

Anne Higelin ^{1,a}, Sandra Le Manchet ¹, Gilles Passot ¹, Sarata Cisse ¹
IIW Doc II-C-597-2021 (<https://iiwelding.org>)

Prevod: Miloš Pavlović

HEAT AFFECTED ZONE FERRITE CONTENT CONTROL OF A NEW DUPLEX STAINLESS STEEL GRADE WITH ENHANCED WELDABILITY

KONTROLA SADRŽAJA FERITA U ZONI UTICAJA TOPLOTE NOVIH DUPEKS NERĐAJUĆIH ČELIKA SA POBOLJŠANOM ZAVARLJIVOŠĆU

Professional paper / Stručni rad

Paper received / Rad primljen:

September 2025.

Paper accepted / Rad prihvaćen:

November 2025.

Author's address / Adresa autora:

¹ Centre de Recherche des Matériaux au Creusot, Industeel – ArcelorMittal, Le Creusot 71200, France

email / ORCID ID :

^a anne.higelin@arcelormittal.com

Keywords: Duplex stainless steels, weldability, ferrite content, heat affected zone, oil and gas, low temperature

Ključne reči: Dupleks nerđajući čelici, zavarljivost, sadržaj ferita, zona uticaja toplote, nafta i gas, niske temperature

Abstract

Duplex stainless steels have a microstructure consisting of 50% ferrite α and 50% austenite γ . This two-phase microstructure provides the duplex stainless steels with attractive mechanical and corrosion properties and is strongly dependent on the heat treatment and chemical composition. During the welding process, the temperature reached in the heat affected zone (HAZ) retransforms austenite into ferrite. Due to the high cooling rates, only a part of the ferrite is retransformed into austenite. This tends to modify the 50/50 phases equilibrium. Cooling rate is linked to heat input but also to parts thickness and increases with the thickness of the plates. Most of the actual standards limits the ferrite content in the range from 30% to 70% in HAZ. However, the 70% limit for ferrite content in HAZ could be difficult to reach on high thickness plate. To avoid this risk, a new duplex stainless grade, called 2205 Arctic, was developed. This paper will provide details on ferrite content measurement by metallographic method and welding results obtained on industrial welds showing very low and stable ferrite content in HAZ. Mechanical properties obtained on these welds at low temperature will also be reported, pushing the limits of use of duplex from -50°C (-58°F) down to -100°C (-148°F).

Rezime

Mikrostruktura dupleks nerđajućih čelika sastoji se od 50% ferita (α) i 50% austenita (γ). Ova dvofazna mikrostruktura pruža dupleks nerđajućim čelicima atraktivna mehanička i korozivna svojstva, pri čemu jako zavisi od termičke obrade i hemijskog sastava. Tokom procesa zavarivanja, temperatura dostignuta u zoni uticaja toplote (ZUT) dovodi do transformacije austenita u ferit. Zbog visokih brzina hlađenja, deo ferita se ponovo transformiše u austenit. Ovim se menja 50/50 ravnotežni odnos faza. Brzine hlađenja direktno su povezane sa unetom toplotom, kao i sa debljinom delova koji se zavaruju, pri čemu se unos toplote povećava sa debljinom limova. Radi izbegavanja navedenih rizika, razvijena je nova klasa dupleks nerđajućih čelika, pod nazivom 2205 Arctic. Ovaj rad prikazuje detalje u vezi merenja sadržaja ferita metalografskom metodom kao i rezultate na industrijskim zavarenim spojevima, koji pokazuju nizak i stabilan sadržaj ferita u ZUT. Prikazane su i mehaničke osobine na niskim temperaturama dobijene na ovim spojevima, a rezultati pomeraju granicu upotrebe dupleks čelika sa -50°C čak do -100°C .

1. Introduction

Industeel developed a new 25% chromium duplex stainless steel, called 2205 Arctic, with improved toughness down to $-100\text{ }^{\circ}\text{C}$, same tensile properties and corrosion resistance as the standard 2205 duplex material. In the first part, we will explain the chemistry modification which allow better austenite-ferrite balance in base material and in welded joint and the mechanical properties obtained. In a second part, we will come back on the influence of welding and methodology of measurement on ferrite content in HAZ. Last part will gather welding examples performed in partnership with 3 companies: VRV (Italy), Enerfab (USA) and FBM Hudson Italiana (Italy) on 55-mm thick plates with arc processes, where ferrite content and mechanical properties obtained will be presented.

2. A new duplex grade for low temperature conditions

2.1 A new duplex with improved toughness at low temperature

Duplex stainless steels are a balanced mix between austenite phase and ferrite phase. They combine high strength and corrosion resistance compared to standard austenitic stainless steels, which explain their wide use in the energy sector.

To keep optimized corrosion and toughness properties, the ferrite content must be under control either on Base material (BM), Heat Affected Zone (HAZ) or Weld Metal (WM).

A new duplex stainless steel was developed to improve toughness below $-50\text{ }^{\circ}\text{C}$ (-58°F) (1) by reducing the ferrite content.

2.2 Modified chemical compositions to obtain lower ferrite content in HAZ

Duplex stainless steels present a two-phase microstructure consisting generally of 50% austenite and 50% ferrite. This balance is due to the chemical composition between ferrite formers (chromium and molybdenum) and austenite formers (nickel and nitrogen) (2), and to the heat treatment. When it is melted, a duplex stainless steel solidifies from the liquid phase in a fully ferritic microstructure. When it cools down, around half of the ferrite transforms to austenite. Duplex stainless steels have a 50-50 austenite-ferrite microstructure after a solution annealing usually at $1050\text{-}1100^{\circ}\text{C}$ ($1922\text{-}2012^{\circ}\text{F}$) followed by a rapid quenching 2205 Arctic contains more nickel and nitrogen (Table 1) and has a 60-40 austenite-ferrite microstructure after water quenching (Figure 1, Figure 2).

Table 1: Typical chemical composition (weight %) of DSS 2205

Tabela 1: Tipični hemijski sastav (tež. %) legure DSS 2205

Name	UNS	EN	% C	%	%	% Mo	% N	%
Standard	S32205,	1.446	<0.02	22.5	5.3	2.7-	0.16	rest
2205 Arctic	S32205,	1.446	<0.02	22.5	6.0	2.7-	0.19	rest

