Corrosion Behavior of Electro-Slag Strip Cladded Weld Overlays in Different Acid Solutions

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ABSTRACT

The electro-slag strip cladding (ESSC) process is development of submerged arc strip cladding process which has quickly established itself as a reliable high deposition rate process. ESSC process increasingly used for the production of corrosion resistant weld overlays in equipments for the offshore, chemical, petrochemical & nuclear industries. In the present work, 309L & 309LNb austenitic Stainless steel strip were used to develop weld overlay on Cr-Mo steel by variation in welding speed. Amount of ferrite content has been evaluated by ferrite-scope & micro structural study has been done on neophot-2 microscope a at cladded region for both weld overlays which show that amount of ferrite in the matrix of austenite decreases with increase welding speed from 160 mm/min to 200 mm/min. Potentio dynamic studies were carried out on both weld overlays in 0.1 N 1 H_2SO_4 & 0.1 N HNO_3 solution using Potentiostat Gammry Reference 600 which reveal that (i) both weld overlays has better corrosion resistance in 0.1 N H_2SO_4 solution as well as in 0.1 N HNO_3 solution, (ii) both weld overlays developed at 180mm /min. welding speed has good corrosion resistance compared to 160 & 200 mm/min. welding speed. Cyclic polarization studies were carried out on both weld overlays in 6 % $FeCl_3$ Solution by using Potentiostat Gammry Reference 600 which shows that 309 L Nb cladded weld overlay has better pitting resistance at 180mm/min welding speed while 309L cladded weld overlays has lower at all welding speed.

Keywords:, Austenitic Stainless steel, Electro-slag strip cladding, Welding speed, Micro-structural changes, Ferrite content, Potentio-dynamic study and cyclic polarization study.

I. INTRODUCTION

Stainless steel strip cladding is a flexible & economical way of depositing corrosion resistant, protective layer on low alloy or low carbon steel due to which it is widely used in the production of components for chemical, petrochemical & nuclear industries [1]. Large pressure vessels are used in hydrogen containing environments, for example, in the petroleum industry in hydro-cracking, hydrodesulphurization and catalytic reforming processes as well as in the chemical and coal conversion industries [2]. All hydro processing reactors require internal protection of the reactor vessel walls to resist the high temperature corrosion due to presence of sulphur in the process stream. This protection is generally provided by stainless steel strip electrodes which are made up of different grade such as 347,309L, 309LNb, 316L, 317L. A stabilized composition overlay also prevents sensitization during the final post weld heat treatment (PWHT) cycle of the reactor [3].The two most productive systems for surfacing the large components which are subjected to corrosion or wear are submerged arc and electro-slag cladding, using a strip electrode. Both processes are characterized by a high deposition rate, low dilution and high deposit quality. Both these processes are suitable for surfacing flat and curved objects such as heat exchanger tube sheets and pressure vessels. Submerged arc welding (SAW) is most frequently used but, if higher productivity and restricted dilution rates are required, electro-slag welding (ESW) is recommended [4].

Electro-slag Strip Cladding

Electro-slag strip cladding relates to the resistance welding processes and is based on the ohmic resistance heating in a shallow layer of liquid electro conductive slag. The heat generated by the molten slag pool melts the surface of the base material and the strip electrode end, which is dipping in the slag and the flux. The penetration is less for electro-slag welding than for submerge arc welding, since there is no arc between the strip electrode and the parent material [5]. To increase the cladding speed at corresponding high welding currents, it is necessary to use fluxes producing a slag of even higher electrical conductivity and lower viscosity. The temperature of the slag pool is about 2300°C and, if it is not fully covered with flux, it emits infrared radiation [6, 7].

