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Influence of Multiple Repairs on the Quality of Duplex Welded Joints

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ABSTRACT

Duplex stainless steels (DSSs) find increasing use as a substitution to austenitic stainless steels in oil, gas and petrochemical industries, particularly in aggressive environments. Duplex stainless steels with appropriate controlled ferrite-austenite balance combine the attractive properties of excellent strength, general corrosion performance and adequate weldability. All the welding joints subjected to the regulation must be controlled before commissioning the pipeline and even before hydrostatic tests; all not acceptable defects detected with non-destructive testing (NDT) control methods must be eliminated. In some cases, several successive repairs are often preferred to part replacement in the pipeline due to lack of experience of the welder performing the repairs or lack of expertise of the controller ensuring the application of the welding procedure. The purpose of this work is to study the influence of repairs on the same welding joint on the microstructure and the mechanical properties of the heat-affected zone in duplex stainless steel with 22% chromium welding joints. For this purpose, a cylindrical specimen is prepared, on which the various repairs are carried out. Then, an NDT control and the main mechanical and micrographic tests are conducted. The results obtained after four repairs revealed that the multiple repairs made to the same joint did not affect the quality of the welding joints.

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1. INTRODUCTION

Duplex stainless steels (DSSs) become commonly used for pipelines construction, particularly for some engineering applications in strongly corrosive environments and where high mechanical strength is required. These steels exhibit excellent characteristics particularly both corrosion and strength resistance when the ferrite-austenite balance is well controlled during welding process.

The effect of nitrogen content and cooling rate on austenite reformation on microstructure and stress corrosion cracking in heat affected zones of welded duplex stainless steels was investigated. It is noted that crack onset is induced by pitting corrosion and selective dissolution of ferrite phases, whereas crack propagation mode is affected by the types and amounts of reformed austenite in the heat affected zone (HAZ) [1, 2].

Various welded sections performed by gas tungsten arc welding (GTAW) process on a duplex stainless steel (DSS) pipeline were carried out according to heat input and weld type in order to study their effect on the weld structure and weld metallurgy in terms of precipitation phases [3], composition and mechanical properties to assess the susceptibility to intergranular corrosion [4]. The effect of weld metal chemical composition and heat input on the structure and properties of duplex stainless steel welds were also the subject of several studies [5–7].

Failure analyzes of 2205 duplex stainless steel welding joints have been presented [8–10], cracks detected in the HAZ are probably initiated due to poor welding process and unbalanced distribution of ferrite/austenite.

To achieve a high quality welded joint and to ensure long-term corrosion resistance of large structures by

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using duplex stainless steels, it is recommended to allow a special attention to the welding and the welded joint surface treatment [11–13]. It was established that the mechanical properties vary depending upon the various heat treatment processes. Suitable heat treatment on duplex stainless steel is to improve ductility, toughness, strength, hardness and to relieve internal stress developed in the material [14]. The high service temperatures of the duplex stainless steels often source of secondary phase precipitations (mainly σ phase) should be avoided since they strongly deteriorate the mechanical properties of steels but small quantities of these phases could be acceptable in the microstructure according to the application of this steel [15]. The effect of heat treatments and strain hardening on microstructure and properties of super duplex stainless steels were highlighted. It is noted that quite homogeneous and good mechanical properties can be obtained controlling the composition, the treatment and strain hardening parameters [16, 17].

Multiple welding repairs on pipelines were carried out to evaluate the residual stresses and their effect on the macrostructure, microstructure and mechanical properties [18, 19].

Since the welding of the pipe is not done completely on the straight line (the nature of the pipe) and the test tube under the machine is moving. Pourasad and Afkar [20] designed an algorithm to reduce the environmental conditions and unstable industrial situations in order to track the weld seam with an acceptable speed. One advantage of this method is to reduce the measurement error and the elimination of mechanical and electrical sensors in non-destructive tests.