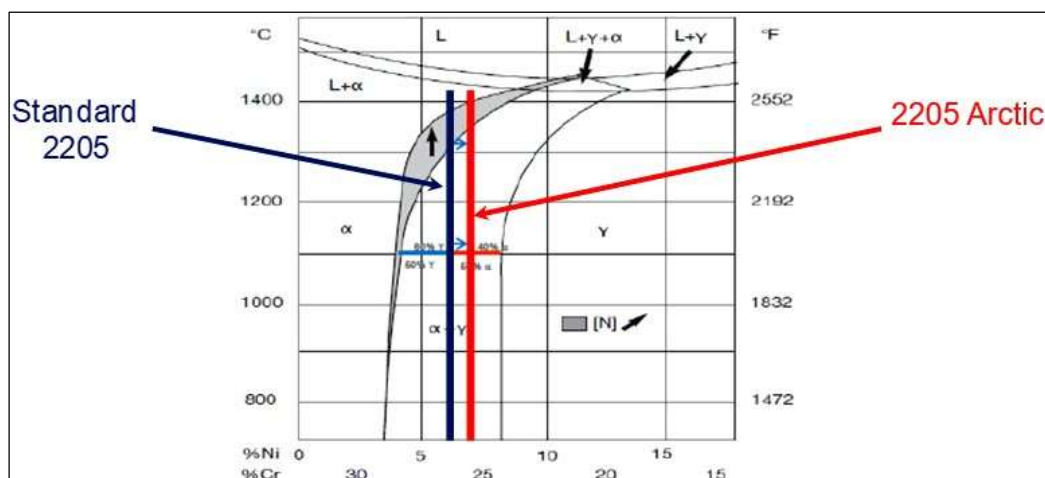


Figure 1: Cr-Ni phase diagram at 68% iron and modification of ferrite content from 50% (Standard 2205) to 40% (2205 Arctic) with Ni and N addition (3)

Slika 1: Cr-Ni fazni dijagram, pri sadržaju Fe od 68% i modifikacija sadržaja ferita od 50% (standardna 2205 legura) do 40% (legura Arctic 2205) dodatkom Ni i N (3)

During welding operation, the thermal cycles induced by welding operations can go up to 1300 °C (2372 °F) and strongly impact the microstructure, by transforming the austenite into ferrite (Figure 2). For instance, nitrogen added (0,14 to 0,21% N₂) into the lean duplex stainless steel 2304 (S32304 / 1.4362) decreases the ferrite content (74 to 65 %) and the width of HAZ (250 to 150 μm) (2).

As the cooling rate is quite high during welding, the re-transformation of ferrite into austenite is not completely achieved and the austenite is made of

needles (Figure 4 in HAZ, Figure 5 in WM). Thus, HAZ and WM of duplex stainless steels are characterized by higher ferrite content than BM.

For the WM, duplex filler metals have high Nickel content (usually 9 to 10% Ni), to promote the austenite and moreover to enhance the toughness in the as-solidified structure. In case of Gas Tungsten Arc Welding or Gas Metal Arc welding, part of nitrogen loss in the arc must be compensated by the nitrogen addition in the shielding gas. It allows to limit the ferrite content in the weld metal (4).

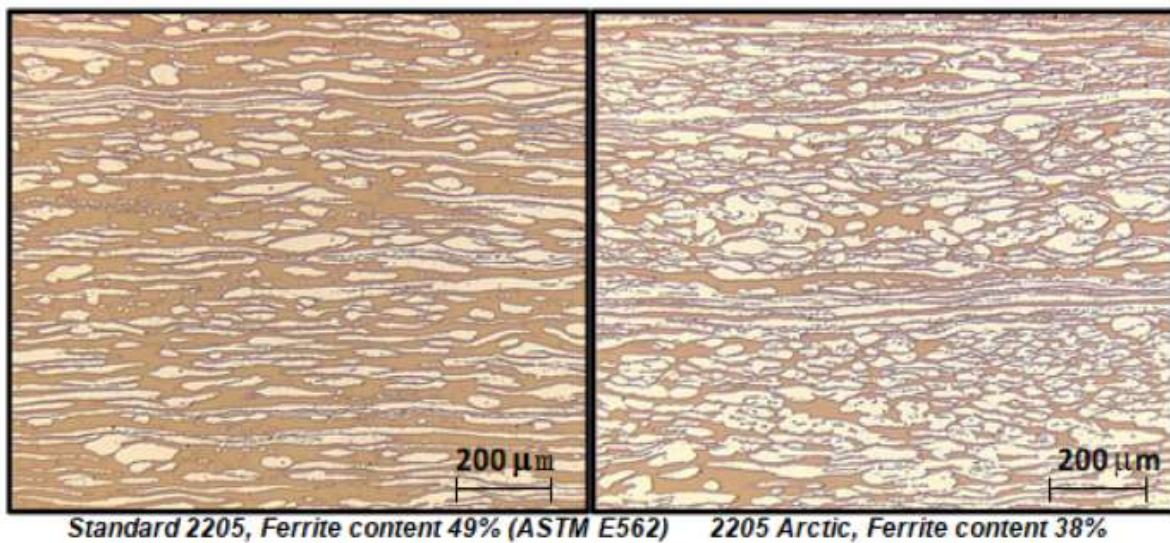


Figure 2: Metallographic examination of a DSS Standard 2205 (left) and 2205 Arctic (right) microstructures (x200) after etching with NaOH 10N (ferrite in brown and austenite in white) (1)

Slika 2: Metalografsko ispitivanje mikrostrukture legura DSS standard 2205 (levo) i 2205 Arctic (desno), x200, posle nagrizanja sa NaOH 10N (braon-ferit, belo-austenit)

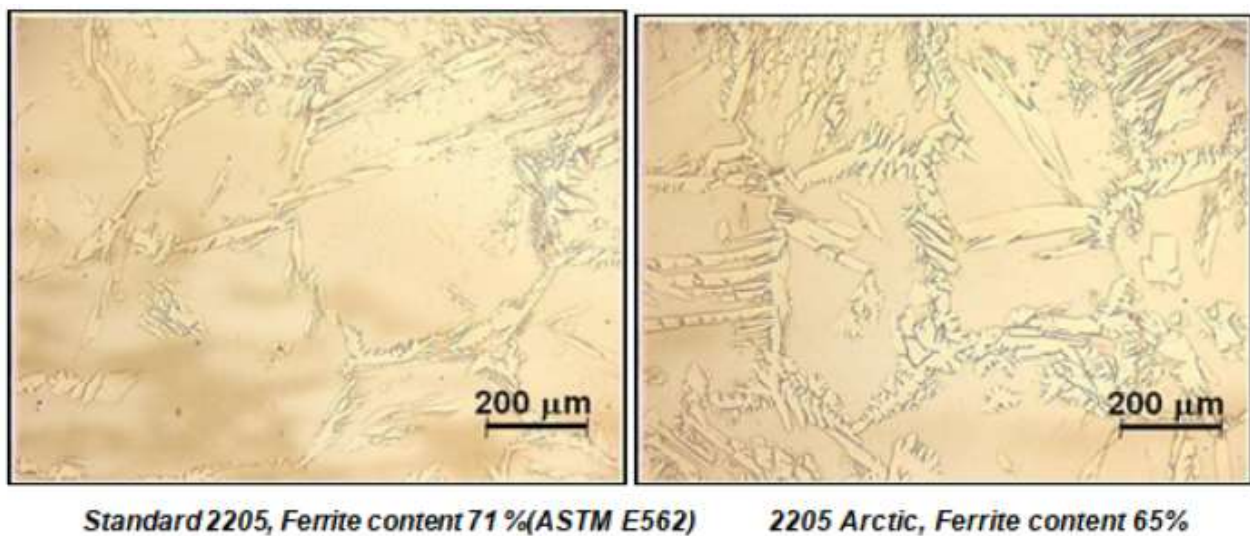


Figure 3: Metallographic examination of a HAZ (single affectation) of a DSS Standard 2205 (left) and 2205 Arctic (right) after etching with NaOH 10N (ferrite in brown and austenite in white) (1)

