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Effect of cold metal transfer on corrosion properties of Duplex Stainless-Steel welds

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Abstract: Duplex stainless steel (DSS), which consists of austenite and ferrite phases are widely use in chemical, petrochemical, offshore, railway and power generation sectors due to its excellent corrosion resistance, high strength, and easy formability. The Cold metal transfer (CMT) is an advanced method of droplet detachment for a dip transfer arc welding process. CMT mode of metal transfer in Gas Metal Arc Welding (GMAW) process used to develop butt welding in 8 mm plates of EN 1.4462 (2205) grade. General corrosion behaviour was determined by potentiodynamic in 0.1%N H_2SO_4 solution, while pitting corrosion susceptibility was studied by cyclic polarization test in 3.5 %NaCl solution. Pitting and crevice corrosion test performed as per ASTM G48 method A and B respectively. The findings demonstrate good general and pitting corrosion resistance with lower weight loss. Cyclic polarization results show greater value of Erp which indicates that after the damage of passive film in DSS once again passivated and if pitting initiates, it will not propagate because of passive film formation.

Keywords: Duplex Stainless steel, Cold metal transfer, Pitting corrosion, Crevice corrosion, Potentiodynamic test, Cyclic polarization test.

I. INTRODUCTION

In Duplex stainless steel, the name duplex comes from the formation of dual structure of austenite-ferrite stainless steels. This steel shows outstanding mechanical and corrosion characteristics so that the tendency towards the utilization of duplex grade 2205 is increasing for the manufacturing of parts used in marine, chemical, oil and gas production and pipelines industries[1,3].Main alloying elements in DSS are Chromium (Cr) and nickel (Ni).The percentage of chromium in the range of 18-28 and the nickel percentage varies in between 4.5-8[4]. DSS are divided mainly in four categories: Lean (PREN= 25-26), Standard (PREN = 35-36), Super (PREN- PREW = 40-42) and Hyper (PREN-PREW > 45)[5]. The GMAW technique is widely used in several industries, including oil and gas, because of its features of high productivity and welding in all locations[6].In GMAW process modes of metal transfer such as dip (short-circuit), globular, and spray occur as a function of the set electrical parameters, i.e., current and voltage, which plays an important role in determining the process stability and weld quality [7-9].

Cold Metal Transfer is a modified MIG welding process based on short-circuiting transfer process developed. CMT provides controlled method of material deposition and low thermal input by incorporating an innovative wire feed system coupled with high-speed digital control. There are two main features of the CMT process: one is at the point of short circuit with low current corresponding to a low heat input, another is the short circuit occurrence in a stable controlled manner [10,11]. The CMT (Cold Metal Transfer) arc welding process is a convenient instrument for the assembly of thin sheets. More particularly, it permits the decrease of the amount of heat transferred to the parts to-be assembled, thus reducing their subsequent deformations [12]. GMAW welding with the CMT device enables low heat input into the joint. In the CMT process, the detachment of the addition material (electrode) tip occurs without the use of an electric pulse, but by the retreat of the welding electrode, associated with the modification of the waveform of the welding current determined by the electronic control of the source, making the movement of the electrode possible. The first system is in the wire feeder, as it is observed in conventional equipment.

The second system is inside the torch, which is responsible for the oscillation movement back and forth of the wire, by means of an alternating current servo motor. This oscillation movement may be performed up to 90 times per second. In addition, the process has a buffer between the two systems, which is allocated in the torch cable, working as a type of wire compensator, absorbing backward movement, and avoiding stress during this electrode feeding motion.

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CMT procedure, combined with pulsed arc, led to an adequate superficial finishing, mechanical properties, and corrosion resistance [13]. The mechanical characteristics of the joint were enhanced by Solution Treatment and Age Treatment.