By using the Tungsten inert gas (TIG) welding process, Salehpour et al. [21] conducted an experimental investigation to determine the mechanical characteristics of the pieces through variation of three main welding parameters including advance speed, welding amperage and preheating temperature. In samples with low advance speed, in addition to increase the solidification time, the coarseness of the structure and the burning of the edges of the welded parts due to the low speed and high amps, reduce the tensile strength. Their results showed also that by increasing the amperage, the strength of welding parts decreases due to the burn defect of the plate edges, which can be minimized by increasing the welding speed and reducing the effect of extreme heat on the edges. Other interesting works may be found in literature [22–24].

In general, most manufacturers do not accept more than two repairs on the same welding joint, and they proceed directly to cutting the joint.The purpose of this work is to study the influence of welding defects of successiverepairs on the microstructure and the mechanical properties of the welding joint.The technique adopted in the present work for carrying out the repairs is presented in Figure 1. The advantage of this original technique lies in the fact that the obtained test pieces belong to the same coupon, in which the metal used is duplex stainless steel with 22% of chromium intended for the hydrocarbons transmission in particular gases and aggressive products. This study requires the realization of the welded specimens, a visual and radiographic control, an in-depth examination of the micrographic structure, and mechanical tests.

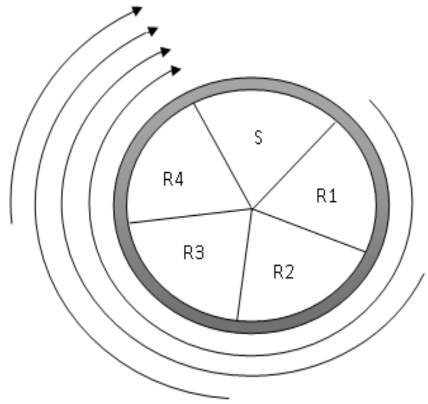


Figure 1. Repair technique on the samewelding joint (Repair sequences)

Duplex stainless steels (commonly called DSS) are a class of stainless steels with a microstructure formed by two main phases: ferrite (alpha) and austenite (gamma). They are widely used in the transport of liquid and gaseous hydrocarbons at high pressure, due to their mechanical properties and corrosion resistance.

The steel used for this study is an austeno-feritic steel called "duplex" because it contains two metallurgical phases, an austenitic phase and a feritic phase hence the name austeno-ferritic.

This paper is divided into three main sections after the state-of-the art. Section 2 contains the experimental tests, where the details of steps for the preparation of test specimens are provided. Then, the experimental conditions are given is section 3, where the chemical composition and and mechanical properties are metals under investigation are highlighted. In section 4, the parameters and process welding are summarized. The main results are plotted and analyzed in section 4.

2. EXPERIMENTAL TESTS

For the preparation of the test specimens used in the present work, a portion of 300 mm length was cut from a pipe of 12 m length, intended for the connection of gas wells to gas center production facilities (CPF), the section was divided into five identical portions and sub-sequently welded by mixed processes GTAW and shielded metal arc welding (SMAW), while leaving a healthy part and creating defects in the first pass over the rest of the section.

In order to get closer to reality, and for more authenticity and accuracy, the repairs were carried out on the same section and on which a visual and radiographic inspection was carried out before and after the repairs, the first control to locate the defects, the second to ensure that the defects have been completely eliminated.

The details of steps for the preparation of test specimens are as follows:

1. Preparation of samples of Ø8″ and wall thickness 8.18 mm, of A928 UNS S31803 material.
2. The partition of the samples in five identical portions.
3. Complete welding of the part first once, while creating defects on the first pass, and leaving the first healthy portion (without any defect).
4. Repair of the four defective portions, for a first time.
5. Repair of the three last portions, for a second time.
6. Repair of the two last portions, for a third time.
7. Repair of the last portions, for a fourth time.
8. Finally we obtain: the first portion only weldedonce with neither defect nor repair which will be used as a reference part while the other portions will be successively re-paired once, twice, three times and four times at last.
9. A radiographic control carried out before and after repairs.
10. The five portions were cut out longitudinally to carry out the mechanical and micrographic tests.

