Corrosion Behaviour of 316 Austenitic Stainless Steel Cladding on Copper Coated Low Alloy Steel by Gas Metal Arc Welding

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ABSTRACT

Cladding has developed growing interest among engineers for providing greater corrosion resistance and erosion resistance of the surface of low grade steel components in aggressive environments. Austenitic stainless steel yields satisfactory results as a clad material and successfully used for last few decades. Among different techniques producing quality clad parts, gas metal arc welding is a popular method for cladding due to its simplicity and cost effectiveness. Corrosion resistance of the clad part depends on different microstructural phases as well as alloying elements present in clad layer. Copper, one of the austenising alloying elements, is used to increase corrosion resistance in steel especially in sulphuric acid atmosphere. In the present investigation, austenitic stainless steel (316) is clad by means of gas metal arc welding (GMAW) on copper coated E250 low alloy steel using 100% CO_2 as shielding gas. Copper coating is done on low alloy steel by electroplating process. Single layer cladding is done keeping 50% overlap. Process parameters of GMAW like welding current and troch travel speed are varied in three levels, keeping welding voltage constant. Heat input varies accordingly. Corrosion tests are carried out in three different media (ferric chloride, copper chloride and sulphuric acid solutions). Experimental results show that copper addition improves corrosion resistance to a great extent in sulphate atmosphere, moderately in ferric chloride and the least in case of copper chloride atmosphere. The corrosion rate decreases at higher heat input on the whole. In every case, the cladding exhibits much better corrosion resistance than the base metal.

Keywords: cladding; GMAW; copper coating; corrosion resistance; buttering layer

1.0 INTRODUCTION

Cladding is one of the surfacing techniques that provide good corrosion or erosion resistance and strength to a workpiece material. Engineers always tend to manufacture a job economically. They often use relatively low cost, low grade material having good manufacturability and then cover it with high grade costly material having high corrosion and/or erosion resistance along with high strength and hardness to improve its service life. Thus, the product possesses desired additional properties at relatively less expense. When cladding is done primarily to raise surface hardness, the process is called hardfacing [1].

Cladding can be done in various ways, such as explosive cladding, roll cladding, strip cladding, and using different welding processes along with some hybrid cladding techniques [1]. Among different weld cladding processes, resistance

cladding and arc cladding using arc welding techniques have become popular. Arc cladding can be done with the help of processes like SMAW, GMAW, FCAW and GTAW. GMAW has established itself as a quite effective, semi-automatic, cheap and user-friendly process. Moreover, effectiveness of the process can be improved by proper selection of process parameters.

Quality of the clad layer made by welding depends upon the process parameters [2-4] like welding current, welding voltage, arc travel speed, nozzle to tip distance, type of shielding gas, gas flow rate, angle of the welding torch, etc. Heat input plays a vital role for producing better weld bead geometry [5]. Unlike welding, cladding requires less penetration for ensuring less dilution. However, there should be sufficient interfacial bonding so that clad layer remaining bonded with the base material for a prolonged duration.

Austenitic stainless steels belong to 300 series and 316 austenitic stainless steels are used as clad material for last few decades due to its better performance against different types of corrosion and also for having better mechanical properties [6]. Different alloying elements like Cu and Ni (austenisers), and Cr, Si and Mg (ferritizers) are responsible to form austenite and ferrite phases respectively in such clad materials. Different proportions of these elements present in a particular cladding electrode exhibit corrosion resistance accordingly. Austenitic stainless steel (316) cladding on low alloy steel exhibits good corrosion resistance at a particular heat input zone [7].

Copper plays both positive and negative roles in corrosion resistance as well as mechanical properties of steels. Basically copper is an austeniser, and is known for decreasing metallic dissolution rate in acidic media and also slowing the propagation of pit growth rate. It can also be added to decrease work hardening for improving machinability, and also increases formability [8]. Different experiments were carried out for Cu addition and to determine influences of copper on corrosion resistance properties. Shen et al. [9] produced pure copper cladding on steel in an experiment by means of both FSW and GMAW processes and observed interlocking of copper with steel. They had also observed significance of Mn and Si diffusion in formation of copper cladding. Jiangnan et al. observed in one experiment that Cu can be used to decrease the active dissolution of 18Cr-10Ni austenitic stainless steel in 3.5% NaCl solution at 80℃. On the other hand, it was observed that Cu had negative impact in passivity of stainless steel [10].