CMT has shed light on several applications, including weld joint repair, overlay, hard-facing, and cladding [14].The technology can be used as a cladding process due to precise control of weld bead dilution. A lower dilution ratio is possible than that realised with pulsed MIG welding microstructural characterization by optical microscopy showed that heat input influences ferrite/austenite phase balance. Secondary austenite that precipitates due to the welding process in DSS are Widmanstatten austenite (WA), grain boundary austenite (GBA), partially transformed austenite (PTA) and intragranular austenite (IGA). The amount of secondary austenite increases with welding energy input. The secondary austenite improves abrasive wear resistance while corrosion resistance is the lowest when welding energy is highest [15]. Corrosion behaviour of metals and their alloys are mainly influenced by the chemical composition, microstructure, internal stress, and heat treatment [16]. CMT technology has become one of the main heat sources for WAAM because of its low heat input, low spatter, and high manipulability. Corrosion rate decreased with increasing heat input due to the positive effect of overaging of AA7075 base metal against corrosion. AA7075 base metal exhibited both pitting and intergranular corrosion while AA5754 base metal experienced only pitting corrosion [17]. The Nitrogen(N_2) content in the shielding gas had significant influence on microstructure of the different zones in the DSS CMT-P welded joint. The N_2 supplemented shielding gas significantly facilitated austenite formation in the weld filler, weld root, and HAZ, which was due to the increase of both N solubility in the molten pool and heat input. However, the excessive N_2 addition in the Argon shielding gas (> 4%) had not obvious influence on austenite content in the welded joint because of reaching solubility limit of N atoms in the molten pool [18].

High heat input and lower arc penetration in GMAW leads to the evolution of a detrimental coarser dendritic structure in the fusion zone (FZ), wider heat affected zone (HAZ), solidification and HAZ liquation cracking, and softening in HAZ. This significantly deteriorates the strength performance and corrosion resistance of welded joints particularly in the salt environment [19]. The critical pitting temperature (CPT) is typically measured with potential-dynamic and potentio-static polarization techniques, or electrochemical impedance spectroscopy (EIS)[20].Cyclic potentiodynamic polarization technique is useful to determine the pitting potential and observe the behaviour of passive surface film of welded specimen [21]. 2205 duplex stainless-steel exhibits active-passive corrosion behaviour in sulphuric acid environment [22].

II. MATERIALS AND METHODS

Plates of BS EN 10088-2 Grade 1.4462 (2205) (8 mm thick, Solution Annealed at 1070˚C) with a single V groove configuration, were joined using the CMT mode of metal transfer in Gas metal arc welding process. Solid welding wire of Ø1.20 mm of grade EN ISO 14343- A-G 22 9 3 N L (ER 2209) was used. ISO14175-M22 Ar0-2 (98%Argon+2%O_2) gas is used as shielding gas and ISO14175-I1(100% Argon) gas is used as purging gas.

A. Base metal and Welding wire description

Base metal description of as received condition, Chemical composition, and Mechanical properties are given in following tables.

TABLE 1: CHEMICAL COMPOSITION OF BASE METAL

Element (%)	C	Cr	Ni	Mo	N	Mn	P	S	Si	Cu
EN 1.4462 (2205)	0.03	21-23	4.5-6.5	2.5-3.0	0.1-0.22	2.0	0.035	0.015	1.0	0.5
Plate(8mm)	0.017	22.2	5.6	3.1	0.17	1.33	0.027	0.001	0.34	-

TABLE 2: MECHANICAL PROPERTIES OF THE BASE METAL

Properties	UTS (Mpa)	YS(Mpa)	Elongation (%)	Hardness (HBW)	Ferrite (%)
EN 1.4462 (2205)	700-950	≥ 460	≥ 25	≤ 293	35-65
Plate (8mm)	827	651	332	269	51

TABLE 3: CHEMICAL COMPOSITION OF FILLER WIRE

Element (%)	C	Cr	Ni	Mo	N	Mn	P	S	Si	Cu
(ER2209)	0.03	21-24	7-10	2.5-4.0	0.1-0.2	2.5	0.03	0.02	1.0	0.5
Filler wire	0.020	22.97	8.90	3.04	0.10	1.52	0.016	0.004	0.47	0.13

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B. Welding Parameters

In Welding machine CMT Universal mode was used to perform the welding. Root run was done with maintaining current 150-160 A. Filling and cap weld passes were done with maintaining current 210-230 A. Thermal efficiency as 0.8 considered for the heat input calculations. Welding parameters were adjusted to obtain heat input from 0.39 to 0.50 kJ/mm for root pass and 0.58 to 0.72 kJ/mm for filling and capping weld pass respectively. Interpass temperature was maintained ≤ 100˚C.