Samples preparation and images of welded pipline pieces are presented in Figure 2.

3. EXPERIMENTAL CONDITIONS

The chemical composition and mechanical properties of base metal: ASTM A928 CL1 Ø 8" SCH 40S 219 x 8.18 mm UNS S31803, stainless steel 22 Cr Duplex and two filler metals welding rod GTAW ER2209 and E2209 coated electrode are given in Tables 1-4 [25].

1-Welded test coupon

2- Partition in 5 portions

3- Joint ready for repair

4- Welding joint repair

Figure 2. Samples preparation

4. WELDING PROCESS

The welding of the coupons was carried out by a certified welder using GTAW process for first passes with direct polarity and SMAW process for fill and cap passes withpositive polarity, uphill position “5G” and direct current. Gas tungsten arc welding is performed with refractory electrode under gas protection with filler metal ER2209 for the first two passes and E2209 for the fill and cap passes (See Tables 5 and 6). The welding processes for the second, third and fourth repairs are summarized in Tables 7-9.

According to hardness values, it can be seen that, the hardness evolution is relatively variable; this can be attributed to the diffusion of Mn and Si from the base metal to the heat-affected zone (HAZ) and the fusion zone (FZ), as well as the concentration of the heat input.

The growth of the grains in the second and third repair is probably due to the repetitive thermal cycles of the welding process, causes a decrease in the hardness in the HAZ. The high hardness of the fusion zone may be related to the formation of acicular ferrite. The hardness values are higher in this region compared to those

TABLE 1. Chemical composition of base metal (BM) (wt%)

C	Si	Mn	Cr	Ni	Mo
0.03	1.0	2.0	22.00	5.5	3.0

TABLE 2. Mechanical properties of base metal (BM)

Yield stress [MPa]	Tensile strength [Mpa]	Elongation [A %]
450	620	25

TABLE 3. Chemical composition of filler metals E2209 and ER 2209 (wt%)

Filler metal	C	Si	Mn	Cr	Ni	Mo	N
E2209	<0.04	0.5	0.9	22.5	9.3	3.0	0.15
ER2209	<0.03	0.5	1.7	22.5	8.5	3.3	<0.3

TABLE 4. Mechanical properties of E2209 and ER2209

Filler metal	Yield stress [MPa]	Tensile strength [MPa]	Elongation [A %]
E2209	650	800	28
ER2209	600	765	28

TABLE 5. Part without repairs

Layers	**1st pass**	**2 nd pass**	**3 rd pass**	**4 th pass**
Welding process	GTAW	GTAW	SMAW	SMAW
Welding position	5 G	5 G	5 G	5 G
Current & polarity	CC (-)	CC (-)	CC (+)	CC (+)
Filler metal	ER 2209	ER 2209	E2209	E2209
ΦElectrode (mm)	-	-	2.5-3,25	2.5-3,25
ΦRod (mm)	2.4	2.4	-	-
Amp. range (A)	100	140	140	100
Volt. range (V)	16	16	16	22
Travel speed (mm/mn)	9.85	19.71	15.33	15.33
Gas	Argon	Argon	-	-
Heat Input (kJ/mm)	36.548	6.818	101.052	8.610

TABLE 6. First repair (R1)

Layers	**1st pass**	**2 nd pass**	**3 rd pass**	**4 th pass**
Welding process	GTAW	GTAW	SMAW	SMAW
Welding position	5 G	5 G	5 G	5 G
Current & polarity	CC (-)	CC (-)	CC (+)	CC (+)
Filler métal	ER 2209	ER 2209	E2209	E2209
Φ Electrode (mm)	-	-	2.5-3,25	2.5-3,25
ΦRod (mm)	2.4	2.4	-	-
Amp. range (A)	75	70	70	70
Volt. range (V)	10	30	30	30
Travel speed (mm/mn)	11.5	34.5	23	34.5
Gas	Argon	Argon	-	-
Heat input (kJ/mm)	3.913	3.652	5.478	3.652

