SELECTION OF DUPLEX STEEL WELDING PROCESS USING LOW CYCLE FATIGUE TEST

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Abstract

Duplex steels are an austenitic-ferritic type of stainless steel. They have better mechanical strength, corrosion resistance, and fatigue strength in aggressive environments compared to traditional stainless steels in the food industry such as AISI 316 or 304. However, duplex steels have poorer weldability because of the inability to achieve higher welding speeds due to the poor weld penetration and fluidity in the weld pool. That is why the responsible selection of the welding process is important for manufacturing components and structures made of duplex steels.

This paper presents the investigation of three different welding processes (BW.141, FW.136, and FW.141) for duplex steel LDX 2101 tee joints. For investigation x-type (cruciform) specimens were tested. The initial static tension experiment has not shown a significant difference in the strength of specimens with different welding processes. Therefore, it was decided to conduct a low-cycle fatigue experiment. Stress controlled fatigue test with pulse type cycle loading was chosen for this analysis. Three specimens for each welding process were tested. Low cycle fatigue results have revealed that the x-type specimen with FW.136 welding process has held out the highest number of cycles to failure. Compared to BW.141 and FW.141 welding processes the durability of the x-type specimen with FW.136 welding was accordingly 1.2 and 1.9 times higher.

Keywords: Duplex steel, welding, low cycle fatigue, x-type specimen test

1. INTRODUCTION

Stainless steels are used in various applications where corrosion of materials can potentially cause a structural failure, contamination of other materials or products, spoiled the aesthetic appearance, etc. Therefore, stainless steel is used for tank semi-trailer manufacturing for the transportation of liquid food products. The most popular food-grade stainless steels are AISI 304 and AISI 316 [1]. However, these steels are not very strong, and making a load-bearing component out of these metals requires using bigger dimensions, which increases the product's overall volume, mass, and price. As an alternative to these steels duplex stainless steel LDX 2101 was studied in this research. Duplex is a family of stainless steels which has an austenitic-ferritic type crystalline structure. Due to this it has not only good corrosion resistance [2] but also great mechanical strength. However, duplex steels have poorer weldability compared to austenitic stainless steels [3]. Therefore, to use duplex steel in the design of new products special attention should be paid to a section of proper welding process.

The aim of this work is to select the best welding process for LDX 2101 steel tee-type joints. For this purpose, three welding processes suggested by the metalworking company Astra LT AB were studied. Static tension tests and low cycle fatigue (LCF) tests in stress control were conducted for the investigation of welding processes.

2. RESEARCH OBJECT AND SPECIMEN

In this study, the research object is tee-type weld joints of duplex stainless steel plates. The main material was a 6 mm thick hot rolled plate made of duplex LDX 2101 steel manufactured by Finnish stainless steel producer Outokumpu. According to the certificate provided by Outokumpu LDX 2101 steel has yield strength $R_{p0.2}$ = 584 MPa and strength limit R_m = 759 MPa. The plate was cut and welded using three different welding processes at the metalworking company Astra LT AB located in Alytus, Lithuania. Final preparation of specimens and experimental testing were conducted at Lithuanian Energy Institute. X-type (cruciform) specimens were used for experimental testing of tee-type weld joints as recommended by the International Institute of Welding (IIW) [4]. The drawing of the specimen is shown in **Figure 1**.