Slika 3: Metalografsko ispitivanje mikrostrukture u ZUT (jednostruki uticaj) legura DSS standard 2205 (levo) i 2205 Arctic (desno), posle nagrizanja sa NaOH 10N (braon-ferit, belo-austenit) (1)

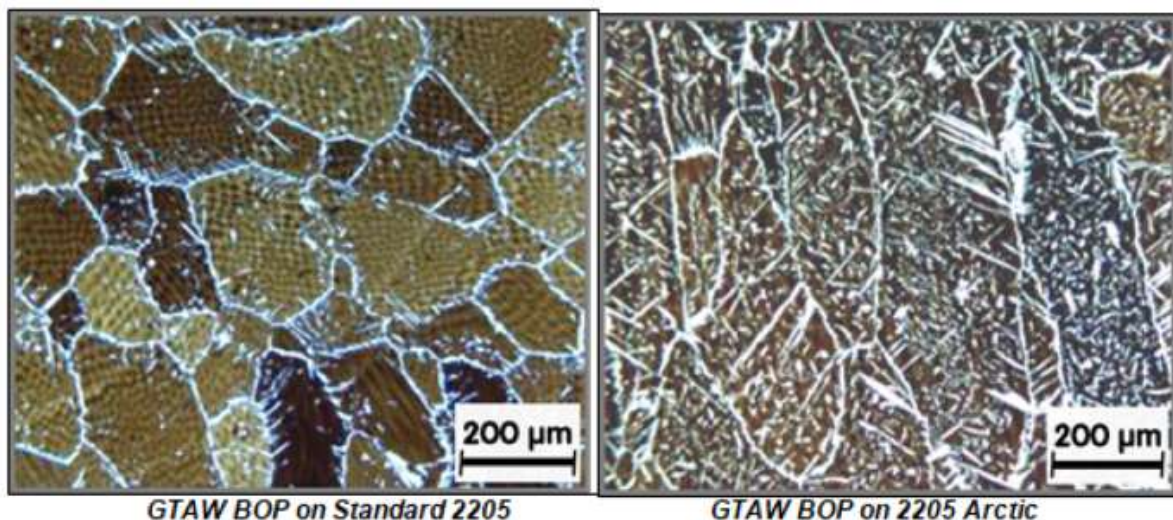


Figure 4: Metallographic examination of a weld metals BOP in GTAW without filler metal on DSS standard 2205 (left) and 2205 Arctic (right) (x200), after Lichtenegger & Bloech etching (ferrite matrix in brown, austenite in white) (1)

Slika 4: Metalografsko ispitivanje metala šava TIG postupak bez dodatnog materijala legura DSS standard 2205 (levo) i 2205 Arctic (desno), x200, nakon nagrizanja Lichtenegger & Bloech reagensom, (braon je matrica ferita, belo je austenit)

2.3 Mechanical properties: same tensile and improved toughness

This two-phases structure gives several attractive properties to the duplex stainless steels, especially in terms of mechanical and corrosion resistance (1) (5). Minimum tensile properties of duplex stainless steels are shown in Table 2.

They present yield strength values twice as high as those of standard austenitic grades which may allow a significant decrease in the thickness of equipment such as storage tanks for instance.

Table 2: Indicative minimum values of YS (Yield Strength), UTS (Ultimate Tensile Strength) and El (Elongation) of duplex 2205 and austenitic grades (6)

Tabela 2: Indikativne minimalne vrednosti YS (granica tečenja), UTS (zatezna čvrstoća) i El (izduženje) za dupleks 2205 i austenitne klase čelika (6)

Name	UNS	YS _{0.2%}		UTS		El, %
		MPa	ksi	MPa	ksi	
Duplex 2205	S31803	460	67	680	98	25
Duplex 2205 Mo	S32205	460	67	680	98	25
Duplex 2205 Arctic	S32205, S31803	460	67	680	98	25
Austenitic 304L	S30403	200	29	520	75	45

Tensile properties between -100 (-148 °F) and 300 °C (572 °F) in base materials are displayed in Figure 5. Samplings were performed from 20-mm thick plates. Results are similar between the grades and above requirements (6) (7). Tensile properties of thicker plates 90 and 150 mm at room temperature are in line with the requirements (5) (6). Toughness properties between -200 °C (-328 °F) and 100 °C (212 °F) in base materials are displayed in Figure 6. Samplings were performed from 20 mm and 90 mm thick plates. Ductile-fragile

transition temperature is shifted to lower temperatures for 2205 Arctic, and in the temperature range [-50; -100 °C] CVN values are significantly enhanced. Requirements of 45J at -46 °C (-50 °F) (8) are fulfilled around -100 °C (-148 °F) for 2205 Arctic instead of -50 °C (-58 °F) for the standard 2205. This increase in toughness values is very interesting especially since the tensile properties as the same as the standard grade (Figure 5).

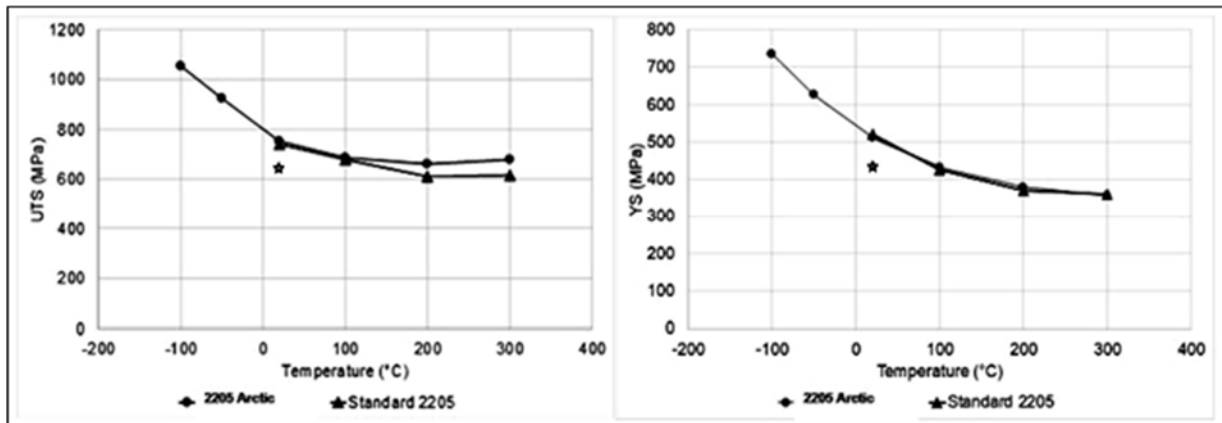


Figure 5: Mechanical properties YS (Yield Strength), UTS (Ultimate Tensile Strength) of standard 2205 and 2205 Arctic; ASTM A240 requirements showed by green stars (5)