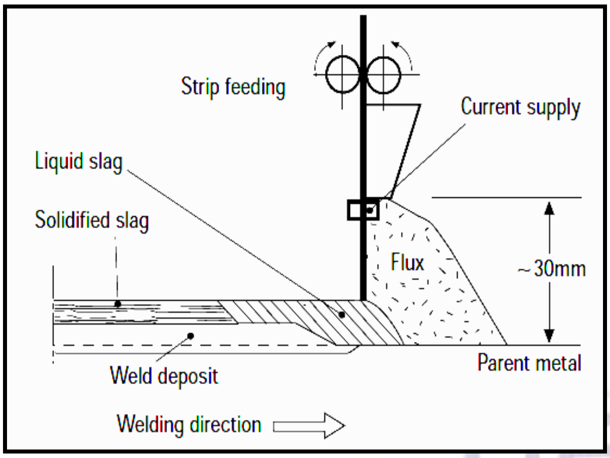

Fig. 1: Schematic Diagram of ESSC Process

The interior temperature of the bath is in vicinity of 1925^0C. The surface temperature is approximately 1650^0 C. Melted electrode and the base metal collect in pool beneath the molten slag bath and slowly solidifies to form the clad [8]. Out of all welding parameters, welding speed is significantly influence the ferrite content & dilution of weld overlays. If a very low welding speed is selected during cladding, it will the result in very low dilution but at the same time acquiring an unacceptable high content of ferrite as it can be impairs the corrosion resistance and the ductility of the welded overlay. In this present work, electro slag strip cladding process were used to developed weld overlay of 309L & 309L Nb austenitic stainless steel on Cr-Mo steel with variation of welding speeds of 160 to 200 mm/min. at fixed current (1,200 Amps) and Voltage(24 Volts). Weld overlay are under gone various corrosion problem such as general, pitting and inter granular corrosion under service conditions. So the corrosion behavior of both weld overlay will be studied in different corrosive environments using various corrosion tests such as potentiodynamic study & cyclic polarization study [9].

II. EXPERIMENTAL PROCEDURE

2.1 Development of weld overlays:

The base material of 55 mm thick plate of SA387 Gr11 Cl2 steel received in the normalized were cladded with single layer of 309 L & 309L Nb by electro-slag strip cladding process using the following welding conditions.

- Polarity: DECP
- Current1100A-1300A
- Voltage: 24-26 V
- Travel speed: 160,180,200 mm/min
- Electrode extension (Stick out): 35 mm max.
- Height of flux: 20-25 mm
- Preheat temperature: 125^0 C min
- Inter pass temperature: 200^0 C max.

Chemical composition of base metal & strip electrodes were measured with the help of X-ray florescent scope and tabulated in table-1.

Table-1: chemical Composition of base metal and strip electrodes (weight%)

Type	Base Metal	309L Clad	309L Nb Clad
%C	0.15	0.005	0.005
% Cr	1.2	21.0	21.0
% Ni	0.16	11.0	11.0
% Mo	0.5	<0.03	<0.03
% Si	0.6	0.5	0.5
% Mn	1.2	1.8	1.8
% Nb	0.001	-	0.52
% N_2	-	0.0036	0.0036
% P	0.003	0.012	0.012
% S	<0.001	0.005	0.005

2.2 Sample Preparation:

Slices of cladded plates have been done across the width area and it was taper grinded on milling machine at angle of 10-15 degree for necessary testing.

III. TESTING & EVALUATION

3.1 Visual Examination:

This is done for bead shape observation & checking any welding defect like undercut during the welding process.

3.2 Determination of Ferrite Content:

Ferrite content was measured with the help of Fischer Ferrite- scope MP 30 for all types weld overlays samples.

3.3 Microstructure Evaluation:

Neophot – 2 Microscope is used to observer micro structural changes at grain boundary as well as at interface using following etchant.

- Etchant for Base Metal: Nital (98% Methanol & 2% HNO_3) solution.
- Etchant for cladded region: Aquzregia (75% HCl & 25% HNO_3) solution.
- All samples were viewed at 400X Magnification.

3.4 Corrosion Testing:

Potentiodynamic studies were carried out on both weld overlays in 0.1 N H_2SO_4 solution & 0.1 N HNO_3 solution as per ASTM G-5 standard, while cyclic polarization studies were carried out on both weld overlays in 6 % $FeCl_3$ Solution as per ASTM G-61 standard using Potentiostat Gammry Reference 600. Corrosion cell was consist of Calomel electrode as reference electrode, graphite rod as counter electrode and test sample as working electrode.

