the ferrite content is suitable in the weld metal in both cases, nitride precipitation in the heat affected zone is not typical, and the corrosion resistance of the welds are accepted according to the immersion tests.

Acknowledgements

We are grateful to Flexman Robotics Kft. For using the Yaskawa robot required for welding. This paper has been supported by the National Research, Development and Innovation Office – NKFIH, OTKA PD 138729.

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