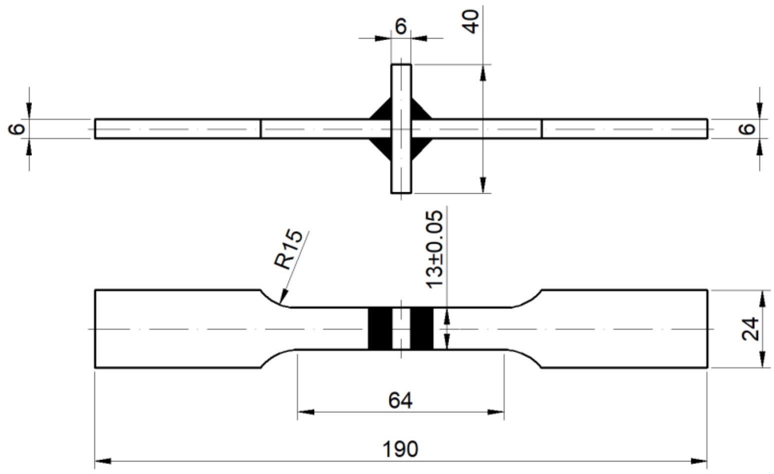
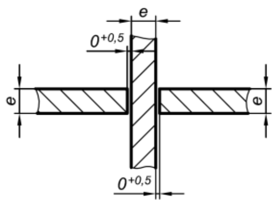
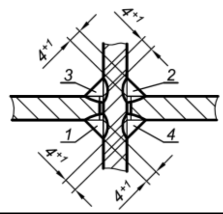
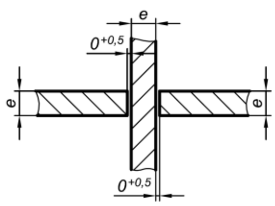
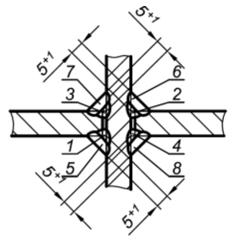
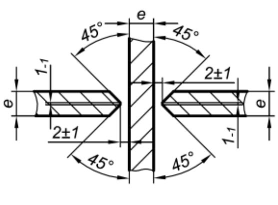
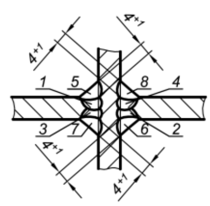


Figure 1 X-type specimen

Table 1 Welding processes for x-type specimen

Welding marking	Welding process	Filler metal			Joint design	Welding sequences
		Marking	$R_{p0.2}$ (MPa)	R_m (MPa)		
FW.136	Semi-automatic MIG	DW 329A	601	844		
FW.141	Manual TIG	LNT 4462	675	826		
BW.141	Manual TIG	LNT 4462	675	826		

Welding processes, filler materials, and joint designs used in this study are presented in **Table 1**. As shown, metal inert gas (MIG) and tungsten inert gas (TIG) processes were used for specimen preparation. For the shielding CORGON 18 gas was used for MIG welding, which is a mixture of Ar and 18 % CO_2 gas, and 99.99% Ar gas was used for TIG welding. FW.136 is a semi-automatic MIG welding process for tee joints with no bevels. Welds were formed with only one run for each seam; therefore, this welding process was the fastest of all investigated welding processes. FW.141 and BW.141 were manual TIG welding processes. Two runs for each seam were used for both. The difference between these processes was that a double bevel joint design was used for BW 141 welding process.

3. EXPERIMENT

Experimental testing was conducted at Instron Model 8801 test machine. Initially, the static tension test at room temperature was conducted for strength evaluation of welds joints. Tension tests were conducted according to ISO 4136 [5] and ISO 6892-1 [6] standards. Two specimens for each welding process were tested and the results are shown in **Figure 2**, **Figure 3**, and **Table 2**. X-type specimens do not have the standard shape recommended for tension tests. Therefore, instead of strain the elongation at the grips of the test machine was measured. As it can be seen from the results the strength limit for all specimens is almost the same (around 770 MPa). Just for FW.141 welding is 0.4% higher. No damage at weld seams were noticed and failures in the main metal were observed in all specimens (see **Figure 3**). These results show that all welding processes are strong enough for static loading. However, that is not enough for a selection of welding process for the tee joint of steel LDX 2101.