Table- 2: Operating Parameters of potentio-dynamic test

Sr.No	Potentio-dynamic test
1	Initial voltage = -0.5 V w.r.t Ref. electrode
2	Final voltage= 1.7 V w.r.t Ref. electrode
3	Scan rate = 5 mV / sec
4	Conditioning time =60 sec
5	Initial delay: = 60 sec
6	Sample area = 0.25 cm^2
7	Density = 7.87 gm / cm^2
8	Equivalent weight = 22.92 gm

Table- 3: Operating Parameters of cyclic polarization test

Sr.No	Cyclic polarization test
1	Initial voltage=0.5V w.r.t Ref. electrode
2	Forward Scan=2.5 mV
3	Reverse Scan=2.5 mV
4	Final Voltage=1.0 V w.r.t Ref. electrode
5	Apex Current= 1000 mA / cm^2
6	Sample area = 0.25 cm^2
7	Density = 7.87 gm / cm^2
8	Equivalent weight = 22.92 gm

IV. RESULTS & DISCUSSION

4.1 Determination of ferrite content:

Results of amount of ferrite content at cladded surface are tabulated in table No 4 which shows that for both weld overlays developed by 309 L & 309 LNb, the ferrite content decrease with increase in the welding speed from 160 to 200 mm / min.

Table- 4 : Variation of ferrite content at different welding speed

Welding speed (mm/min.)	Amount of ferrite Content	
	309 L Cladded surface	309 LNb cladded surface
160	10.4	9.2
180	8.9	8.8
200	8.8	8.0