In one experimental work, Savage et al. [11] explained Copper-contaminated hot cracking phenomenon for heat affected zone of Cu alloyed (abrated) 'Haynes 188', a Co based super-alloy. Banas and Mazurkiewicz [12], observed the effect of copper deposition on passivity of ferritic (Fe-18%Cr) and duplex (Fe–24%Cr–6%Ni–3%Mo) cast steels. They noticed that Cu dissolved as solid solution in austenite or ferrite had no detrimental effect on stability of passive film. High concentration of Cu in ferrite phase increased hardness and decreased corrosion resistance of ferrite and increased pitting corrosion and intergranular corrosion for duplex cast steel. In one experiment, Chan et al. observed that an addition of Cu (up to 4%) improved corrosion resistance behavior of alloyed 516L cladding on plain carbon steel by powder metallurgy process both in H_2SO_4 and $FeCl_3$ solutions [13]. Tomio et al. concluded that Cupper addition in austenitic steel enhanced pitting corrosion rate in H_2S-Cl media [14]. Lee et al. found that addition of Cu in base metal enhanced general corrosion resistance of hyper duplex stainless steel by means of passive layer generation that protects job material [15].

In the present investigation, 316 austenitic stainless steel cladding was carried out on Cu electroplated E350 low alloy steel by gas metal arc welding process using 100% CO_2 as shielding gas. Process parameters like welding current and welding torch travel speed were varied at three levels keeping welding voltage constant throughout the experiment. Single layer cladding was done with 50% overlap of weld bead. Nine numbers of test pieces were produced applying nine different heat input rates and the whole process was replicated twice. Accelerated corrosion tests were carried out with three different corrosive media, namely $CuCl_2$, $FeCl_3$ and H_2SO_4 solutions. Microstructure evaluation was done to justify different corrosion rates of the clad parts.

2.0   EXPERIMENTAL PROCEDURE

Base material used for cladding was E250 low alloy steel and chemical composition of the base metal is given in **Table 1**. Chemical composition of 316 austenitic stainless steel electrode used for depositing clad layer is given in **Table 2**.

At first, the base metal was cleaned and copper was deposited on base metal by electroplating. 12μm copper layer was deposited on all sides of base metal (55mm X 45mm X 25mm). **Fig. 1** shows copper coated base plate.

Table 1: Chemical composition of E350

%C	%Si	%Mn	%P	%S	%Cr	%Mo	%Ni
0.2010	0.1509	0.5330	0.0859	0.0389	<0.0011	<0.0017	<0.0024
%Al	**%Co**	**%Cu**	**%Nb**	**%Ti**	**%V**	**%W**	**%Pb**
0.0031	0.0071	0.0231	0.0053	0.001	0.0038	<0.009	0.0156
%Sn	**%As**	**%Zr**	**%Ca**	**%Ce**	**%Ta**	**%B**	**%Zn**
<0.0014	<0.0037	0.0032	0.0002	0.101	0.0197	<0.00	0.007
%La	**%Fe**						
<0.0009	<98.8913						