TABLE 7. Second repair (R2)

Layers	**1st pass**	**2 nd pass**	**3 rd pass**	**4 th pass**
Welding process	GTAW	GTAW	SMAW	SMAW
Welding position	5 G	5 G	5 G	5 G
Current & polarity	CC (-)	CC (-)	CC (+)	CC (+)
Filler métal	ER 2209	ER 2209	E2209	E2209
F Electrode (mm)	-	-	2.5-3,25	2.5-3,25
F Rod (mm)	2.4	2.4	-	-
Amp. range (A)	80	60	60	70
Volt. range (V)	30	25	25	25
Travel speed (mm/mn)	19.71	34.5	34.5	19.71
Gas	Argon	Argon	-	-
Heat input (kJ/mm)	7.305	0.260	2.608	5.327

TABLE 8. Third repair (R3)

Layers	**1st pass**	**2 nd pass**	**3 rd pass**	**4 th pass**
Welding process	GTAW	GTAW	SMAW	SMAW
Welding position	5 G	5 G	5 G	5 G
Current & polarity	CC (-)	CC (-)	CC (+)	CC (+)
Filler métal	ER 2209	ER 2209	E2209	E2209
ΦElectrode (mm)	2.4	2.4	2.5-3,25	2.5-3,25
ΦRod (mm)	-	-	-	-
Amp. range (A)	70	70	70	70
Volt. range (V)	21	20	19	25
Travel speed (mm/mn)	27.6	46	46	34.5
Gas	Argon	Argon	-	-
Heat input (kJ/mm)	3.195	1.826	1.734	3.043

TABLE 9. Fourth repair (R4)

Layers	**1st pass**	**2 nd pass**	**3 rd pass**	**4 th pass**
Welding process	GTAW	GTAW	SMAW	SMAW
Welding position	5 G	5 G	5 G	5 G
Current & polarity	CC (-)	CC (-)	CC (+)	CC (+)
Filler métal	ER 2209	ER 2209	E2209	E2209
ΦElectrode (mm)	-	-	2.5-3,25	2.5-3,25
ΦRod (mm)	2.4	2.4	-	-
Amp. range (A)	80	60	60	70
Volt. range (V)	30	25	25	25
Travel speed (mm/mn)	19.71	34.5	34.5	19.71
Gas	Argon	Argon	-	-
Heat input (kJ/mm)	7.305	0.260	2.608	5.327

observed in the lower part (root pass). The refining of grains and the increase in the density of dislocations in the HAZ of the first repair increases the hardness. However, the molten metal of the weld is not homogeneous, which is the case for all multi-pass welds (Figure 4). The internal pass has higher hardness than the external pass, which can be explained by a slower cooling when welding the external pass.

The values of hardness are homogeneous and acceptable according to ASTM specification, whether in the longitudinal or transverse direction, since the succession of passes give a similar effect to heat treatments as noted in Figure 4.

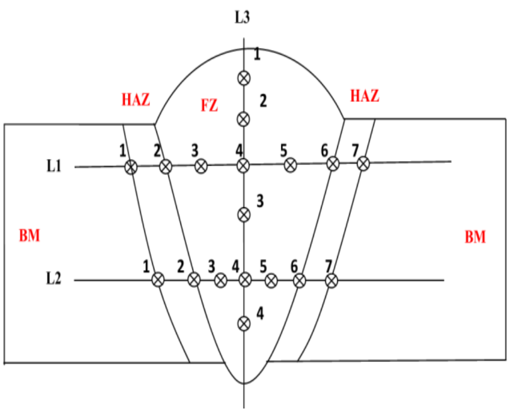
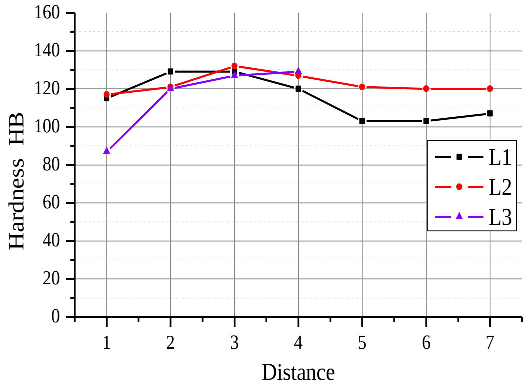
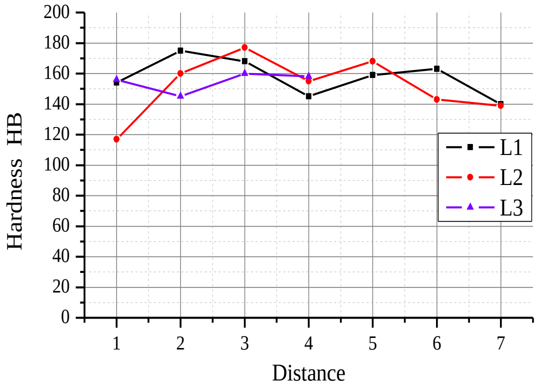