4.2 Results of Micro structural studies:

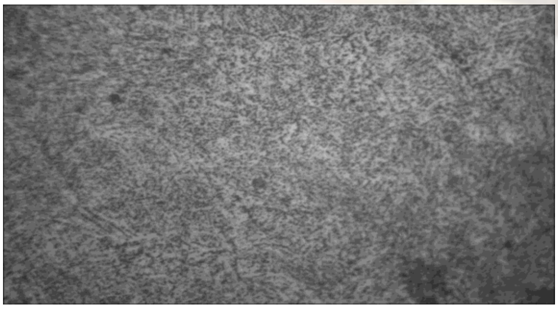

Fig. 2 : microstructure of base metal weld overlay with 160 welding speed

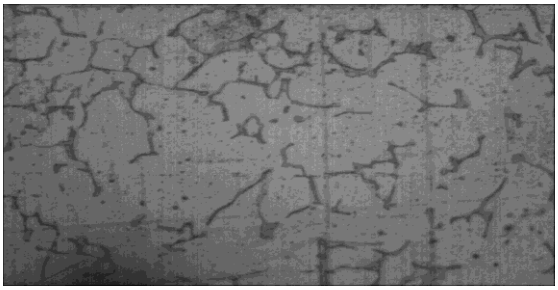

Fig. 3: microstructure of 309L cladded weld overlay with 160 welding speed

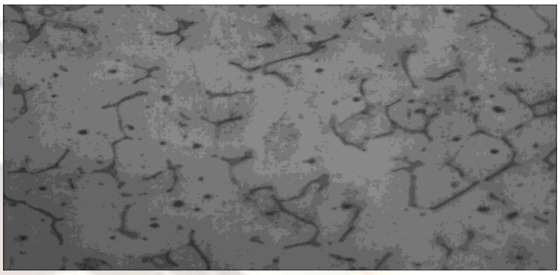

Fig. 4: microstructure of 309L cladded weld overlay with 180 welding speed

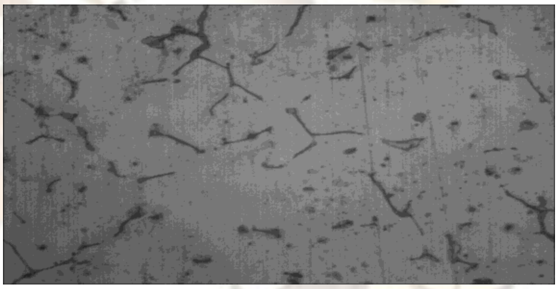

Fig. 5: microstructure of 309L cladded weld overlay with 200 welding speed

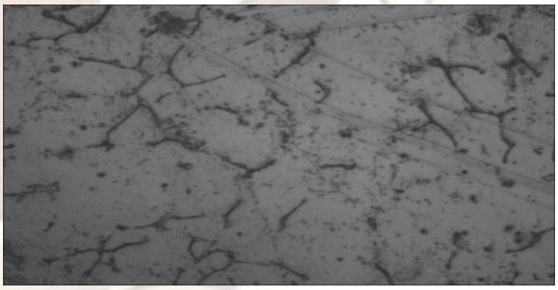

Fig. 6 : microstructure of 309L Nb cladded weld overlay with 160 welding speed

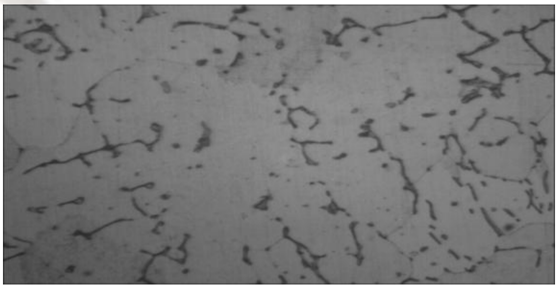

Fig. 7: microstructure of 309 LNb cladded weld overlay with 180 welding speed

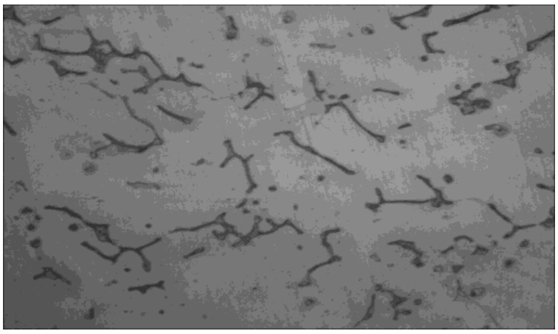

Fig. 8: microstructure of 309L Nb cladded weld overlay with 200 welding speed

Microstructure at base metal shows that mixture of tempered bainite with martensite structure. Microstructure at cladded region shows that amount of ferrite (black) in the matrix of austenite (white) decreases with increase welding speed from 160 mm/min to 200 mm/min for both 309L & 309 LNb cladded weld overlays.

4.3Results of Potentio-dynamic Tests:

4.3.1 Effect of Welding Speed on corrosion behaviour of Base metal in 0.1 HNO_3 Solution

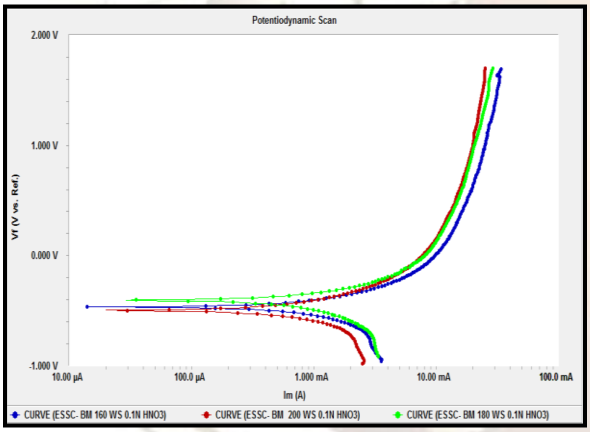

Fig. 9 : Potentiodynamic scans of Base Metal at different welding speed in 0.1N HNO_3 solution

Table-5: Electrochemical Parameters of Potentiodynamic study of Base Metal in 0.1N HNO_3 solution

Sr. No	Samples	i_{Corr} (µA)	E_{Corr} (mV)	C.R. (mpy)
1	Base Metal 160 WS	609.0	-465	228.9
2	Base Metal 180 WS	567.0	-404.0	213.0
3	Base Metal 200 WS	518.0	-496	194.6

By comparing corrosion behavior of base metal at different welding speed in 0.1N HNO_3 solution, it shows that corrosion rate is decrease with increase in the welding speed but all sample exhibit similar kind of corrosion resistance at all welding speed.

