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Study of Mechanical Properties, Microstructure and Corrosion Behavior of Super Duplex-2594 Weld Overlay on Carbon Steel Substrate by Smaw

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ABSTRACT
In today's industrialization world, there is very common problem faced in every industry from long time where the material wear and tear is happened and required to eliminate as soon as possible to get the more utilization of equipment and avoid the shut down timing to increase the productivity and earn more and more money for getting good growth in company as well as nation.The wear and tear mainly occurs due to corrosion, abrasion and erosion. This happens in the chemical process industries, refineries, oil –gas industry, offshore plate forms, steel mills, Logistic industry etc. In these industries the equipment may be statics pressure equipments, boilers, heat transfer equipments, hydro equipment, etc. are working on higher temperatures and getting always the corrosion problems inside the equipment by its processing.
In study work, weld overlay of Super duplex-2594 on SA 516 grade 70 carbon steel using barrier and clad layer of E-2594 welding electrode. Microstructure analysis, bend test, hardness test & corrosion testing were performed to characterization of Super duplex-2594 material by SMAW process.

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I. INTRODUCTION

Super Duplex stainless steel is having good resistance to chloride pitting and crevice corrosion attack. "Duplex" means, two-phase microstructure consisting of grains of ferritic and austenitic stainless steel.

When super duplex stainless steel melts and solidifies from the liquid phase to ferritic structure and as it cools between temperature range of about approx 1000 deg C to room temperature, 50 percentage ferritic transfer to austenitic. Its results is microstructure of 50% austenite and 50% ferrite.

Super duplex is having more percentage of chromium content and lower percentage of Nickel content in comparison of austenitic stainless steel material. Nitrogen content is added in super duplex which is very strong elements of austenite promoter to speed formation of austenite during cooling instead of nickel.

Higher Cr promotes the formation of intermetallic phases. Chromium also increases the oxidation resistance at elevated temperatures.

Molybdenum acts to support Cr in providing pitting corrosion resistance to stainless steels. When the Cr content of a Stainless steel is at least 18%, addition of Mo become about three times as effective as Chromium addition against pitting and crevice corrosion in Chloride-containing environment.

Molybdenum is a ferrite former which forms the detrimental intermetallic phases in stainless steel. So it is maintained to below than about 8 % in ASS and 3-4% in super Duplex Stainless steel.

Nitrogen is a main element for austenite formation after nickel; it plays a major role in partitioning of alloying element Cr, Mo between ferrite and austenite.

Nitrogen increases the pitting and crevice corrosion resistance of austenite and Duplex SS. It also increases strength and is most effective solid solution strengthening element and low cost element. The improved toughness of nitrogen bearing duplex SS is due to their greater austenite content and reduced intermetallic content. Nitrogen does not prevent the precipitation of intermetallic phases but delays the formation of inter- metallic enough to permit processing and fabrication of duplex stainless steel. Nitrogen is added to highly corrosion resistant austenite and duplex stainless steels that contain high chromium and molybdenum contents to offset their tendency to form sigma phase. Nitrogen is the key element, apart from aiding austenite formation, it plays a role in partitioning of alloying element Cr,Mo between ferrite and austenite.

During welding, there is a danger that the austenite formed from ferrite from heating, will contain only the low amount of N that was in the ferrite from which it was formed. if heating time is sufficient ,Nitrogen can diffuse from the original austenite to restore equilibrium. But, if the heating time is too short, the so called secondary austenite will have low N & therefore lower pitting corrosion resistance.

Nitrogen helps to alter phase stability , making austenite stable to higher temperature,& this prevents welds from becoming excessively ferritic and disturbing the desirable 50 to 50 ratio.

Super duplex stainless steel material is a member of steel family which is having two phases that is ferrite –austenite microstructure with major chemical elements of chromium, nickel, molybdenum and nitrogen. Super duplex is having higher tensile strength and higher corrosion resistance properties than the other stainless steel materials as shown in Table 1.