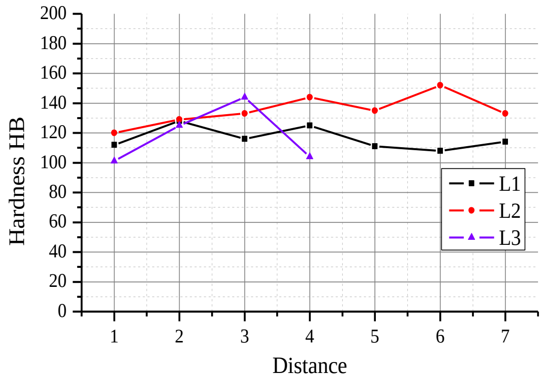
Figure 3. Hardness points measurements



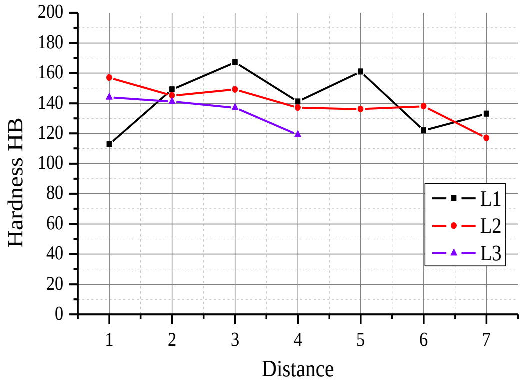
a) Hardness without repair



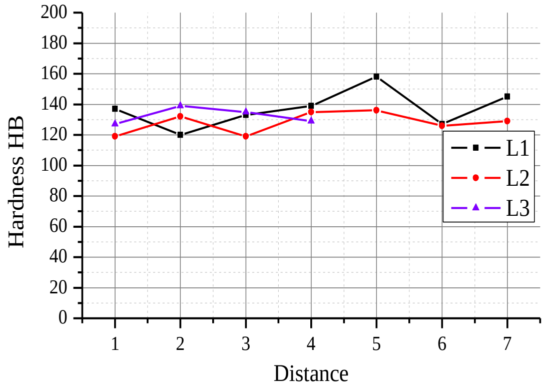
b) Hardness after first repair R1



c) Hardness after second repair R2



d) Hardness after third repair R3



e) Hardness after fourth repair R4

Figure 4. Hardness values a) before repair, b-e) after successive repairs

5. 1. Mechanical Tests Mechanical bending and tensile tests were carried out on a conventional machine; for the resilience tests, V shape specimens were used. Notched specimens results are gathered in Table 10.

This table illustrates the values corresponding to the tensile strength (Rm). An increase in the tensile strength for the specimens test R1 and R3 is observed, while the tensile strength values remain close to that of the base metal for the test specimens R2 and R4. Nevertheless, the values of the resilience display a minimum for specimen R1 and a maximum for R4. The values of the resilience remain substantially constant for S, R2 and R3 specimens.