4.3.2 Effect of Welding Speed on corrosion behaviour of 309 L cladded weld overlay in 0.1 N HNO_3 Solution

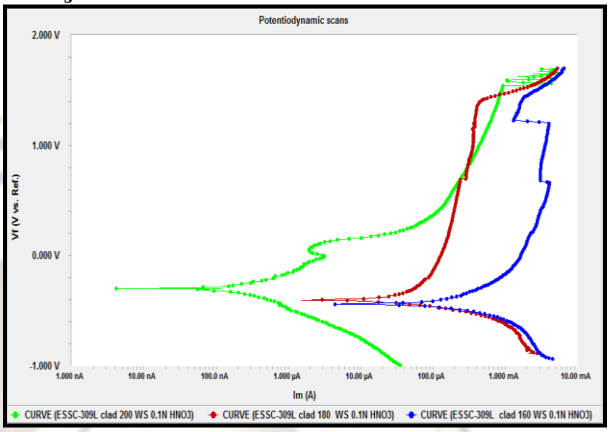

Fig. 10: Potentiodynamic scans of 309L cladded weld overlays at different welding speed in 0.1N HNO_3 solution

Table-6: Electrochemical Parameters of Potentio-dynamic study of 309 L cladded weld overlay in 0.1N HNO_3Solution

Sr. No	Samples	i_{Corr} (µA)	E_{Corr} (mV)	C.R. (mpy)
1	Clad 309L 160 WS	74.2	-374.0	135.5
2	Clad 309L 180 WS	48.5	-440 .0	18.24
3	Clad 309L 200 WS	35.7	-402.0	13.41

By comparing corrosion behavior of 309L cladded weld overlays at different welding speed in 0.1N HNO_3 solution it shows that (i) all weld overlays exhibit passive behavior in 0.1N HNO_3 solution (ii) weld overlay developed at 200 mm / min. welding speed has best corrosion resistance compare to weld overlay developed at the 160 & 180 mm / min. welding speed. (iii) Weld overlay developed at 180 & 200 mm / min. welding speed exhibit similar kind of corrosion rate.

4.3.3 Effect of Welding Speed on corrosion behaviour of 309 L Nb cladded weld overlay in 0.1 HNO_3 solution

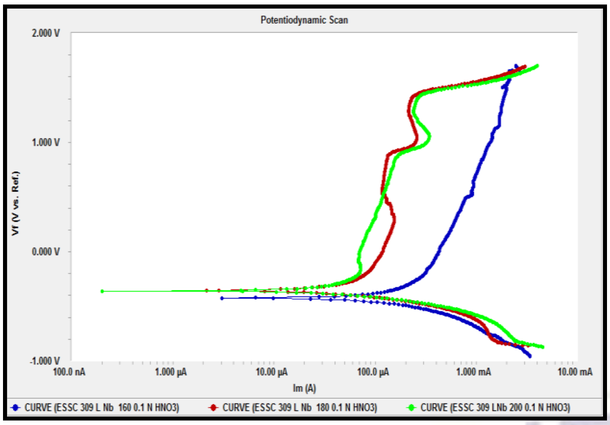

Fig. 11: Potentiodynamic scans of 309L Nb cladded weld overlays at different welding speed in 0.1N HNO_3 solution

Table-7: Electrochemical Parameters of Potentio-dynamic study of 309 LNb cladded weld overlay in 0.1N HNO3Solution

Sr. No	Samples	i_{Corr} (μA)	E_{Corr} (mV)	C.R. (mpy)
1	Clad 309L Nb 160 WS	80.60	-424.0	147.3
2	Clad 309L Nb 180 WS	52.90	-354.0	96.62
3	Clad 309L Nb 200 WS	49.70	-359.0	90.80

By comparing corrosion behavior of 309L Nb cladded weld overlays at different welding speed in 0.1N HNO_3 solution it shows that (i) all weld overlays exhibit passive behavior in 0.1N HNO_3 solution (ii) weld overlay developed at 200 mm / min. welding speed has best corrosion resistance compare to weld overlay developed at the 160 & 180 mm / min. welding speed (iii) weld overlay developed at 180 & 200 mm / min. welding speed exhibit similar kind of corrosion rate.