Table 2 : Chemical composition of 316 austenitic stainless steel

%C	%Si	%Mn	%P	%S	%Cr	%Mo
0.0758	0.1824	1.1017	0.0289	0.0076	15.0464	2.0906
%Ni	**%Al**	**%Co**	**%Cu**	**%Nb**	**%Ti**	**%V**
9.9370	0.0105	0.0741	0.3417	0.0431	0.0136	0.0475
%W	**%Sn**	**%Ce**	**%B**	**%Fe**		
0.0261	0.0103	0.0103	<0.0010	<70.9524		
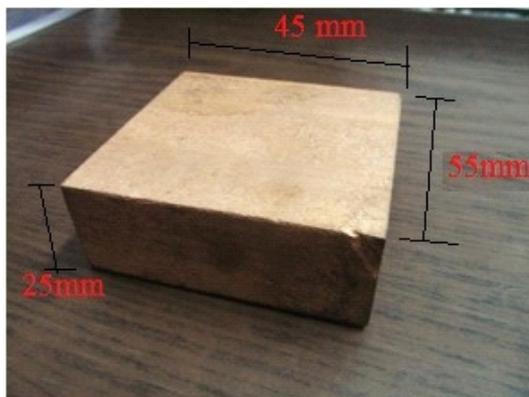
Fig. 1 : Copper coated E350 base plate

Fig. 2: Welding machine

Weld cladding was performed usinga GMAW machine (Model No. Auto K 400) having 60% duty cycle (**Fig. 2**). Cladding was done under different heat inputs. Heat input was measured theoretically using equation (1). Two parameters, such as welding current and torch travel speed were chosen at three levels so that nine numbers of samples were prepared with nine values of heat inputs. Welding voltage was kept constant throughout the experiment. The range of process parameters had been selected on the basis of previously done trial experiments where the weld bead formation was found to be acceptable. Whole experiments were replicated twice. The process parameters chosen for the experiments are shown in **Table 3.**

$$\text{Heat input} = \eta \; V \, I \, / \, S \qquad (1)$$

Where, V= Welding voltage, V

I = Welding current, A

S = Arc travel speed, mm/min

η= Efficiency of GMAW= 0.8

Table 3: Process parameters selected for the experimental work

Sample No.	Weld current (I)	Weld voltage (V)	Travel Speed (mm/min)	Heat input (kJ/mm)
1	140	27	460	0.394
2	140	27	443	0.409
3	170	27	460	0.479
5	170	27	443	0.497
6	200	27	460	0.563
8	200	27	443	0.585
4	140	27	300	0.605
7	170	27	300	0.734
9	200	27	300	0.864

Both sets of clad samples were subjected to visual inspection, metallography test and corrosion test in different mediums. Visual inspections revealed no major defect on clad parts except very few numbers of spatters which were the basic characteristics of metal active gas welding (GMAW using 100 % CO_2 as shielding gas). Number of spatters increases with heat input.

3.0 MICROSTRUCTURAL STUDY

Test samples were ground on a belt grinder using 60, 80 and 120 grades of emery belts. Then, these samples were polished by using seven different grades of emery papers (180, 400, 800, 1000, 1200, 2000 and 2500) and finally buffed on velvet cloth covered disc with alumina suspension as abrasive using a rotating disc grinding machine to obtain mirror finished specimens. The samples were etched by Glyceregia solutions (ASTM E 407 designation is 87 Glyceregia) (15cc HCl +10cc Glycerol + 5cc HNO_3). Samples were observed under metallurgical microscope (Make: LEICA, Model: 2700M) at 500x magnification.

4.0 CORROSION TEST

First, samples were polished and weighed by digital weighing machine (Model: M K 100E, Petit Balance) with capacity of 100gm and a readability upto 0.001gm. Then, test samples were coated by Teflon tapes leaving only the cladded area exposed and each sample was immersed in the chosen corrosive medium for 24 hours. First corrosive medium was prepared with a composition of 29gm cupric chloride, 24 ml hydrochloric acid and 76ml distilled water. Second corrosive medium was made with 29 gm ferric chloride, 24 ml HCl and 76ml distilled water and the third corrosive medium was prepared by adding 50ml sulphuric acid in 50ml distilled water. After removal from the corrosive medium, test samples were cleaned with water, teflon tape was removed, and samples dried and then weighed again. Weight losses caused by the corrosive medium were found by the difference of initial and final weights of the samples.