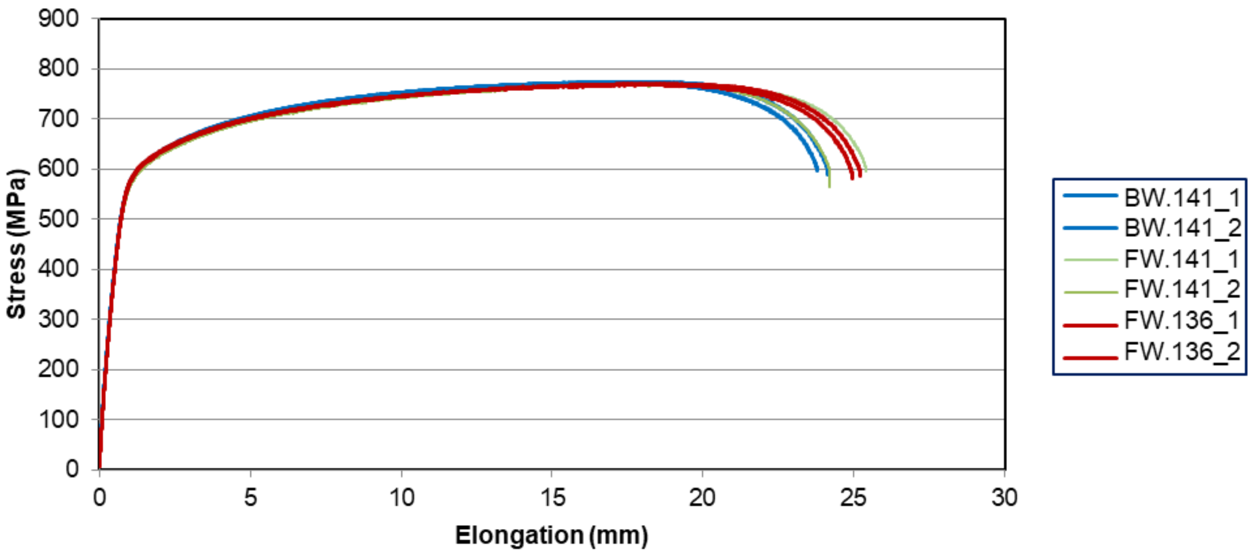


Figure 2 Tension experiment results of x-type specimens

Table 2 Tension experiment results of welded x-type specimens made of LDX 2101 steel

Specimen	Strength limit, R_m (MPa)		
	FW.136	FW.141	BW.141
1	769.0	772.8	770.1
2	771.9	775.0	770.8
Average	770.5	773.9	770.5

Figure 3 The view of x-type specimens after the static tension experiment

As static tension test results do not allow selecting the strongest weld process it was decided to conduct a Low Cycle Fatigue (LCF) test. The same specimens shown in **Figure 1** were used in the LCF test as well. The fatigue test was conducted at room temperature according to ASTM E466-21 standard [7]. Three specimens were tested for each welding process. It was designed to be in stress control with a pulse-type cycle loading, where stress ratio R = 0 and loading frequency was equal to 2 (Hz). The maximal load was chosen to be slightly higher than the yield strength of LDX 2101 steel and was equal to $\Delta\sigma$ = 615 MPa. Failure cycle number N_{f30} was determined at a 30 % increase of specimen elongation measuring from the regression line determined at stabilized cycles. As an example, the elongation vs. cycle number curve of one specimen is presented in **Figure 4**. As shown, the elongation of the specimen is increasing as the cycle number grows, which shows a cyclic softening behavior of the welded joint.

Low cycle fatigue test results of all specimens are presented in **Table 3**. The highest endurance to cyclic loading had specimens with FW.136 welding process. Compared to BW.141 and FW.141 welding processes the durability of specimens with FW.136 welding process is accordingly 1.2 and 1.9 times higher.

Representative specimens with primary and secondary cracks for each welding process are presented in **Figure 5**. Unlike in static tension tests, all specimens had failed at the weld seam or heat affected zone (HAZ) in the low cycle fatigue test. In all cases, the cracks start to form at the toe of the weld in the main metal's HAZ region. As the x-type specimen has two tee-type joints the cracks start to form in both joints. When the crack establishes, it grows in the main metal perpendicularly to the specimen's surface. Later, the faster growing crack becomes the main one and leads to the failure of the tee joint.

In the case of FW.136 and BW.141 welding processes, the growth direction of primary cracks does not change till the failure of the specimen (**Figure 5 a, c**). However, in FW.141 welding process, due to shear strain between the main metal and weld seam, the primary cracks change direction and grow along the axis of the specimen till they reach the root of the weld seam (**Figure 5 b**). This behavior is observed in both tee joints of the specimen.

In all tested specimens with BW.141 welding process, no secondary cracks were observed, but they can be seen in specimens with FW.136 and FW.141 welding processes at the roots of the weld seams. The largest secondary crack in the FW.136 specimen was 1.5 mm in depth. However, a more recent study had shown that secondary cracks are dependent on the loading amplitude, i.e., an increase in loading amplitude reduces the size of the secondary cracks.