Slika 5: Mehanička svojstva YS (granica tečenja), UTS (zatezna čvrstoća) standarda legura 2205 i 2205 Arctic; zahtevi ASTM A240 prikazani zelenim zvezdicama (5)

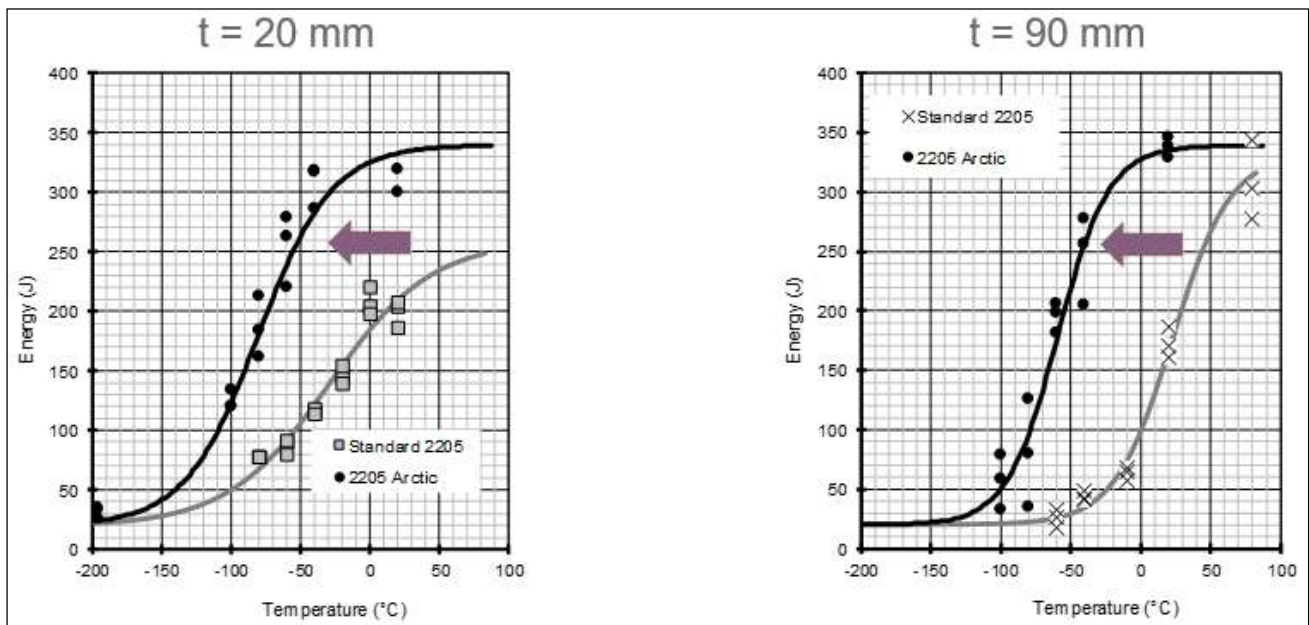


Figure 6: Toughness properties of 2205 Arctic for 20 mm (left) and 90 mm (right) thick plates (5)

Slika 6: Žilavost čelika 2205 Arctic za ploče debljine 20 mm (levo) i 90 mm (desno) (5)

The main conclusion is that 2205 Arctic has the same YS and UTS properties than the standard 2205 grade (Figure 5), and better toughness properties (Figure 6). All results are in line with the most common requirements and specifications (5) (6).

3. Influence on ferrite content of a duplex joint: welding and measurement

The ferrite content after cooling of the weld and HAZ is mainly dependent on the chemical composition of the plate, welding parameters (heat input, welding process...) or configuration (thickness, preparation...).

When measuring the ferrite content on welded joint, it appears clearly that the ferrite / austenite ratio is not only depending on the previous parameters but also on the measurement parameters: method, location or magnification. (2)

3.1 Effect of the welding conditions

On welded joints (HAZ or WM), two areas can be considered: the as-welded condition (single affectation, higher ferrite content) and the re-heated part (multiple affectations which promote the

formation of secondary austenite, lower ferrite content) (1) (2). Maximal ferrite content will be measured in as-welded condition.

In addition to the number of thermal cycles, ferrite content is depending on the welding cooling rate, in other words on the thickness of the plate, the weld preparation (butt weld or fillet), the efficiency of the welding process and the welding heat input.

As the austenite formation occurs at high temperature, preheating, postheating or interpass temperature are not influent parameters.

Based on Industeel database on welded joints, several formulas have been determined to predict

the microstructure and the properties of duplex welded joints (9). The maximal ferrite content

is emphasized by the following graphs depending on the cooling rate (Figure 7). Higher the cooling rate is, higher the ferrite content is. It also highlights the beneficial effect of nitrogen

on the weldability. High nitrogen content at 0.19% allows a ferrite content lower than 70%, whatever the cooling rate.

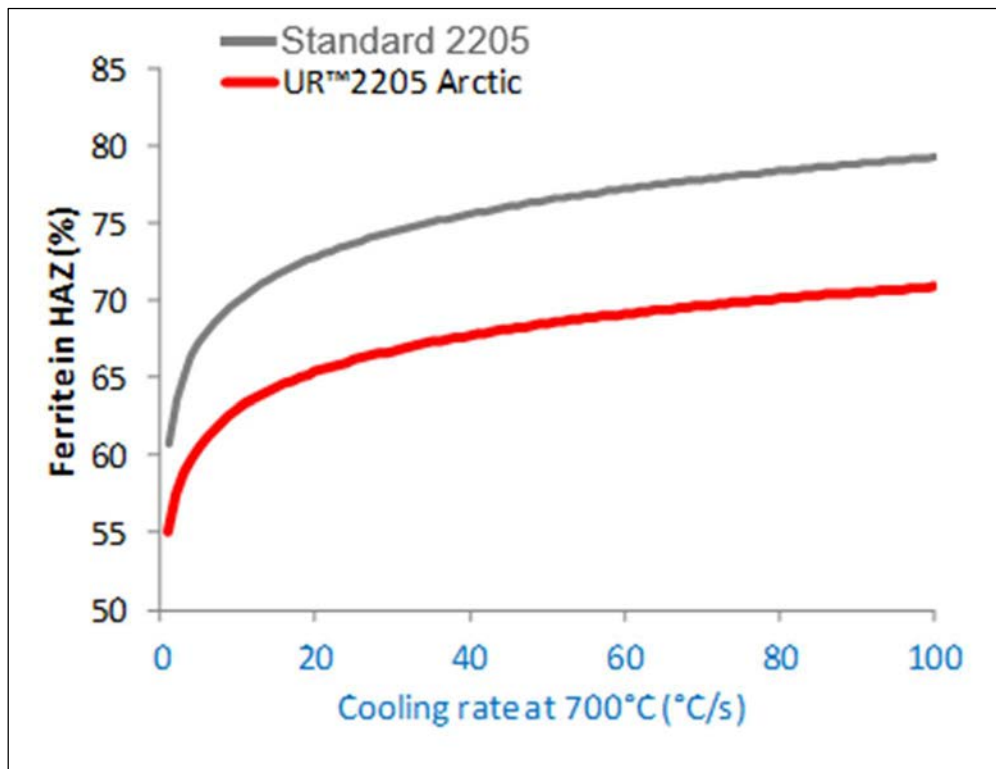


Figure 7: Ferrite content in HAZ of Standard 2205 (0.16%N₂) and 2205 Arctic (0.19%N₂) according to cooling rate of the weld at 700 °C (1292 °F) (°C/s)