C. Pitting and Crevice corrosion test

Standard ASTM G 48 with Method A and Method B were used to check and study the resistivity of Duplex stainless-steel welding toward pitting and crevice corrosion in chloride media respectively. Time duration for testing was for 72 hours at 22˚C.Standard specimens of size 50 x 25 x 8 mm were prepared and ground through 120 grit size paper. All test specimens were weighed prior to immersion in the solution of $FeCl_3 \cdot 6H_2O$. After testing, removed specimens were carefully scrubbed under running water and then cleaned in methanol for 30 minutes. Evaluation of pitting and crevice was determined by visual examination as well as by optical microscopy at magnification of 20 X. Weight loss, Number of pits, Pit density and average pit depth were recorded and analyzed the results.

D. Potentiodynamic and Cyclic Polarization test

Potentiodynamic test was used to study the corrosion rate & passivity behaviour. Potentiostat consists of three cells, Working electrode (sample specimen), Reference electrode (Standard calomel electrode) and Auxiliary electrode (graphite). The scan rate employed was 5 mV/sec for Potentiodynamic and 2.5 mV/sec for cyclic polarization test. Tests were conducted at room temperature. 0.1N H_2SO_4 solution and 3.5% NaCl solution were taken for potentiodynamic and cyclic polarization test respectively. Corrosion rate (Icorr values) was determined by Tafel Extrapolation. The plot of E v/s log I is obtained in monitor in few minutes and the value of Icorr, Ecorr & corrosion rate in mpy unit are calculated by standard software. The corrosion current density (Icorr) is an important parameter to evaluate the kinetics of corrosion reactions, normally proportional to the corrosion current density measured via polarization. The lower the Icorr, the lower corrosion rate of the sample. In cyclic polarization test Erp is also determined by Tafel fit.

III. RESULTS AND DISCUSSION

Standard ISO 5817 Level B was used to perform Visual examination of weld Joint; results were found satisfactory. Surface defects on root and final welding pass were evaluated using Liquid penetration test as per EN ISO 23277, results found satisfactory.

Radiographic testing for Volumetric evaluation of full butt weld joint was performed as per standard ISO 10675-1 and ISO 10675-2, results found satisfactory. Chemical testing of the weld joints by Spectro and results are shown in Table 4. Results are found satisfactory.

TABLE 4: CHEMICAL COMPOSITION OF WELD METAL

Element (%)	C	Cr	Ni	Mo	N	Mn	P	S	Si
Weld metal.	0.0230	23.1	8.76	3.24	0.16	1.60	0.015	0.003	0.43

A. Pitting and Crevice corrosion test

Pitting and Crevice corrosion test results of CMT welded sample are mentioned in Table 5. Acceptable limit of weight loss for pitting and crevice corrosion rate is taken as 1 x 10^{-3} gms/cm^2 maximum and sample should not show any visible pits on surface.

TABLE 5: PITTING AND CREVICE CORROSION TEST WEIGHT LOSS RESULTS.