Tensile tests reveal that rupture is located out of joint for the four repairs. The bending tests for both face and root test reveal noting to report close to the joint.

The fourth repair R4 has absorbed a high energy compared to that of the initial weld; this can be attributed to both the grain refinement and the high dislocation density recorded in the HAZ. In addition, a slight decrease in energy in R2 and R4 was observed (126 and 166 J/cm^2, respectively). This may be related to the grain growth observed in the area near the melting line in accordance with a significant decrease in dislocation density. The toughness loss is due to the presence of hard and brittle constituents known by their low resistance to cracking distributed along the grain boundaries which generates a stress concentration zone, which allows the formation of micro-cracks in the constituents and thus a drop of the toughness.

5. 2. Radiographic Inspection Radiographic inspections were carried out by means of the gamma rays Ir192, D7 films gave the following stereotypes before repair (Figure 5) and after repairs (Figure 6).

TABLE 10. Mechanical tests results

Tensile strength		Bending test		Impact test KCV [J/cm^2]	Elongation [A%]
Rm [MPa]	**Rupture**	**Face bend**	**Root bend**		
Sample without repair (Healthy part) S					
690	Out of joint	NTR	NTR	167	3.12
Sample with only one repair R1					
987	Out of joint	NTR	NTR	126	6.25
Sample with two repairs R2					
670	Out of joint	NTR	NTR	161	4.51
Sample with three repairs R3					
860	Out of joint	NTR	NTR	166	7.26
Sample with four repairs R4					
690	Out of joint	NTR	NTR	186	6.66