Slika 7: Sadržaj ferita u ZUT standardna 2205 (0,16%N₂) i 2205 Arctic (0,19%N₂) u skladu sa brzinom hlađenja zavara na 700 °C (1292 °F) (°C/s)

2205 Arctic shows a very good microstructural stability of HAZ during internal welding tests: BOP with autogeneous GTAW and actual weld in SAW in half V groove with 2209 or nickel base filler metals (1).

3.2 Effect of the methodology of measurement on the ferrite content

Based on API RP 582 guideline (10), maximal ferrite content can be measured in as-welded state (under cap pass) (2) using manual point counting as defined by ASTM E562 (11) or automatic counting defined by ASTM E1245 (7) after

calibration with ASTM E562 method only for base material and weld metal.

Several requirements regarding the ferrite content are observed in standards, guidelines or customers specifications. Those related to the oil & gas industry are summed up in the Table 3.

If the ferrite content requirements are globally common for BM and WM, with an appropriate and representative magnification, the ferrite content requirements in HAZ can evolve in terms of maximal ferrite content and magnification, from 60 to 70% ferrite content and from x400 to x1000 magnification.

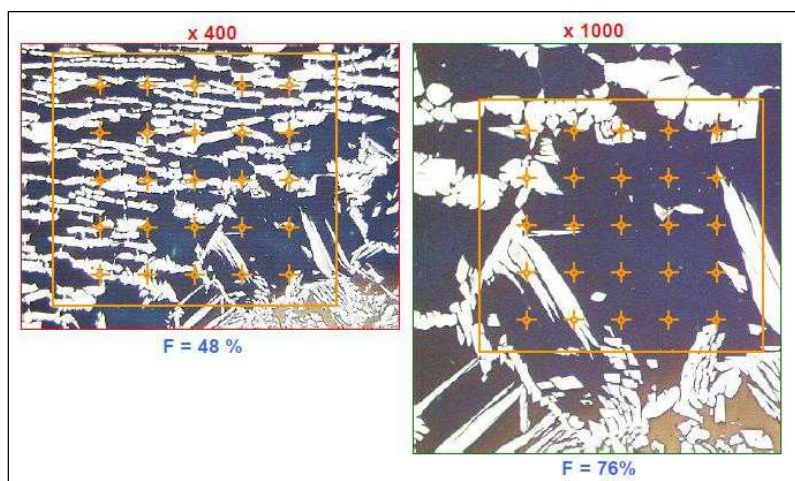
Table 3: Requirements regarding ferrite content and measurement methods (12)**Tabela 3: Zahtevi u vezi sa sadržajem ferita i metodama merenja (12)**

	Base material	Heat Affected Zone	Weld metal
API RP 582 (10) (API A938C)	30 – 65%	30 – 65%	30 – 65%
Method	ASTM E562 Grid : >100 points Magnification : x400	ASTM E562 Grid : >100 points Magnification : x700 – x1000	ASTM E562 Grid : >100 points Magnification : x400
NORSOK M630 D45 (8)	35 – 55%		30 – 70 %
Method	ASTM E562 and ASTM E562 Magnification x400		ASTM E562
Current Oil&Gas specifications	35 – 55 %	< 60 – 65 %	< 60%
Method		ASTM E562 Magnification > x400 or x500	

ASTM E562 is a guideline for phase measurement (duplex and austenite) but does not precisely specify the magnification for the micrographic examination. Consequently, the ferrite content interpretation is strongly dependent on the operator. According to Industeel's experience, a difference of 5 points can be measured from different operators using the same measurement method and the same sample. A difference of 12 points is obtained when considering different operators and different methods. Usually, oil & gas requirements are more precise: x400 for base material and weld metal and higher than x400 or x500 magnification for HAZ. Figure 8 highlights the influence of a ferrite measurement at x400

magnification and x1000 magnification in the same HAZ.

Even with these recommendations, it appears that the ferrite content can evolve from roughly 50% to 75-80% for one microstructure. For instance, a higher magnification allows to place the grid measurement in a high temperature heat affected zone (HTHAZ) characterized by a high temperature and high cooling rate thermal cycle, whereas at x400 magnification the grid is located into a mix between parent material, HAZ and even weld metal. Rationally, the first one is severe but more representative of the HTHAZ and the second one does not represent the HAZ.

**Figure 8: Magnification of x1000 in HTHAZ will give a more representative ferrite content (12)****Slika 8: Uvećanje od x1000 u visokotemperaturnoj ZUT daje reprezentativniji sadržaj ferita (12).**

The magnification rate must be properly chosen to allow a representative measurement of the HAZ. According to Industeel's experience, a x400 magnification is not fully representative whereas a

x1000 magnification is more relevant to evaluate the HAZ ferrite content.

4. Case studies of welding by fabricators

4.1 Example of standard 2205 and 2205 Arctic 55-mm plates welded by VRV in SMAW and SAW: better properties and lower ferrite content with 2205 Arctic VRV company performed welding trials on two materials: the standard 2205 and 2205 Arctic. The

filler material was 2209 and the gas mixture consisted in Ar+2%N₂. The bevel design was U-shape 12 ° opening with a root gap of 3 mm, root face of 2 mm and radius of 8 mm. After root passes in GTAW, filling was performed by 20 passes with SMAW and the rest with SAW. Heat input used were between 0,5 and 1,6 kJ/mm.