Corrosion Rate = W / (A x T), gm/m^2-hr   (2)

Where, W is weight loss (gm), A is exposed area (m²) and T is exposed time (hr)

5.0 RESULTS AND DISCUSSIONS

Results obtained from the metallography test are shown in **Table 4**. The microstructures are taken at 500 magnifications. Each microstructure is shown along with process parameters at which cladding was done, and corresponding rate of heat input, Chromium equivalent, Nickel equivalent, equivalent ratio (Eq-ratio), as well as corrosion rate under $CuCl_2$, $FeCl_3$ and H_2SO_4 solutions.
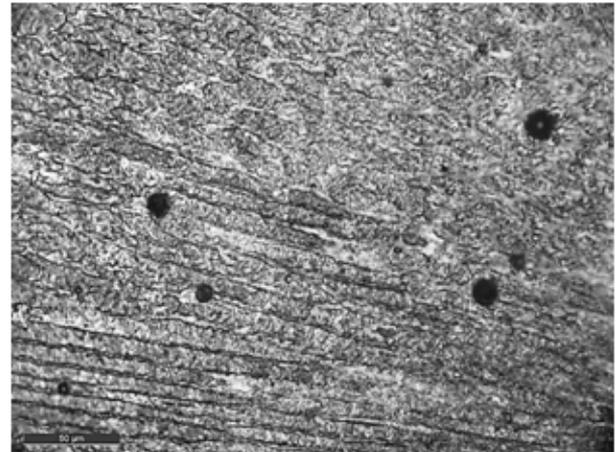
Table 4 : Microstructure of clad samples along with relevant information (500X)

Sample No : 1			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
140	27	460	**0.394**

Cr Eq	Ni Eq	Eq-ratio
12.4641	10.6473	1.171

Corrosion Rate (gm/m²-hr)

CuCl$_2$	FeCl$_2$	H$_2$SO$_2$
378.81	209.98	14.19

500X

Sample No : 2			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
140	27	443	**0.409**

Cr Eq	Ni Eq	Eq-ratio
11.51	11.53	0.998

Corrosion Rate (gm/m²-hr)

CuCl$_2$	FeCl$_2$	H$_2$SO$_2$
275.77	315.91	8.91
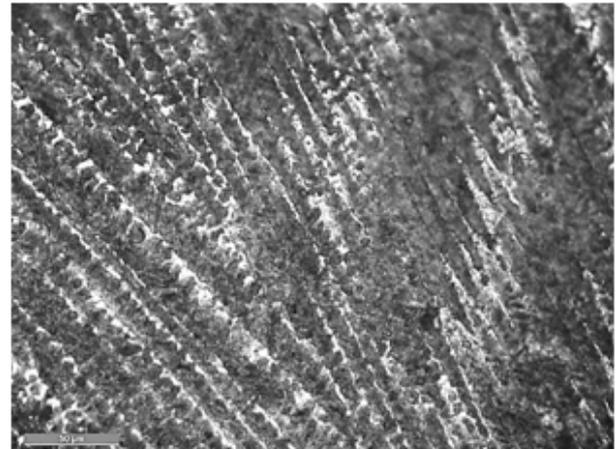
500X

Sample No : 3			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
170	27	460	**0.479**

Cr Eq	Ni Eq	Eq-ratio
14.146	10.818	1.307

Corrosion Rate (gm/m²-hr)

CuCl$_2$	FeCl$_2$	H$_2$SO$_2$
416.468	271.099	10.624
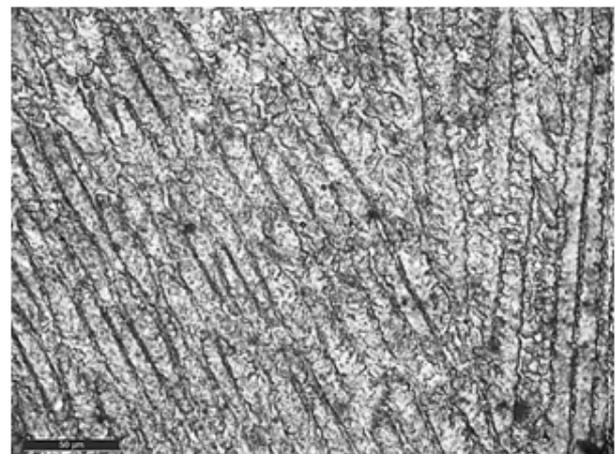
500X