Table-1 Strength Comparison of Different Stainless steels

Sr.No.	TYPE OF STEEL	YEILD STRENGTH(KSI)	TENSILE STREGTH(KSI)	%AGE ELONGATION
1.	316 L	30	78	55
2.	430	45	75	30
3.	2209	65	95	25
4.	2594	80	116	15

1.1 **Chemical Composition of Super Duplex 2594**

Element	% Composition
Nickel	8.0~10.5
Chromium	24 ~27
Molybdenum	3.5 ~4.5
Carbon	0.04 max
Manganese	2.0 max
Sulfur	0.03 max
Silicon	1.0 max
Phosphorous	0.04 max
Nitrogen	3.0 ~ 4.5

Table 2 Typical Chemical values of Super Duplex

1.2 **Characteristics of Super Duplex stainless steels**

- Good stress corrosion resistance cracking
- Higher mechanical strength
- Good crevice and pitting corrosion resistance
- Good weld ability and work ability
- Higher Service Life
- Lower thermal expansion rate

Cladding/weld overlay is a process where a skin layer of any corrosion resistance material is laid down or bonded on the load bearing material like carbon steel or low alloy steels. This cladding of corrosion resistance material on any carbon/magnese or low alloy steel material can be done by different bonding process as mentioned below.

These different processes are:

- Roll bonding process where both the plates are overlapped and rolled in between pressure roller with heat.
- Explosion bonding process where a explosive material is placed in between both of the plates to make a metallurgical bond after explosive detonation as a energy source.
- Clad/weld overlay plates produced by welding process

Further, Clad/weld overlay Plates made by welding can be done using various techniques:-

- Shielded metal arc welding
- Submerged arc welding (Wire electrode)
- Submerged arc welding (Twin Wire electrode)
- Submerged arc welding (Strip Electrode)
- Electro slag strip welding(Strip Electrode)
- Flux cored arc welding
- Gas Tungsten Arc Welding

Among all the welding processes SMAW process is used for weld overlay where other process cannot be used due to their size, equipment complexity or position. SMAW is very easy to use and having good approach to non accessible areas.

II. PROCESS DESCRIPTION:

Shielded metal arc welding is also known as manual metal are welding process ,It is a manual arc welding process that uses an flux coated electrode as a consumable.

SMAW is an arc welding process wherein coalescence is produced by heating the work piece with an electric is set up between a flux coating electrode and the base metal. The covering flux decomposes due to arc heat and performs other functions like arc stability; weld metal pool protection form atmospheric contents etc. The electrode itself melts and supplies the necessary filler metal.

In SMAW required heat is obtained by arc struck between electrode and base metal. The arc temperature can be increased or decreased by employing higher or lower arc currents. Higher current with smaller arc length can produce intensive heat.

The arc melts to the electrode and base metal. As the electrode melts, its droplet transferred to base metal weld pool and fill up the required depth to join the two base metal with filler metal. Coated flux produces a gaseous shield and slag to prevent atmospheric contamination of the molten weld metal.

Fig.1 SMAW Process

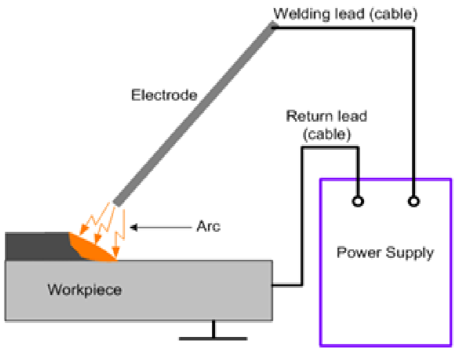


Table 3 Typical parameter of SMAW

Electrode Diameter	Voltage (Volts)	Electrode Current (Amp)
3/32 (2.4)	22-26	45-75
1/8 (3.2)	22-24	90-120
5/32 (4.0)	26-30	130-160
3/16 (4.8)	28-32	200-220