4.3.4 Effect of Welding Speed on corrosion behaviour of Base metal in 0.1NH_2SO_4 Solution

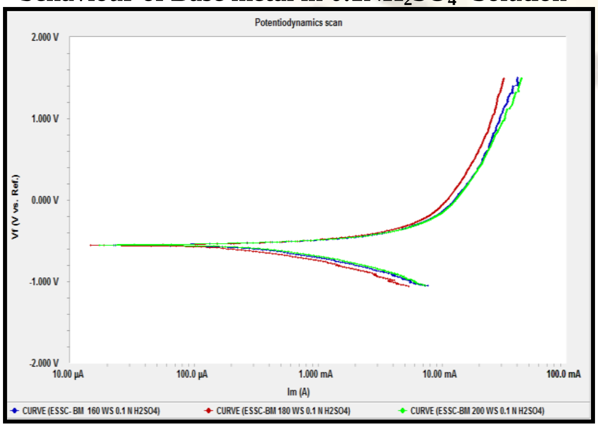

Fig. 12: Potentiodynamic scans of Base metal at different welding speed in H_2SO_4 solution

Table-8: Electrochemical Parameters of Potentio dynamic study of Base Metal in 0.1N H_2SO_4 solution

Sr. No	Samples	i_{Corr} (μA)	E_{Corr} (mV)	C.R. (mpy)
1	Base Metal 160 WS	609.0	-465	228.9
2	Base Metal 180 WS	567.0	-404.0	213.0
3	Base Metal 200 WS	518.0	-496	194.6

By comparing corrosion behavior of base metal at different welding speed in 0.1N H_2SO_4 solution, it shows that (i) weld overlay developed at 180 mm / min. welding speed has best corrosion resistance compare to weld overlay developed at the 160 & 200 mm / min. welding speed (iii) corrosion resistance of weld overlay developed at 160 & 200 mm / min. welding speed were similar.

4.3.5 Effect of Welding Speed on corrosion behavior of 309 L cladded weld overlay in 0.1N H_2SO_4 Solution

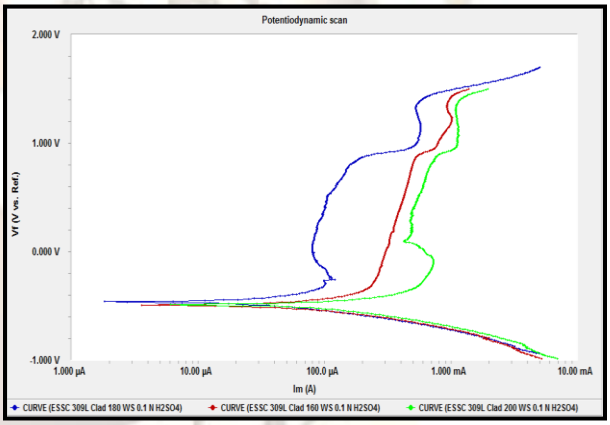

Fig. 13: Potentiodynamic scans of 309L cladded weld overlays at different welding speed in 0.1N H_2SO_4 solution

Table-9: Electrochemical Parameters of Potentio-dynamic study of 309 L cladded weld overlay in 0.1N H_2SO_4 Solution

Sr. No	Samples	i_{Corr} (μA)	E_{Corr} (mV)	C.R. (mpy)
1	Clad 309L 160 WS	85.80	-462	156.8
2	Clad 309L 180 WS	56.10	-493	102.5
3	Clad 309L 200 WS	97.30	-489	177.9

By comparing corrosion behavior of 309L cladded weld overlays at different welding speed in 0.1N H_2SO_4 solution, it shows that (i) all weld overlays exhibit passive behavior (ii) weld overlay developed at 180 mm / min. welding speed has best corrosion resistance compare to weld overlay developed at the 160 & 200 mm / min. welding speed (iii) corrosion resistance of weld overlay developed at 160 & 200 mm / min. welding speed were similar.

4.3.6 Effect of Welding Speed on corrosion behaviour of 309 L Nb cladded weld overlay in 0.1 H_2SO_4 Solution

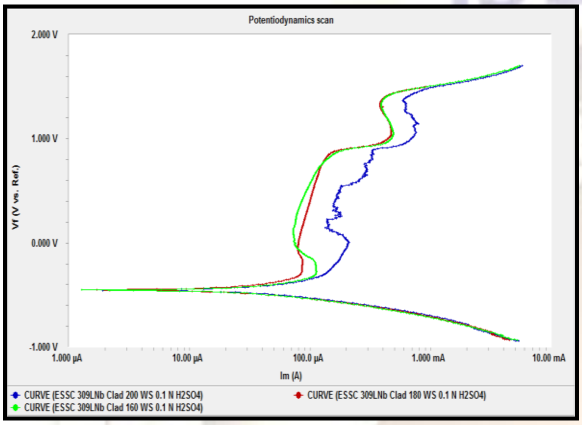

Fig. 14: Potentiodynamic scans of 309LNb cladded weld overlays at different welding speed in 0.1N H_2SO_4 solution