Sample No : 4			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
140	27	300	**0.605**

Cr Eq	Ni Eq	Eq-ratio
13.828	11.384	1.214

Corrosion Rate (gm/m^2-hr)

$CuCl_2$	$FeCl_2$	H_2SO_2
394.569	184.965	13.539
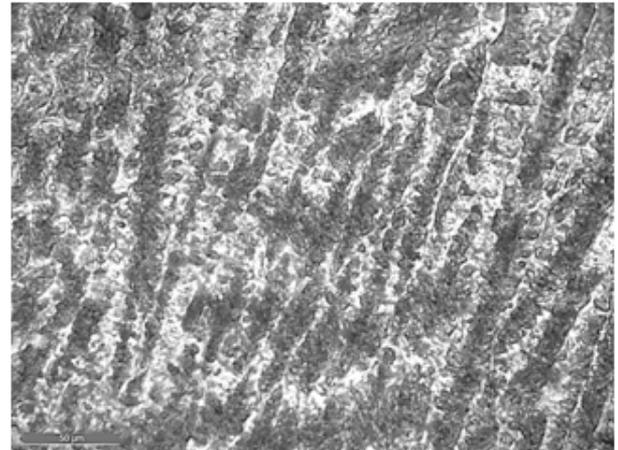
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Sample No : 5			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
170	27	443	**0.497**

Cr Eq	Ni Eq	Eq-ratio
14.13	11.29	1.251

Corrosion Rate (gm/m^2-hr)

$CuCl_2$	$FeCl_2$	H_2SO_2
284.63	168.86	11.84
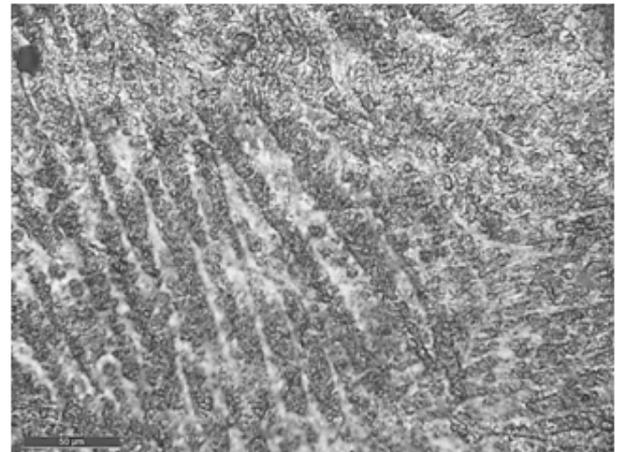
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Sample No : 6			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
200	27	460	**0.563**

Cr Eq	Ni Eq	Eq-ratio
15.33	10.89	1.407

Corrosion Rate (gm/m^2-hr)

$CuCl_2$	$FeCl_2$	H_2SO_2
217.23	245.57	17.89
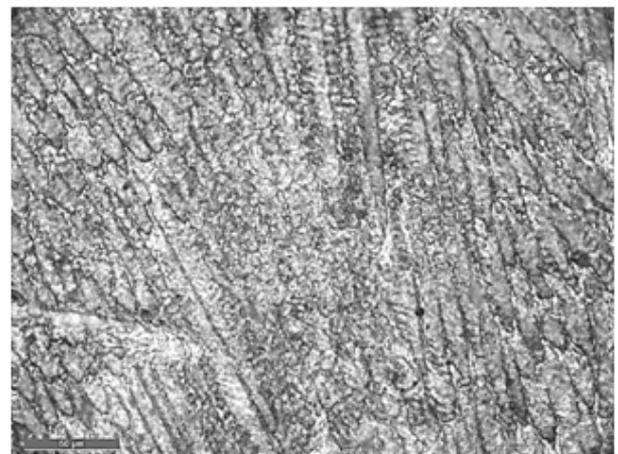
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Sample No : 7			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
170	27	300	**0.754**

Cr Eq	Ni Eq	Eq-ratio
13.23	10.80	1.225

Corrosion Rate (gm/m^2-hr)