NTR: Nothing to report

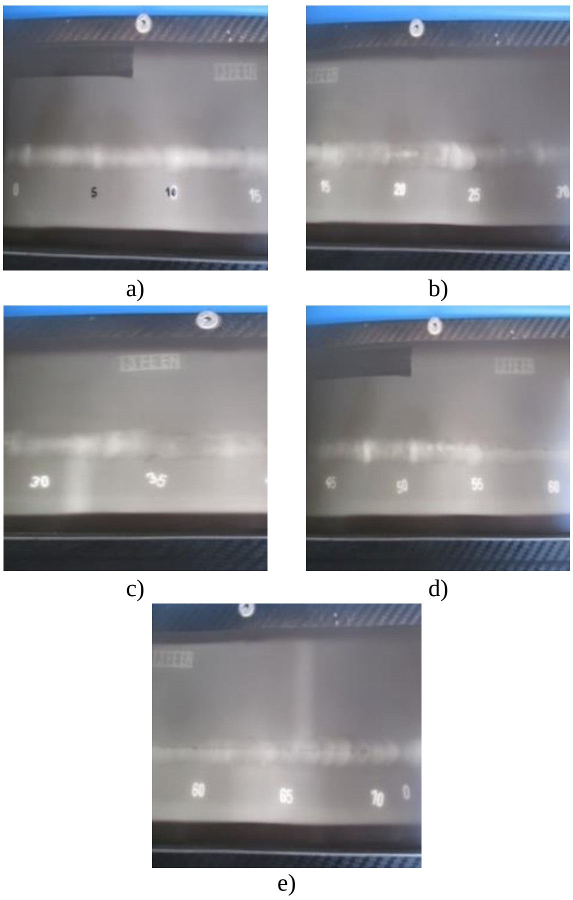


Figure 5. Radiographic stereotypes before repairs

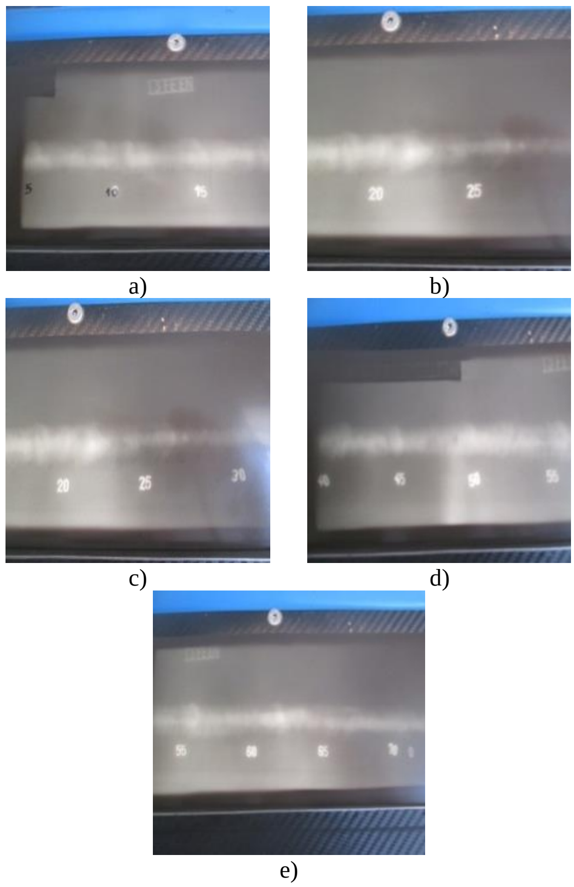


Figure 6. Radiographic stereotypes after repairs

Radiographic films present concavity defects from 25 to 30 (Figure 5b), lack of matter and excess of penetration from 20 to 25 (Figures 5b and 5d), an undercut defect from 35 to 40 (Figure 5c), a concavity and lack of fusion from 55 to 60 (Figure 5d), and a film presenting a lack of penetration from 60 to 70 (Figure 5e).

This film (Figure 6c) shows the grinding traces from 22 to 32. All the rest of stereotypes reveal joints with acceptable defects.

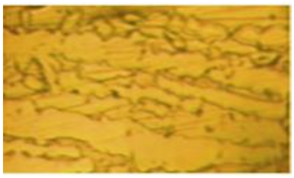
5. 3. Metallography A semi-automatic polishing was carried out with abrasive papers (120, 150, 180 400, 500, 600, 1000, and 1200, respectively) followed by chemical etching in HCl solution with concentration ranging from 35% to 38.This steps are highly recommended for preparation of specimen surface which allows highlighting the metallographic structures for microscopic analysis.

The semi-automatic polishing allows a fast polishing; the holding of the sample is manual but the polishing action is automatic. It is effective in the case of samples taken from pipes whose shape is not flat.

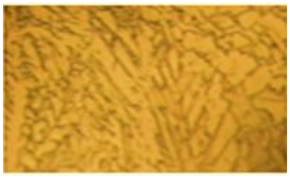
The metallographic control for healthy(S) and repaired (R1 to R4) samples gave the micrographs represented in Figures 7-11.

The visual aspect of all the parts has an homogeneous structure without apparent defects, the succession of the passes is not visible (fillers of even similar close nuances).

Metallographic samples were prepared in welding joint cross-section. The micrographs using light microscopy up to 400X illustrate an austenitic-ferritic



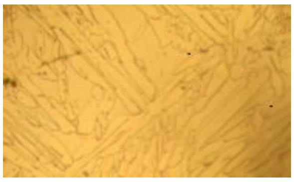
a) HAZ (Heat Affected Zone) X400



b) FZ (Fusion Zone) X400

c) Healthy Sample(S)