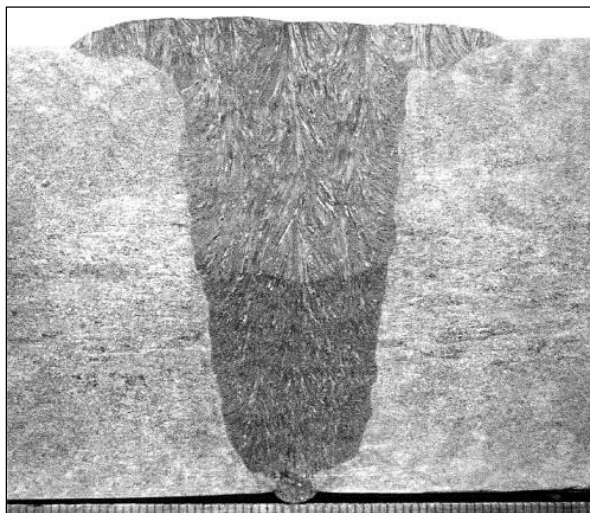


Figure 9: Macrograph on U-shape root GTAW + ½filling SMAW + ½ filling SAW

Slika 9: Makrografija korena u obliku slova U, TIG koreni prolaz + ½ popuna REL + ½ popuna EPP

Microscopic examination Figure 9, show that microstructures are free from precipitate or intermetallic phase according to ASTM A923 method A (13). Ferrite measurements (Table 4) have been performed with micrographic counting

according to the ASTM E1245 standard. Ferrite contents in WM are about 55% in standard 2205 and 50% in 2205 Arctic. Ferrite contents are below 60% as required by oil and gas specifications.

Table 4: Ferrite contents in standard 2205 and 2205 Arctic

Tabela 4: Sadržaj ferita u standardnoj leguri 2205 i 2205 Arctic

Grade	Ferrite cap WM	Ferrite root WM
Standard 2205	55 %	55 %
2205 Arctic	50 %	37 %

Tensile specimens failed in base metal at 750 MPa while bending tests did not lead to cracks in the welds. Impact test results are better for 2205

Arctic HAZ thanks to the lower ferrite content (Table 5). In WM, base material composition impacts more at the root thanks to dilution.

Table 5: Absorbed energy and lateral expansion at -46 °C (-50 °F) are better with 2205 Arctic

Table 5: Apsorbovana energija i bočno širenje na -46 °C (-50 °F) su bolji kod 2205 Arctic legure

Grade	Heat Affected Zone			Weld Metal		
	Top SAW	3/4 SMAW	Root GTAW (subsize samples 2.5x10)	Top SAW	3/4 SMAW	Root GTAW (subsize samples 2.5x10)
Standard 2205	63 J	84 J	28 J	68 J	82 J	31 J
2205 Arctic	122 J	116 J	43 J	74 J	80 J	41 J

4.2 Example of plate 2205 Arctic 55-mm welded by Enerfab in FCAW, SAW: influence of O₂ on WM toughness, ferrite content below 70% in HAZ

Enerfab company performed welding trials on 2205 Arctic and 2209 filler material using two welding processes: FCAW in vertical position with Ar + 18%CO₂ shielding gas on one side and SAW

in flat position on the other side. Welding heat inputs of the two processes were between 1,3 and 1,8 kJ/mm. The bevel design is a symmetric X-shape opened at 60 ° with root gap and root face of 2-3 mm. 17 passes were needed on face side by FCAW and 20 passes on root side by SAW. Macrograph (Figure 10) shows no defect.

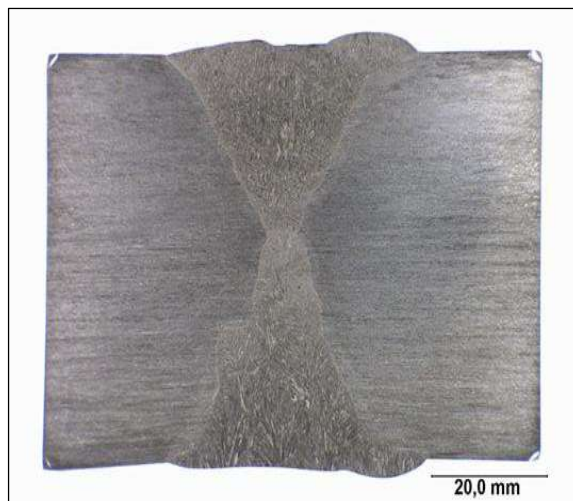


Figure 10: Macrograph of 2205 Arctic 55-mm done by Enerfab

Slika 10: Makro prikaz spoja 2205 Arctic debljine 55mm zavareno u Enefabu

Micrographs (Figure 10) show microstructures free from precipitates and intermetallic phases. Ferrite contents (Table 6) were measured according to the ASTM E562 standard (11) (50 points per grid) in four different locations: in as-welded or reheated parts of WM (at x500, 20 fields)

or HAZ (at x1000 of magnification, 30 fields). Maximal ferrite content in HAZ (which corresponds to as-welded part with lower heat input) is about 63 %. The results are in good agreement with common specifications: below 55% in WM and below 65 % in HAZ.

Table 6: Ferrite measurements in WM and HAZ of 2205 Arctic welded by FCAW and SAW

Tabela 6: Merenja sadržaja ferita u MŠ i ZUT u materijalu 2205 Arctic zavarenog punjenom žicom i EPP metodama

		Ferrite content (%) ASTM E562	
		Weld metal	HAZ
		x500	x1000
FCAW	As-welded	42	63
	Reheated	37	53
SAW	As-welded	52	62
	Reheated	35	57

It appears that appropriate ferrite content, in accordance with API RP 582 (10) and NORSOK (8), can be achieved using the duplex grade 2205 Arctic. Tensile specimens failed in the base metal in average at 730 MPa, in accordance with typical

values of 2205 Arctic and above requirements. Impact tests at -46 °C (-50 °F) (Table 7) are about 50 J in WM (FCAW or SAW) because of higher O₂ content and 115 J in HAZ.

Table 7: Absorbed energy and lateral expansion at $-46\text{ }^{\circ}\text{C}$ ($-50\text{ }^{\circ}\text{F}$) with 2205 Arctic, influence of O_2 in WM

Tabela 7: Apsorbovana energija i bočno širenje na $-46\text{ }^{\circ}\text{C}$ ($-50\text{ }^{\circ}\text{F}$) legura 2205 Arctic, uticaj O_2 u MŠ

	WM		HAZ	
	Charpy test (J)	Lateral expansion (mm)	Charpy test (J)	Lateral expansion (mm)
Face side FCAW	58	0.77	108	1.18
$\frac{1}{4}$ upper thickness FCAW	42	0.50	115	1.28
$\frac{1}{4}$ lower thickness SAW	58	0.68	129	1.41
Root side SAW	55	0.68	107	1.24

To be able to use the full capacity of the 2205 Arctic grade, weld metal properties could be

improved to 100 J at $-100\text{ }^{\circ}\text{C}$ ($-148\text{ }^{\circ}\text{F}$) by using processes with low oxygen. This finding will be further described in § 4.3.