Sample ID	Weight loss X 10^{-3} gms/cm^2	
	Pitting	Crevice
C1-8	0.000067	0.005

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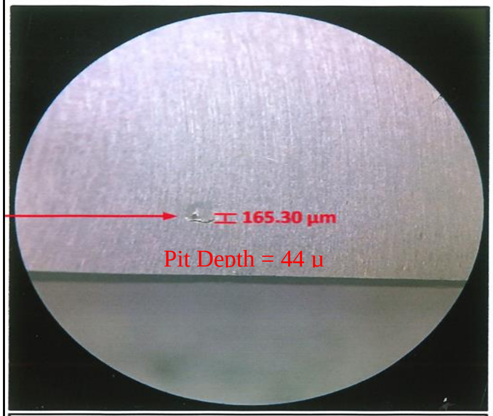
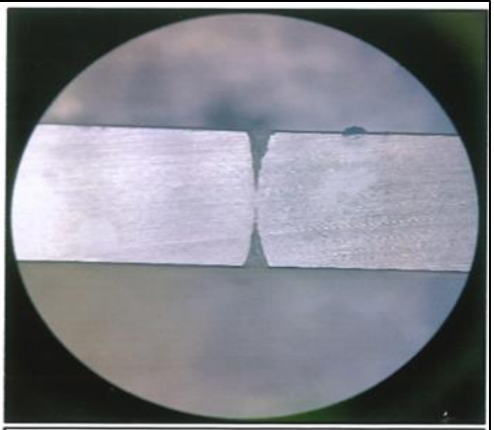
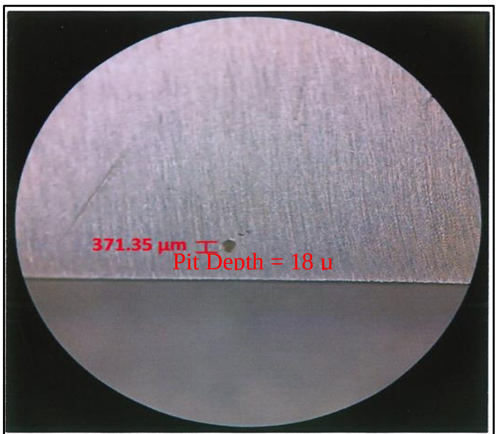
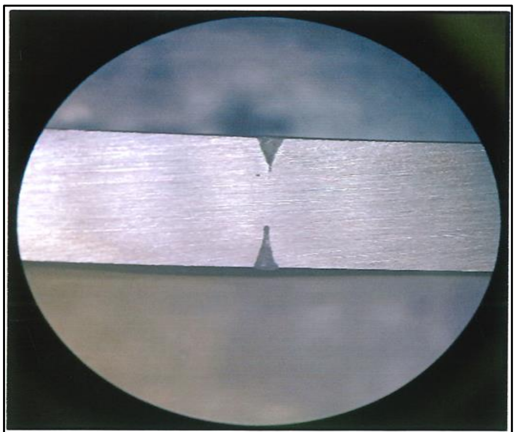
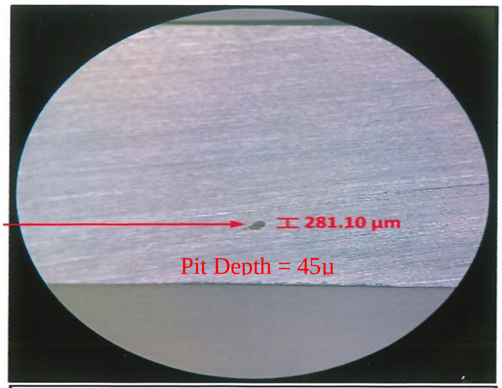
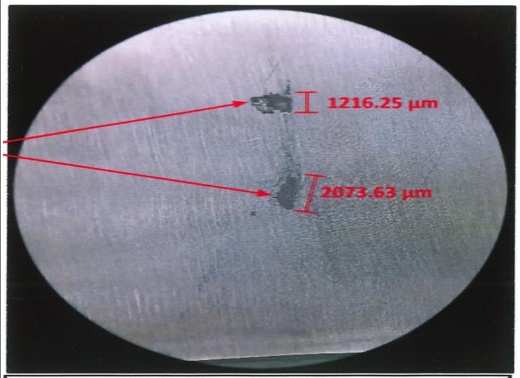
<table>
<tr><th>Sample ID</th><th>Pitting</th><th>Crevice</th></tr>
<tr><td rowspan="3">C1-8</td><td>
Location: Parent Metal Top Side (20X)</td><td>
Location: Weld Bead Thk. Side (10X)</td></tr>
<tr><td>
Location: Weld Bead Bottom Side (20X)</td><td>
Location: Weld Bead Thk. Side (10X)</td></tr>
<tr><td>
Location: Weld Bead Thk. Side (20X)</td><td>
Location: Weld Bead Bottom Side (10X)</td></tr>
</table>

Fig. 1 Pitting and crevice test photographs.