$CuCl_2$	$FeCl_2$	H_2SO_2
264.79	212.72	14.76
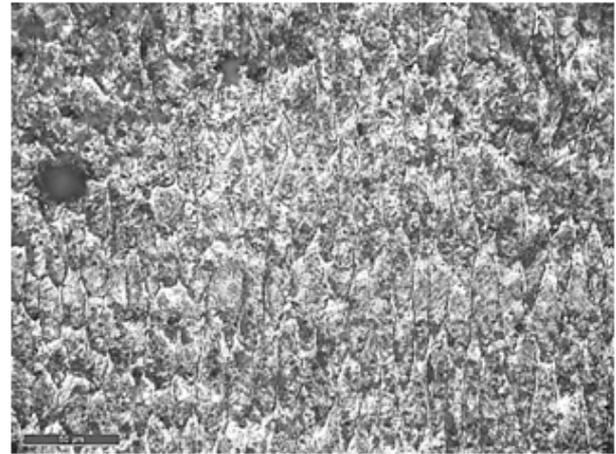
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Sample No : 8			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
200	27	443	**0.585**

Cr Eq	Ni Eq	Eq-ratio
15.63	11.34	1.378

Corrosion Rate (gm/m^2-hr)

$CuCl_2$	$FeCl_2$	H_2SO_2
337.12	154.12	13.52
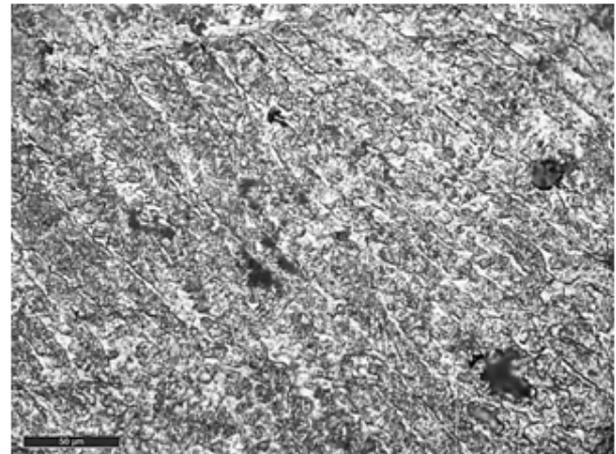
500X

Sample No : 9			
Welding current (I)	Welding voltage (V)	Travel Speed (mm/min)	Heat input
200	27	300	**0.864**

Cr Eq	Ni Eq	Eq-ratio
12.665	10.714	1.182

Corrosion Rate (gm/m^2-hr)

$CuCl_2$	$FeCl_2$	H_2SO_2
313.33	241.75	17.14
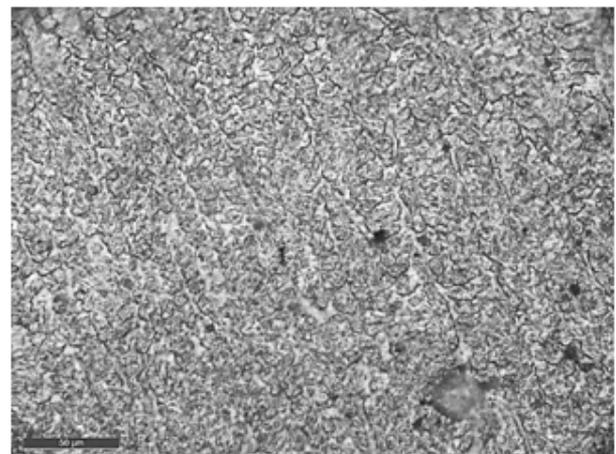
500X