III. EXPERIMENTATION AND TESTING :

Experiment are performed as per following flow chart

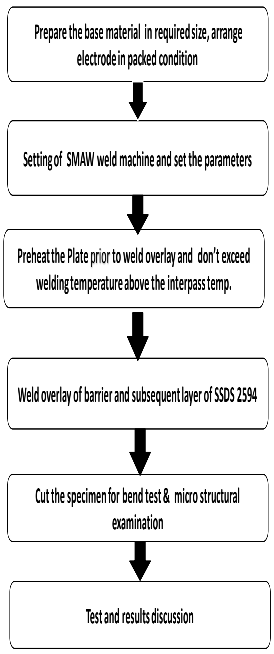


Fig.2 Plan of Experimentation

3.1 **Base Metal and Strip Metal**

The low carbon steel (SA 516 Grade 70), normalized heat treated condition steel of 20 mm thickness were used for experiment. The welding electrode E2594 was used for weld overlay.
Below table provides the information of chemical composition for base material & welding electrode.

Elements (Wt.%)	**Base Metal**	**Super Duplex 2594**
Carbon, C	0.27	0.03
Silicon, Si	0.15 - 0.40	1.0
Sulfur, S	0.035	0.02
Phosphorous, P	0.035	0.03
Manganese	0.85 - 1.20	2.5
Chromium	-	24-27
Nickel	-	8-10.5
Molybdenum	-	2.5-4.5
Nitrogen	-	0.20-0.30
Cupper	-	1.5
Tungestun	-	1.0

Table 4 chemical composition for base material & welding electrode.

3.2 **Welding Parameters**

Material thickness : 20 mm
Plate size : 150 X 200 X 60 mm thick
Joint design : weld overlay on CS base plate
Strip for barrier & Clad : E 2594
Weld Bead Height : 5-6 mm- multi Layer

Fig.3 Barrier Layer & Clad

Fig.4 Sample Preparation

Fig.5 Specimen Cutting

Parameters	Range
Welding current (I)	100-140 Amp
Voltage (V)	24-26V
Travel Speed	220-250 mm/min
Pre heat	50 degree Celsius
Interpass	Max 175
Polarity	DCEP

Table 5 Welding Parameter

IV. RESULTS:

- ✓ Visual Examination : Bead Finish- Good
- ✓ Non Destructive Testing
- Dye Penetrant Testing : Acceptable as per ASME Sec IX .

Fig.5 Dye Penetrate examination

- ✓ **Macro Examination** : No porosity, No Lack of Fusion & complete fusion of weld metal & base metal

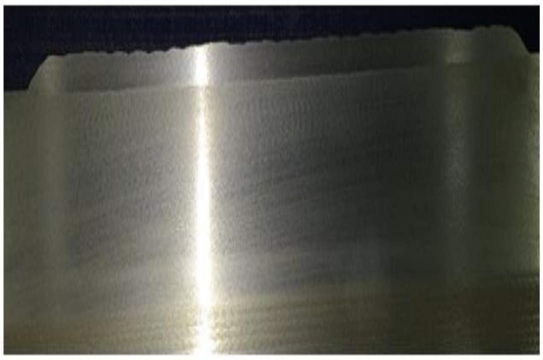


Fig.6 Macro Examination

- ✓ **Bend Test : satisfactory**

Fig.7 – Bend Specimen

Fig.8 Bend Specimen

Test Performed	Number of Sample Tested	Degree of Bend	Acceptance Standard	Results
Side Bend Test	4	180^0	ASME Sec IX	Satisfactory

