Manufacturing of Duplex Stainless Steel Pipe for Oil and Gas Application

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Abstract — *Stainless steel has always been a fascinating area of interest for researchers, manufacturers and end-users. They face many challenges and very attractive service characteristics. In addition, Duplex Stainless Steel enjoys an excellent cost / ownership ratio in vital markets including: Oil & Gas, Chemical Industry, Paper & Cellulose, Chemical Oil Tankers, Desalination Plants, and Water Networks. Underwater arc welding allows very large welds to be deposited less time compared to a larger number of passes with less deposition per pass. For large constructions and large straight welding operations, SAW is a relatively profitable and satisfactory way of welding stainless steel. In the current investigation, SAW machine was used to manufacture double stainless-steel tubes. The pilot work focuses on compliance with ASME and NORSOK requirements. The GTAW seal is used only for backup purposes for internal welding. In the current investigation, stainless steel duplex plates with a thickness of 32205 and 31803 degrees with a thickness of 20 mm were used to manufacture 20-inch, 20 mm and 5725-meter tubes. The stainless-steel stainless steel is manufactured according to the NORSOK standard and complies with the ASTM standard requirements such as corrosion tests, crash tests and ferrite content measurement.*

Keywords **(Size 10 & Bold) —** *Put your keywords here, keywords are separated by comma.*

I. Introduction

In this current scenario, adverse conditions in the oil and gas industry have grown steadily in intensity. The offshore oil industry is constantly pushing for deeper oil exploration, leading to higher pressure conditions and more hostile environments. In addition, advanced technologies have allowed to increase the total production of local reservoirs, which has led to an increase in the useful life of underground wells and the concentration of corrosive factors in these wells. As the age increases, the water to oil in the produced fluids increases to 95% or more. To adapt to these difficult environments, as well as to protect against the high cost of component failures, it became necessary to ensure the selection of suitable alloys for applications within the oil and gas industry. This has created an excellent opportunity for Duplex 2205 and other double-sided stainless steel.

Two-sided stainless steel was first introduced into the oil and gas industry in the late 1970s, when it was selected for natural gas pipelines. At that time, this option made a commercial breakthrough for 2205 Duplex (UNS S32305 / S31803). This has helped pave the way for the acceptance of Duplex 2205 not only in the oil and gas industry, but also in many other industries. Now, more than 30 years ago, Duplex 2205, Duplex Duplex, Double Duplex and Duplex are playing an increasingly important role in the oil and gas industries on land and at sea.

II. Welding Consumables

Use of overmatching consumables now considered to be a viable option which can give improved properties provided the correct welding procedure and heat treatment are applied. We have a number of choices for filler wire and flux combination. According ASME Sec II Part C, when close control of ferrite content is required, the effects of flux/electrode combination should be evaluated before production welding is undertaken. So we have used a continuous solid corrosion resisting duplex wire OK Autrod 2209. OK Autrod has a higher general corrosion resistance. In media containing chloride and hydrogen sulphide alloy has higher resistance to intergranular, pitting, and as specially stress corrosion. OK Autrod 2209 can be used in combination with OK Flux 10.93. OK Autrod 2209 is approved by many societies like DNV, LR, ABS, DB, CE, GL. It has also a overmatching nickel content that is required for balancing the austenite against the ferrite. Typical weld metal composition and mechanical properties due to combination of this flux/electrode combination is shown in Table 1. OK Flux 10.93 is a basic non-alloying agglomerated flux for the submerged arc welding of duplex stainless steel. These consumables are designed in such a way that minimum matching mechanical properties and corrosion resistance can be guaranteed. They are therefore higher in elements promoting austenite formation compared to the corresponding steel grade, to avoid excessively high weld metal ferrite content. [21]

Before going for the manufacturing of duplex stainless steel pipe, we want be ensure whether welding of duplex stainless steel by SAW will going to give us desired results or not. So, we have done two experiments on plate of UNS S32205. Multiple pass welds, a portion of the previous weld pass is refined, and the toughness improved, as the heat from each pass tempers the weld metal below it. If the beads are smaller, more grain refinement occurs, resulting in better notch toughness. We have taken two trials on duplex stainless steel plate of 20 mm thickness (Grade: UNS S32205).

For plate no 111, we have done testing without heat treatment and for plate no. 222 after heat treatment. For plate no. 111 without heat treatment, we have found deformed grains in weld after micro-examination and also low temperature toughness values were not meeting with standards like MESC SPE, PDO, and DEP.