Figure 1 shows pitting, and crevice photographs taken with optical microscope at 10 X and 20 X magnification. Pitting corrosion test results shows that sample welded with CMT shows 03 Nos of pits with pit density < 2.5 x $10^3/m^2$. 02 Nos pits observed on weld bead while 01 No pit observe on parent metal surface. Dial gauge with Needle point was used to check the pit depth. Maximum and average depth of the pit observed 45 micron and 36 microns respectively. Weight loss observed 0.000067 gms/cm^2, which is acceptable as per standard requirements. Crevice corrosion observed on weld bead at 02 Nos location. Weight loss observed 0.0005 gms/cm^2 which is acceptable as per standard requirements.

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B. Potentiodynamic test

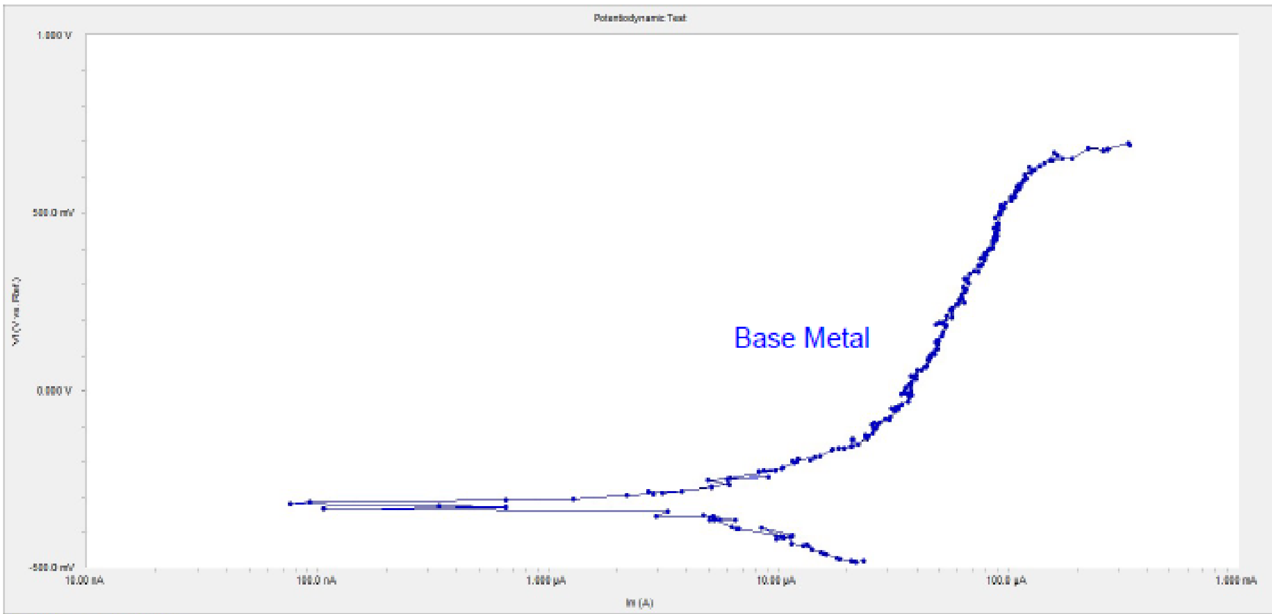

Fig. 2 Potentiodynamic scan of base metal

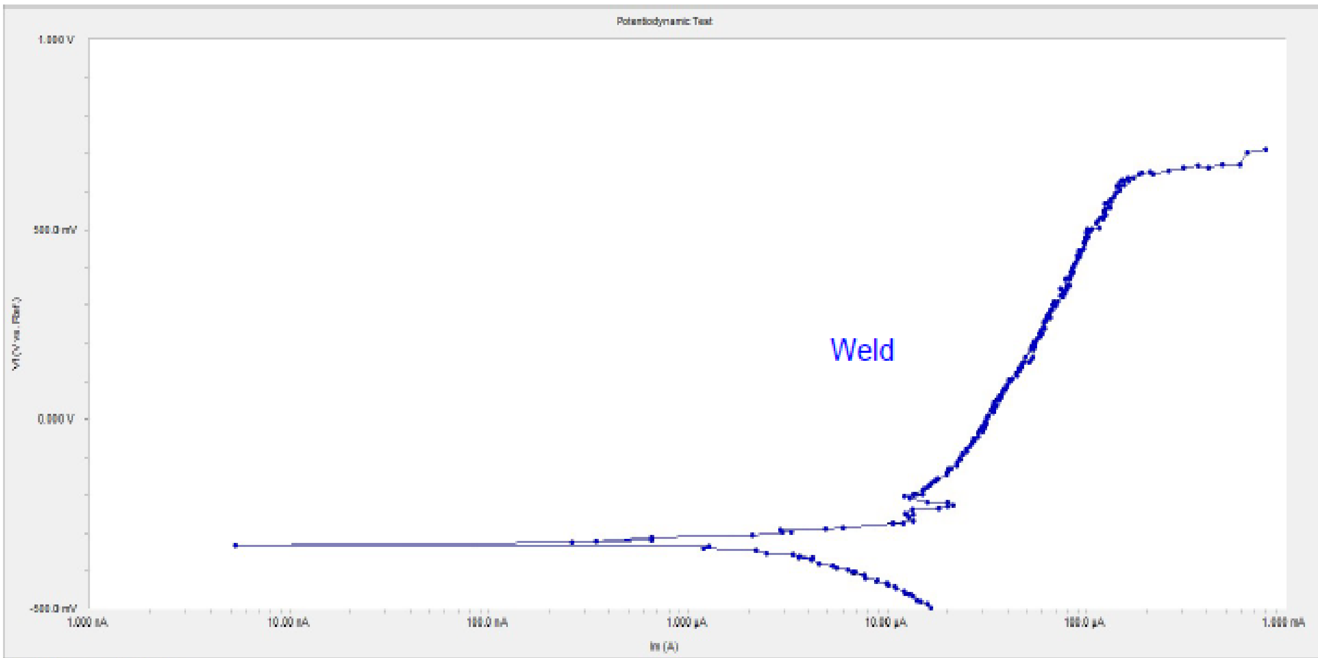

Fig. 3 Potentiodynamic scan of weld metal

TABLE 6: POTENTIODYNAMIC SCAN RESULTS OF WELD METAL AND BASE METAL

Sample ID	Potentiodynamic scan details		
	I corr (µA)	E corr(mV)	mpy
Base Metal	96	-333	0.165
Weld Metal	484	-321	0.833

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Figure 3 shows Potentiodynamic test curves in as welded conditions for weld metal and base metal of CMT welded sample. Results of test is tabulated in Table 6. Icorr value is directly related to corrosion rate. Icorr value of 96 µA and corrosion rate of 0.165 mpy observed for base metal while Icorr value of 484 µA and corrosion rate of 0.833 mpy observed for weld metal.