Figure 7. Micrographs before repair



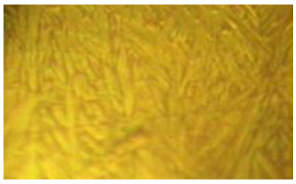
a) HAZ (Heat Affected Zone) X400

b) FZ (Fusion Zone) X400

c) R1

Figure 8. Micrographs after the first repair

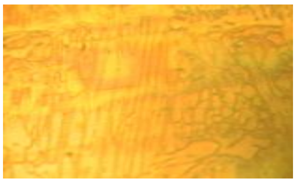
a) HAZ (Heat Affected Zone) X400



b) FZ (Fusion Zone) X400

c) R2

Figure 9. Micrographs after the second repair

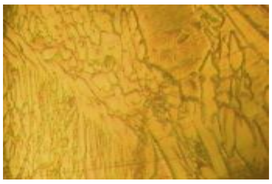


a) HAZ (Heat Affected Zone) X400

b) FZ (Fusion Zone) X400

c) R3

Figure 10. Micrographs after the third repair



a) HAZ (Heat Affected Zone) X400

b) FZ (Fusion Zone) X400

c) R4

Figure 11. Micrographs after fourth repairs

two-phase structure, the dark color is ferrite while the light color is austenite, we also notice the absence of the sigma phase as shown in Figure 12. The heat affected area width is from 2 to 4 mm and it is similar from R1 to R4.

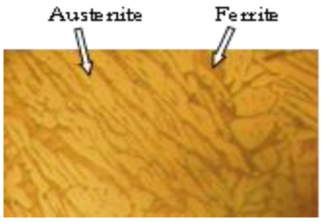


Figure 12. Ferrite dark and austenite light 400X

The heat affected zone presents a microstructure with fine grains, we notice that the number of repairs does not have any influence on morphologies of the HAZ microstructure, since the thermal cycles repeated during each repair lead to the same transformations.

6. CONCLUSIONS

The effect of multiple repairs on the quality of duplex welded joints has been investigated by experiments. The visual aspect of the healthy part had an intact surface quality and unaltered by the operation of grinding. The latter decreased the thickness of the base metal on the two edges of the groove. This reduction was about 0.2 mm for the first repair and 0.8 mm for the fourth repair. The reduced thickness does not have an impact on the mechanical properties of the welding joint and it can be easily avoided by a careful grinding.

All welding joint showed higher strength than the parent metal since tensile tests revealed that the tensile coupon failure was localized outside the welding joint for all of the four repairs.

The obtained results showed that the succession of repairs in the same place of the welding does not have any harmful effect on the mechanical properties of the welding joint. The successive repairs allow performing several repairs without a problem, saving thus a valuable time and effort for the production instead of cutting the entire joint and welding it again.

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Persian Abstract

چکیده

فولادهای زنگ نزن دوبلکس (DSS) به عنوان جایگزینی برای فولادهای زنگ نزن آستیل در صنایع نفت، گاز و پتروشیمی، به ویژه در محیط‌های تهاجمی، کاربرد روزافزونی پیدا می‌کنند. فولادهای ضد زنگ دوبلکس با تعادل فریت–آستنیت کنترل شده مناسب، خواص جذاب استحکام عالی، عملکرد خوردگی عمومی و جوش‌پذیری کافی را ترکیب می‌کنند. قبل از راه‌اندازی خط لوله و حتی قبل از آزمایشات هیدرواستاتیک، کلیه اتصالات جوشکاری که تحت مقررات تنظیم می‌شوند باید کنترل شوند. تمام عیوب غیرقابل قبول شناسایی شده با روش‌های کنترل NDT باید حذف شوند. در برخی موارد، به دلیل عدم تجربه جوشکار در انجام تعمیرات یا عدم تخصص کنترل‌کننده که اجرای روش جوشکاری را تضمین می‌کند، معمولاً چندین تعمیر متوالی به تعویض قطعه در خط لوله ترجیح داده می‌شود. هدف از این کار بررسی تأثیر تعمیرات روی همان اتصال جوشی بر روی ریزساختار و خواص مکانیکی ناحیه متاثر از حرارت در فولاد ضد زنگ دوبلکس با اتصالات جوشکاری کروم ۲۲ درصد است. برای این منظور یک نمونه استوانه‌ای تهیه می‌شود که تعمیرات مختلف روی آن انجام می‌گیرد. سپس یک کنترل NDT و آزمایشات مکانیکی و میکروگرافیک اصلی انجام گرفت. نتایج به‌دست‌آمده پس از چهار تعمیر نشان داد که تعمیرات متعدد انجام‌شده در یک اتصال بر کیفیت اتصالات جوش تأثیری ندارد.