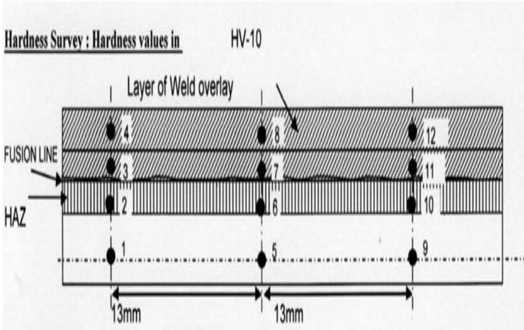
Table 6 Bend Test Results

- ✓ **Chemical Composition was found satisfactory from 4mm fusion line**

Height (mm)	% Element									
	C	Si	S	P	Mn	Ni	Cr	Mo	N	Cb+Ti
Reqd. value	0.04 Max	1.0 max	0.03 max	0.04 max	2.0 max	8.0~ 10.5	24 ~ 27	3.5 ~ 4.5	3.0 ~ 4.5	----
0.5	0.041	0.65	0.004	0.018	0.74	8.33	22.32	3.31	0.21	0.026
1.0	0.043	0.66	0.004	0.018	0.74	8.26	21.79	3.29	0.20	0.025
1.5	0.040	0.64	0.004	0.018	0.71	8.63	22.71	3.48	0.21	0.025
2.0	0.030	0.67	0.004	0.018	0.88	9.19	24.44	3.76	0.21	0.024
2.5	0.031	0.64	0.003	0.017	1.17	9.23	24.52	3.70	0.21	0.017
3.0	0.029	0.64	0.004	0.018	1.13	9.56	25.31	3.64	0.22	0.024
3.5	0.028	0.63	0.004	0.018	1.08	9.4	25.11	3.66	0.22	0.019

Table 7 Chemical Result of Weld overlay

- ✓ **Hardness Measurement**
- ✓ CORROSION TESTING AS PER ASTM 923 METHOD C



Hardness Survey : Hardness values in HV-10 Sample No. W67					
SPOT No.	HARDNESS VALUES	SPOT No.	HARDNESS VALUES	SPOT No.	HARDNESS VALUES
1	165	5	168	9	164
2	160	6	155	10	162
3	170	7	164	11	162
4	224	8	227	12	249

Table 8 hardness Results

- ✓ **Crevice Corrosion test-Method B**

The protective passivation oxide thin layer form on the surface of material in confined space, but in the specific condition passivation oxide layer can be break, location where the protecting oxide layer can break down and thickness of the material at this location is tends to reduce, it is called crevice corrosion. Examples of crevices are very narrow gap in between two mechanical joint, gaskets area in between the flanges.

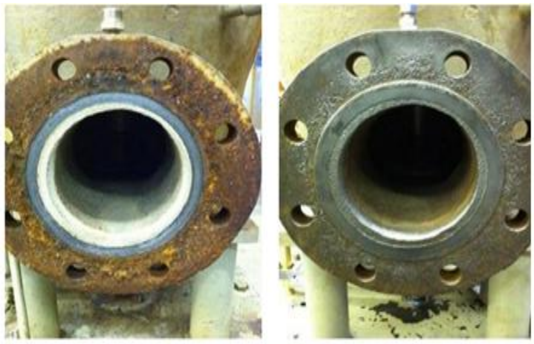


Fig. 9 Crevice Corrosion

Specimen detail

Specimen size: 62.31L x 18.04W x 7.08T,
Total surface area: 33.86 cm2,

Weight: 94.6533 gm
Test temp : 25˚C
(Reqd. 25 [+ -] 1°C
Test solution : 6%
Ferric Chloride by weight with Distilled water
Test duration : 24hrs

Testing results:
Total weight loss: - 94.6533 – 94.6183 = **0.0350 gm**
Result: - No Crevice attacks observed on the surface at 20X Magnification.

✓ **Intermetallic phases testing as per ASTM A-923:96-METHOD-A**

Method : ASTM A-923:96-METHOD-A
Etchant used : 40% NAOH (ELECTROLYTE)
Structure observed at magnification: 400X to 500X
Microstructure is performed at the polished & etched surface
Result: "Acceptable", Unaffected structure without any significant detrimental phases.

V. CONCLUSION:

Typical to weld of super Duplex 2594 welded successfully and meets all the requirement of ASME Sec IX & Sec IIC to perform weld overlay on tube sheet and shell/channel etc for pressure vessel and heat exchanger. .

VI. SCOPE OF FUTURE WORK

As a future work, we will establish corrosion test as per customer requirement such as ASTM G-48 method A-pitting corrosion and ASTM G-36 etc.

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