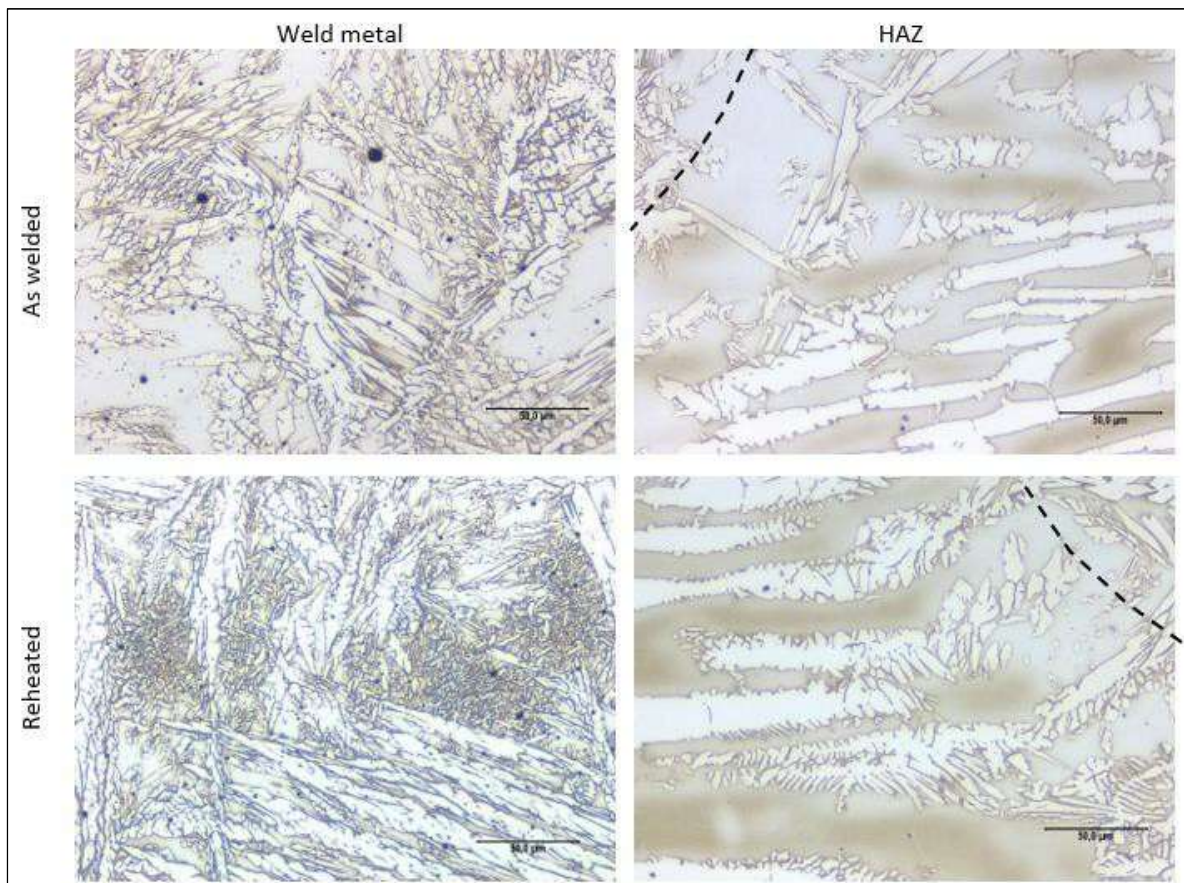


Figure 11: Metallographic examinations of WM and HAZ into FCAW joint on 2205 Arctic, etching NaOH 10N (ferrite brown and austenite white)

Slika 11: Metalografska ispitivanja metala šava (MŠ) i ZUT spoja zavarenog obloženom elektrodom na 2205 Arctic, nagrizanje NaOH 10N (ferit – braon, austenit - bela)

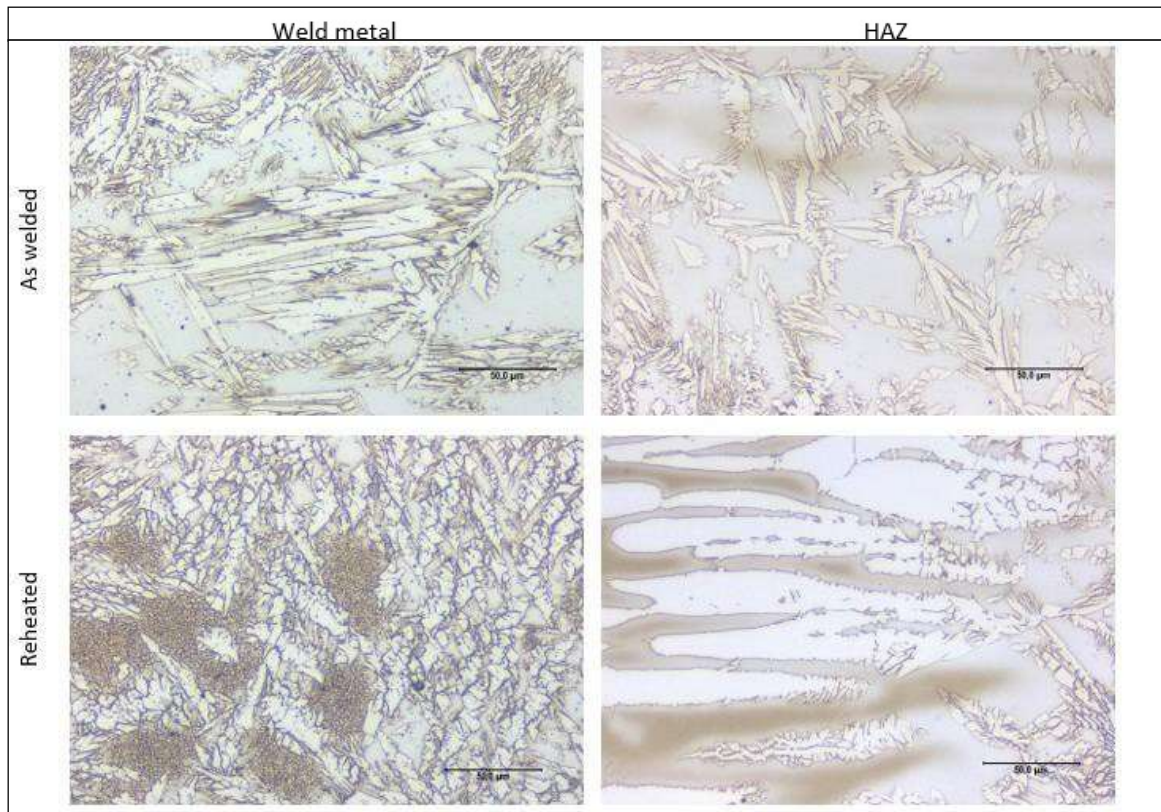


Figure 12: Metallographic examinations of WM and HAZ into SAW joint on 2205 Arctic, etching NaOH 10N (ferrite brown and austenite white)

Slika 12: Metalografska ispitivanja metala šava (MŠ) i ZUT spoja zavarenog EPP postupkom na 2205 Arctic, nagrizanje NaOH 10N (ferit – braon, austenit - bela)

4.3 Example of plate 2205 Arctic 55-mm welded by FBM Hudson Italiana in GTAW Hot wire: improved toughness until $-101\text{ }^{\circ}\text{C}$ ($-150\text{ }^{\circ}\text{F}$)

FBM Hudson Italiana, which has the experience of welding hyperduplex, performed welding trials on

2205 Arctic 55-mm thick and 2209 filler material with Ar + 2%N₂ shielding gas using automatic GTAW Hot Wire process in flat position. Welding heat input was 1,3 kJ/mm. 20 passes were done on each side of the double U-shape bevel 20° (Figure 13).