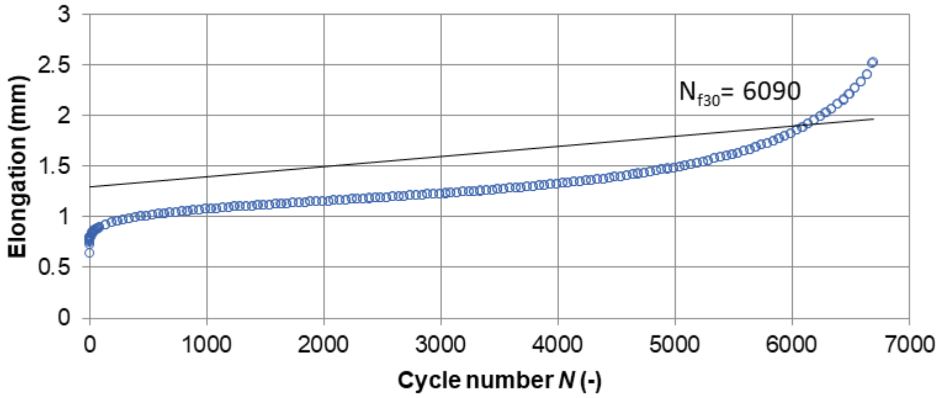
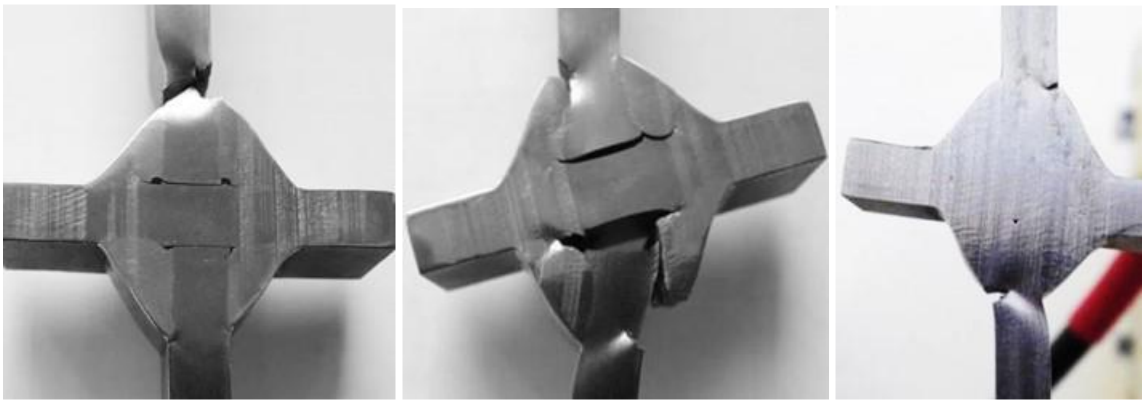


Figure 4 Elongation vs. cycle number of specimen FW.136_4 ($\Delta\sigma$ = 615 MPa, R = 0)

Table 3 LCF test results of welded x-type specimens at $\Delta\sigma$ = 615 MPa, R = 0 loading

Specimen		The cycle number at N_{f30}	Cycle number after stopping of experiment N_{st}
FW.136	3	5942	6592
	4	6090	6691
	5	6692	7241
Average		**6241**	-
FW.141	3	3399	3591
	5	2150	2190
	4	4192	5392
Average		**3247**	-
BW.141	3	4920	5591
	5	6091	6742
	4	4242	5292
Average		**5084**	-



(a) (b) (c)

Figure 5 The view of x-type specimens after low cycle fatigue test: a) FW.136_5; b) FW.141_4; c) BW.141_3

4. CONCLUSION

The experimental research of three welding processes of duplex steel LDX 2101 was done in this study. The x-type specimens with FW.136, FW.141, and BW.141 welding processes were prepared for the experimental testing of tee joint welds. The static tension tests have shown that all welding processes are strong enough to withstand a static load as all tested specimens have failed at the main metal, but not at the weld seam or heat affected zone. Static tension tests have not yielded a clear result allowing us to select the best welding process; therefore, the low cycle fatigue tests were conducted. According to LCF results the highest average failure cycle number N_{f30} = 6241 has been determined for specimens with FW.136 welding process at $\Delta\sigma$ = 615 MPa and R = 0 loading. Compared to BW.141 and FW.141 welding processes it was accordingly 1.2 and 1.9 times higher. Therefore, FW.136 welding process was selected as the most durable weld and was recommended to be used for LDX2101 steel tee joint welding.

However, before a welding process can be used in the design of a new product a full fatigue study must be carried out for the construction of the *S-N* curve and determination of IIW FAT class and endurance limit.

ACKNOWLEDGEMENTS

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