Table 10: electrochemical parameters of Potentio-dynamic study of 309 LNb cladded weld overlay in 0.1N H_2SO_4 solution

Sr. No	Samples	i_{Corr} (µA)	E_{Corr} (mV)	C.R. (mpy)
1	Clad 309LNb 160 WS	64.60	-452	118.2
2	Clad 309L Nb 180 WS	53.40	-451	97.64
3	Clad 309LNb 200 WS	72.60	-454	132.6

By comparing corrosion behavior of 309L Nb cladded weld overlays at different welding speed in 0.1N H_2SO_4 solution it shows that (i) all weld overlays exhibit passive behavior (ii) weld overlay developed at 180 mm /min. welding speed has best corrosion resistance compare to weld overlay developed at the 160 & 200 mm / min. welding speed iii) corrosion resistance of weld overlay developed at all welding speed exhibit similar in nature.

4.4 Results of Cyclic polarization test:

4.4.1 Effect of Welding Speed on Pitting corrosion behaviour of Base metal of cladded weld overlay in 6% $FeCl_3$ Solution

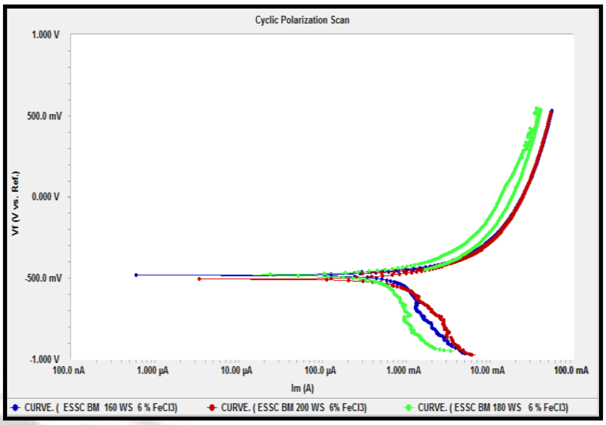

Fig. 15: cyclic polarization scans of base metal at different welding speed in 6% $FeCl_3$ Solution

Table-11: electrochemical parameters of cyclic scan of base metal in 6% $FeCl_3$ solution

Parameters	Base metal		
Welding speed (mm/min.)	160	180	200
C.R.(mpy)	2127	1330	2687
E_{pit} (mV)	-488.0	-529.6	-502.5
E_{corr}(mV)	-481.0	479.0	505.0
I_{corr}(µA)	1420	886	1790

By comparing pitting behavior of base metal cladded at different welding speed in 6% $FeCl_3$ solution ,it shows that $E_{pit} < E_{corr}$ for 160,180 & 200 mm / min. welding speed which indicate that pitting will occur & damage passive film will not repaired which leads to further corrosion.

4.4.2 Effect of Welding Speed on Pitting corrosion behaviours of 309 L cladded weld overlays in 6% $FeCl_3$ Solution

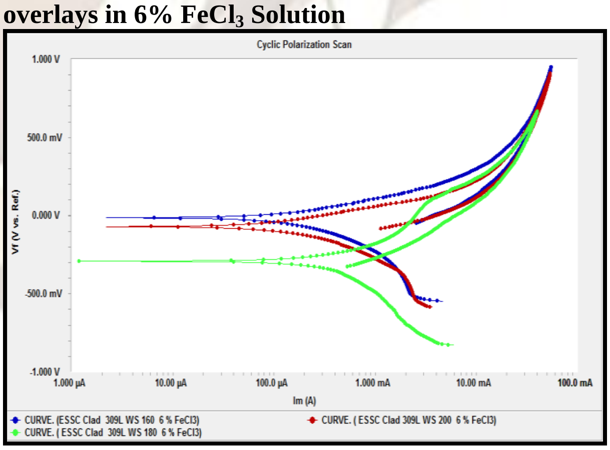

Fig. 16 : cyclic polarization scans of 309L cladded weld overlays at different welding speed in 6% $FeCl_3$ Solution