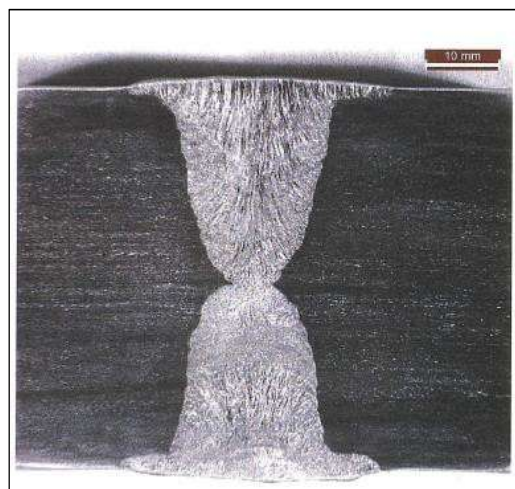


Figure 13: Macrograph of GTAW Hot wire joint 55-mm thick

Slika 13: Makro prikaz spoja dobijenog TIG postupkom sa vrućom žicom, debljina 55mm.

Test method used for ferrite measurements is as following:

- Micrographic counting according to the ASTM E562 standard
- Number of field: 5 fields in the WM: 225 points per grid
- 5fields in the HAZ: Automatic counting

- Magnification: x500 in WM and x500 in HAZ
- Relative accuracy < 10%

Ferrite contents were measured on the same location of impact tests notches. Results are gathered in Table 8. They are well below 70 % and in line with specifications.

Table 8: Ferrite measurements in GTAW hot wire joint

Tabela 8: Merenje sadržaja ferita u spoju dobijenom TIG postupkom sa vrućom žicom

	WM	HAZ
Upper side	38 %	51 %
¼ upper thickness		46 %
½ thickness	36 %	
¾ lower thickness		45 %
Bottom side	35 %	46 %

Toughness are all above 100 J at -101 °C (-150 °F) with GTAW Hot Wire (Table 9). Results are well above requirements. FBM Hudson Italiana will now work to improve productivity.

Table 9: Absorbed energy and lateral expansion at -101°C with 2205 Arctic, influence of low O₂ in WM on toughness

Tabela 9: Apsorbovana energija i bočno širenje na -101°C legure 2205 Arctic, uticaj niskog sadržaja O₂ u MŠ na žilavost

GTAW Hot Wire	WM		HAZ	
	Charpy test (J)	Lateral expansion	Charpy test (J)	Lateral expansion (mm)
1.3 kJ/mm				
Requirements	Min 27 J	Min 0.38 mm	Min 27 J	Min 0.38 mm
Upper side	188	1.7	146	1.6
½ thickness	196	1.7		
¾ lower thickness			203	1.5
Bottom side	125	1.2	200	1.6

5. Conclusions

Duplex grades are interesting and cost-effective alternatives to equivalent austenitic grades, due to their better mechanical properties and good corrosion resistance.

The duplex stainless steel 2205 Arctic ensures good microstructure stability of base metal and ferrite contents meeting requirements of API 582. The ferrite content is indeed lower than 70% in HAZ without minimal heat input.

This new material presents very good toughness properties even down to -80°C (-112°F) and can even reach 100 J at -100°C (-148°F) when welded with welding processes with low oxygen (GTAW, GTAW with hot wire).

5. Zaključci

Dupleks čelici su zanimljiva i isplativa alternativa ekvivalentnim austenitnim vrstama, zbog svojih boljih mehaničkih osobina i dobre otpornosti na koroziju.

Dupleks nerđajući čelik 2205 Arktik obezbeđuje stabilnu mikrostrukturu osnovnog metala, a sadržaj ferita ispunjava zahteve standarda API 582. Sadržaj ferita je zaista niži od 70% u ZUT kada nije ostvaren minimalan unos toplote.

Ovaj novi materijal pokazuje veoma dobru žilavost čak i do -80°C (-112°F) a može dostići čak 100 J na -100°C (-148°F), kada se zavari postupcima sa niskim sadržajem kiseonika (TIG, TIG sa vrućom žicom).

References / Literatura

[1] S. Cissé, S. Le Manchet, D. Paul, V. Villaret, (2017): Duplex stainless steels for low temperature applications.. San Francisco, California, : ISOPE 2017 conference, June 25–30

[2] A. Corolleur, A. Fanica, G. Passot (2015): Ferrite content in the Heat Affected Zone of duplex stainless steels. Graz, Austria : Stainless steel conference, 28-30 April 2015

[3] J.Charles, (1991): Super duplex stainless steels: structure and properties., Beaune, France: Duplex Conference.

4] B. Bonnefois, J. Charles and L. Coudreuse : Welding superduplex stainless with Nickel base filler material: innovation in the consumables and industrial experience.

[5] S. Le Manchet, S. Cissé, G. Passot, D. Paul, (2019): Development of 22%Cr Duplex Stainless Steel with Enhanced Weldability and Toughness Properties for Oil & Gas Applications. Nashville, Tennessee, USA : CORROSION 2019, March 24–28, NACE-2019-12931.

[6] ASTM A240-13. tandard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications

[7] EN 10088-05. Stainless steels — Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes.

[8] Norsok M-630, Edition 6, October 2013. Material data sheets and element data sheets for piping.

[9] B. Bonnefois, P. Soullignac, (1997): Statistical system of prediction for duplex and superduplex weld properties. 5thworld conference : in Proc. Duplex stainless steel

[10] API 582-09. Welding guidelines for the chemical, oil, and gas industries.

[11] ASTM E562-08. Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count.

[12] Fanica, A., (2011): Forming and Stress Relieving of welded superduplex.. : Stainless Steel World Conference & Expo 2011 Maastricht, The Netherlands, 29 November -1 December 2011.

[13] ASTM A923 - 14. Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steels.

[14] A. Fanica, B. Bonnefois, J-C Gagnepain ,(2007): Welding duplex stainless steels: recent improvements. Grado, Italy

[15] S. Hertzman, J. Charles. Beaune, (2005) On the effect of nitrogen on DSS: Duplex stainless steel, 13-15 October 2010. Vol. International Conference & Exhibition . 355.

[16] Robineau, A. Beaune, (2010):Lean duplex grades: weldability and properties of welded joint. Duplex stainless steel 2010, International Conference & Exhibition , 13-15 October 2010.



SVIM ČITAOCIMA ŽELIMO SREĆNE NOVOGODIŠNJE I BOŽIĆNE PRAZNIKE!!