Table I: - Weld Metal Composition and Mechanical Properties for Different Filler Wire/Flux Combination

Product name	Description	Classification	Typical all weld metal chemical composition	Mechanical Properties	Ferrite content/CPT/ PRE	Approvals
OK Flux 10.93/ OK Autrod 2209	Basic flux/ duplex solid wire for SAW welding	EN 760 SA AF 2 DC EN ISO 14343-A S 22 9 3 NL	C 0.03 Si 0.5 Mn 1.4 Cr 22 Ni 9 Mo 3 N 0.15	YS: 630 Mpa UTS 780 MPa Charpy-V -	FN 30-50/27.5-30°C/34	TUV CE DNV LR GL Rina BV ABS
OK Flux 10.93/ OK Autrod 2307	Basic flux/ lean duplex solid wire for SAW welding	EN 760 SA AF 2 DC EN ISO 14343-A Z 23 7 N L	C 0.02 Si 0.7 Mn 1.1 Cr 22.5 Ni 7.5 N 0.12	YS : 640 Mpa UTS 840 MPa Charpy-V - 40°C 60 J	FN 35-65	CE
OK FluxN 10.93/ OK Autrod 2509	Basic flux/ super duplex solid wire for SAW welding	EN 760 SA AF 2 DC EN ISO 14343-A S 25 9 4 NL	C 0.02 Si 0.5 Mn 0.5 Cr 24.5 Ni 9.5 Mo 4 N 0.25	YS : 640 Mpa UTS 840 MPa Charpy-V - 60°C 50 J YS : 626 Mpa	FN 30-50/60°C/43	TUV
OK Flux 10.94/ OK Autrod 2509	Basic flux/ super duplex solid wire for SAW welding	EN 760 SA AF 2 Cr DC EN ISO 14343-A S 25 9 4 NL	C 0.02 Si 0.5 Mn 0.5 Cr 25 Ni 9.5 Mo 4 N 0.25	UTS 830 MPa Charpy-V B -60°C 50 J	FN 30-50/60°C/43	

Table II: - Submerged-Arc Welding Details

SAW Wire Diameter	2.4 mm
SPECN/GRADE	SFA 5.9, AWS ER 2209
FLUX MFG	ESAB OK FLUX 10.93

As we have choose a 2.4 mm wire diameter electrode , so current range that we can use is generally between 250 – 600 A and voltage between 25 – 35 V. Joint geometry that we have used for SAW of plate is as shown in fig 1.

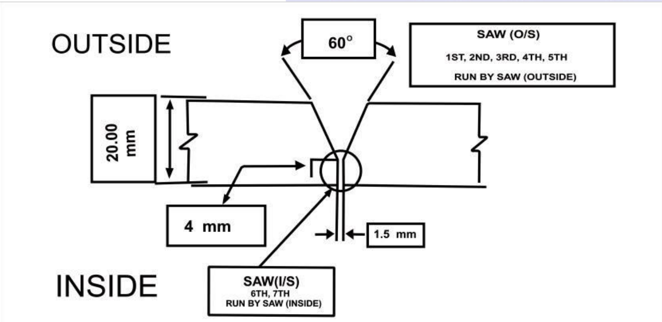

Fig 1: Joint Geometry for SAW of Plate

Table III: Welding Parameter for Plate No 111

Plate : 111 (coupon plate of UNS S32205)				
O/S	Current (A)	Voltage (V)	Travel Speed mm/min	Heat Input KJ/mm
1	375	26	450	1.3
2	480	30	450	1.92
3	475	30	500	1.71
4	490	30	500	1.76
5	500	30.5	500	1.83
I/S	Current	Voltage	Travel Speed	Heat Input
6	485	30.5	500	1.77
7	500	32	500	1.92

We want to observe the effect of heat treatment on toughness of the welded duplex stainless steel. So, for plate no 111, we have done testing without heat treatment and for plate no. 222 after heat treatment.

For plate no. 111 without heat treatment, we have found tensile strength and side bend test satisfactory but found deformed grains in weld after micro-examination and also low temperature toughness values were not meeting with standards like MESC SPE, PDO, and DEP.

Table IV: Welding Parameter for Plate No 222

Plate : 222 (Coupon plate of UNS S32205)				
O/S	Current (A)	Voltage (V)	Travel Speed mm/min	Heat Input KJ/mm
1	360	27	450	1.30
2	415	30.5	500	1.52
3	460	30.5	500	1.68
4	450	30.5	500	1.65
5	475	30.5	550	1.66
I/S	Current	Voltage	Travel Speed	Heat Input
6	460	30.5	550	1.53
7	475	32	550	1.65