Table 12: electrochemical parameters of cyclic scan of 309L weld overlay in 6% $FeCl_3$ Solution

Parameters	309 L Cladded weld overlay		
Welding speed (mm/min.)	160	180	200
C.R.(mpy)	463.0	203.2	395.5
E_{pit} (mV)	-195.3	-350.4	-136.2
E_{corr}(mV)	-13.00	-291.00	-70.80
I_{corr}(µA)	309.0	135.0	264.0

By comparing pitting behavior of 309L cladded weld overlays at different Welding speed in 6% $FeCl_3$ solution, it shows that E_{pit} < E_{corr} for all welding speed which indicate that pitting will occur & damage passive film will not repaired which leads to further corrosion.

4.4.3 Effect of Welding Speed on Pitting corrosion behaviours of 309LNb cladded weld overlays in 6% $FeCl_3$ Solution

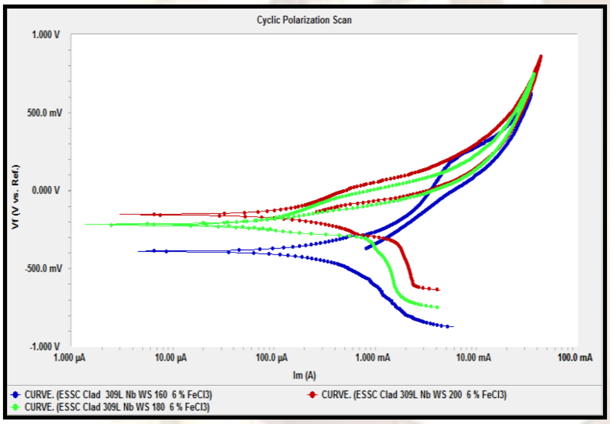

Fig. 17 : cyclic polarization scans of 309 L Nb cladded weld overlays at different welding speed in 6% $FeCl_3$ Solution

Table 13: electrochemical parameters of cyclic scan of 309L Nb weld overlay in 6% $FeCl_3$ Solution

Parameters	309 LNb Cladded weld overlay		
Welding speed (mm/min.)	160	180	200
C.R.(mpy)	275.9	70.62	155.0
E_{pit} (mV)	-478.6	-192.8	-167.3
E_{corr}(mV)	-388.0	-222.0	-153.0
I_{corr}(µA)	184.0	47.10	103.0

By comparing corrosion behavior of 309L Nb cladded weld overlays at different Welding speed in 6% $FeCl_3$ solution it shows that E_{pit} > E_{corr} for 180 mm / min. welding speed which indicate that the pitting will occur but damage passive film will repaired & protecting further corrosion while in case of 160 & 200 mm / min. welding speed Epit < E_{corr} which indicate that pitting will occur & damage passive film will not repaired which leads to further corrosion.

V. CONCLUSIONS

1. Electroslag strip cladding process can be advantageously and profitably used to deposit austenitic stainless steel weld overlays on low-alloy steel.
2. Amount of ferrite content is decrease with increase the welding speed from 160 to 200 mm /min for both weld overlays developed by 309 L & 309 L Nb grade austenitic stainless steel.
3. Corrosion rate is decrease with increase the welding speed from 160 to 200 mm /min for both weld overlays developed by 309 L and 309 L Nb grade austenitic stainless steel in 0.1 N H_2SO_4 and 0.1N HNO_3 solutions.
4. Both weld overlays developed by 309 L and 309 LNb grade austenitic stainless steel exhibit best corrosion resistance at 200 mm /min welding speed in 0.1N HNO_3 solution.
5. Both weld overlays developed by 309 L and 309 LNb grade austenitic stainless steel exhibit best corrosion resistance at 180 mm /min. welding speed in 0.1 N H_2SO_4 solution.
6. 309L cladded weld overlay developed at all welding speed has lower pitting resistance in 6% $FeCl_3$ solution.
7. 309L Nb cladded weld overlay developed with 180 mm /min. welding speed has good pitting resistance than weld overlay developed with 160 & 200 mm /min. in 6% $FeCl_3$ solution.

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