C. Cyclic Polarization test

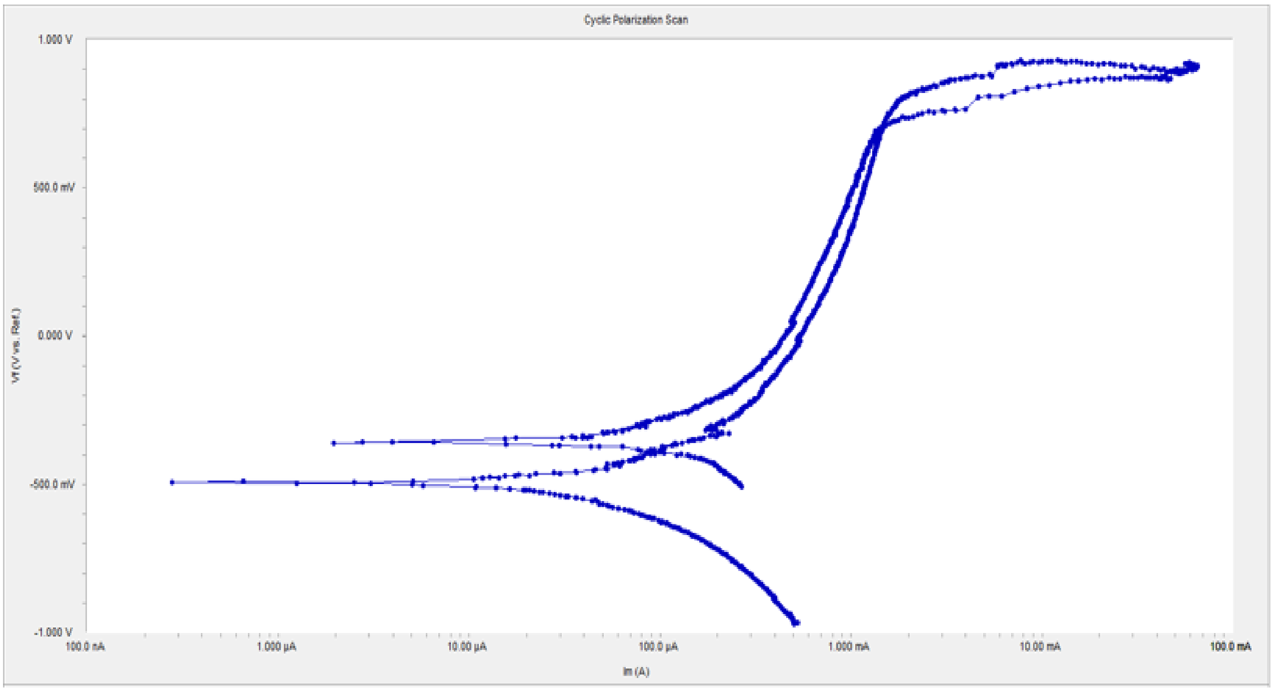

Fig. 4 Cyclic polarization scan of weld metal

TABLE 7: CYCLIC POLARIZATION SCAN RESULTS OF WELD METAL

Sample ID	Cyclic polarization scan details			
	I corr (µA	E corr(mV)	mpy	Erp(mv)
C1-8	103	-493	153.9	706.4

Figure 4 shows Cyclic polarization test curves in as welded conditions for weld metal and base metal of CMT welded sample. Results of the test is tabulated in Table 7. Icorr value is directly related to corrosion rate. Erp is greater than Ecorr value which indicates that pitting occurs, but damage passive film get repair which increases pitting corrosion resistance.

IV. CONCLUSION

From the study of the effect of CMT mode of metal transfer on corrosion properties of Duplex stainless steel (2205) using GMAW process, the following conclusions are drawn:

Visual testing, Chemical analysis, Liquid penetrant, and Radiography testing found satisfactory as per applicable code requirements. Pitting test shows welding loss of value of 0.000067gms/cm^2 and crevice test results shows weight loss value of 0.005 x10^{-3} gms/cm2 which is acceptable against the requirement of 1 x10^{-3} gms/cm2. More experiment and study to be done to improve the minor visible pits and crevice marks observed in weld bead locations.

Potentiodynamic scan shows excellent results of Icorr of 96 µA and corrosion rate of 0.165 mpy for base metal, while Icorr of 484 µA and corrosion rate of 0.833 mpy for weld metal. In Cyclic polarization scan results show Erp (706.4mv) and is greater than Ecorr(-493mv) value which indicates that pitting is occur, but damage passive film get repair which increases pitting corrosion resistance.

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From the study, it is recommended to use CMT mode of metal transfer to weld DSS plates as it gives sound weld joint with good corrosion properties.

However, one need to check application of the product and solution media of use as results may vary for different conditions and use. Also, one needs to exercise how to control uniform lack of penetration from the single side by strictly controlling the welding parameters. Additional study on mechanical properties along with corrosion properties will helpful for future use.

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