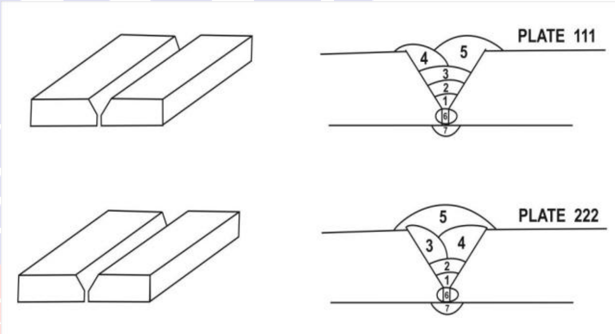

Fig 2: Number of weld layers for plate no. 111 and plate no. 222

III. MECHANICAL TESTING RESULTS

TABLE V: Mechanical Testing Results

	PLATENO. 111	PLATENO 222	Required
SIDE BEND TEST	Satisfactory	Satisfactory	
U.T.S. (N/mm2)	796.54	752.36	655 Min
HARDNESS	15 - 20 HRC	17 – 21 HRC	MAX 31 HRC

Table VI: - Impact Values for Plate no 111 and Plate no 222

Impact Value (Energy in Joule)		
Plate No.	**111 (Without HT)**	**222**
Parent	150	83.33
Weld	52	94.00
HAZ	64.67	95.00

Table VII: Specified Impact value requirements according to different standards.

SPECIFIED REQUIREMENTS	MESC SPE 74/022 Clause 15.5 & Table-3	PDO SP-1189 Clause 7.21.1 & Table Page 12	DEP 31.40.20.34-Gen Clause 7.21.1 & Table Page 21
Temperature (°C)	-50˚C	-50˚C	-50˚C
Min. Avg. Value (Joule)	60	70	60
Min. Ind. Value (Joule)	45	53	45

IV. Microstructural Examination

Etchant: 40% NaOH electrolyte Magnification: 500 X

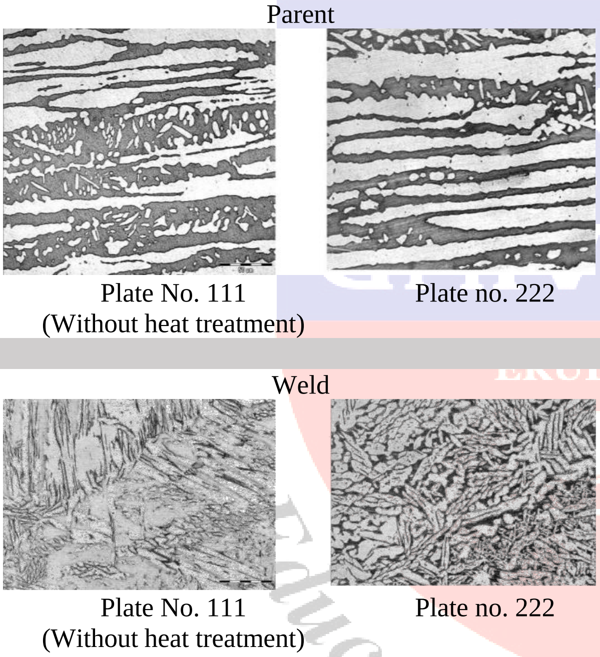

Fig 3: Micro-structure of Weld and Base of plate no 111 and plate no 222

From the parameters for the welding, you can clearly see that we have maintained a heat input between 1.5 to 2.0 kJ/mm by increasing the travel speed. Tensile test and side bend test results were found satisfactory for both the plate no 111 and plate no 222. For low temperature toughness measurement, plate no. 111 was not meeting with the intended requirement from the agencies like PDO and specifications like MESC. On the other hand, plate no 222 that was heat treated after welding meeting the intended requirements.

Micro examination of parent metal shows the smooth interface between ferrite and austenite phases without any significant presence of any inter-metallic phases, unaffected structure for both the plates. Micro examination of weld shows different structure. For plate 111 which are tested without heat treatment shows distorted structure whereas plate no 222 shows smooth interface between ferrite and austenite phase without ant presence of inter-metallic phases, unaffected structure.

V. Conclusions

Weld metal possessed excellent ductility and soundness as there was no crack, fissure or any other discontinuity found during bend test. Bend test results are satisfactory.

Tensile strength of weld metal was high as compared to the base metal. Toughness in terms of absorbed energy in joule value for UNS S31803 pipe for all three locations from weld and HAZ at -46 º C temperatures are 73.55 J and 115.11 J respectively. For pipe of grade UNS S32205 for all three locations toughness values from weld and HAZ at -46˚C are 76.67 J and 188.67 J respectively. All these values are meeting the NORSOK standard requirement that is 35J single and 45J average.

From micro-examination, it is clear that PWHT results in avoiding the precipitation of inter-metallic phases and also results in acceptable low temperature toughness requirement. With use of HI in the range of 1.5 - 4.0kJ/mm for welding in a combination with full solution annealing after welding results in absence of inter-metallic phases in micro-examination and acceptable low temperature toughness requirement in weld and HAZ for both the grades

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