Different patterns of austenitic phases can be observed in the microstructure. Austenitic phase observed in samples 1, 2 and 3 are long and narrow in shape. The shape of austenitic phase in sample 4, 5 and 6 are also long, and wide. In case of sample No. 7, 8, and 9, the grains have become short and wide. In all cases, grain boundaries are prominent.
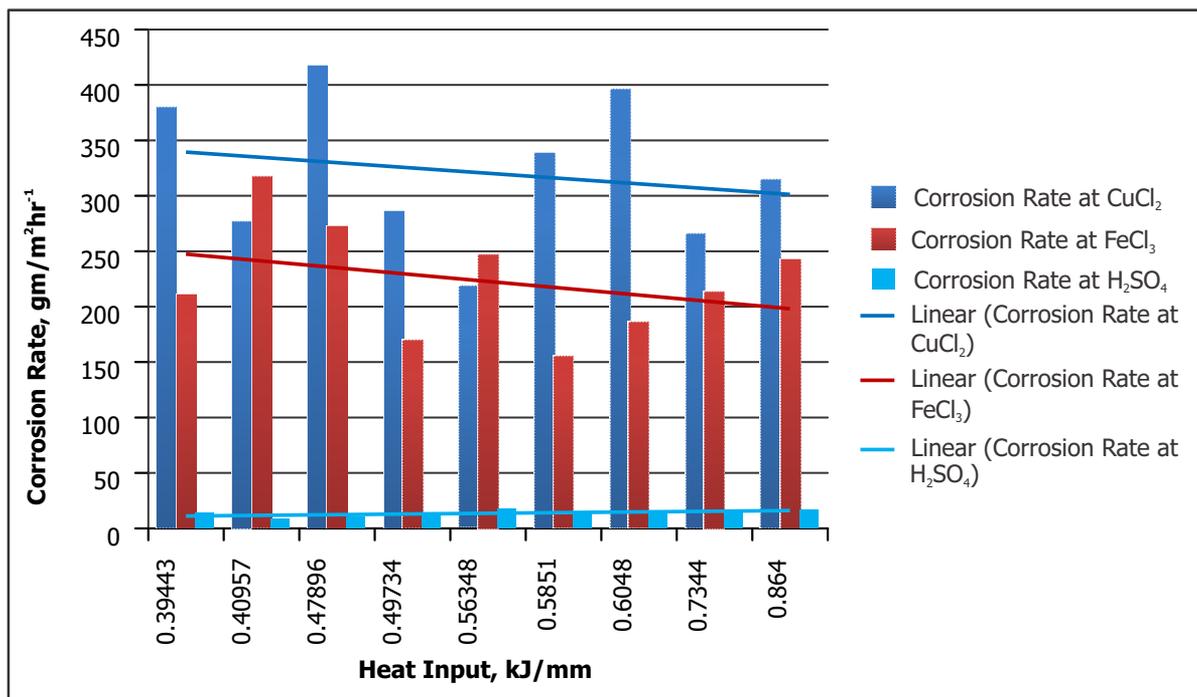
Results obtained from corrosion test in three different corrosive media like $CuCl_2$, $FeCl_3$, H_2SO_4 solutions are shown in **Table 5**.

Based on results obtained from corrosion test, bar chart is produced in **Fig. 3**. Corrosion rate is observed to be the highest and lowest in $CuCl_3$ solution and H_2SO_4 solution respectively. In $FeCl_3$, corrosion rate is observed to be moderate. In all cases, pitting corrosion resistance of clad sample is remarkably more than that of base material.

Table 5 : Corrosion Rate of Austenitic Stainless Steel (316) Cladding on Copper Coated Low Alloy Steel (E350)

Sample No.	Heat input (kJ/mm)	Corrosion in $CuCl_2$ (gm/m²-hr)	Corrosion in $FeCl_3$ (gm/m²-hr)	Corrosion in H_2SO_4 (gm/m²-hr)
1	0.394	378.81	209.98	14.19
2	0.41	275.77	315.91	8.91
3	0.479	416.47	271.1	10.62
5	0.497	284.63	168.86	11.84
6	0.563	217.23	245.57	17.89
8	0.585	337.12	154.12	13.52
4	0.605	394.57	184.97	13.54
7	0.734	264.79	212.72	14.76
9	0.864	313.33	241.75	17.14

Fig. 3 : Bar charts of pitting corrosion rate against heat input in three corrosive media

6.0 CONCLUSION

The following inferences may be drawn from the experimental investigation carried out:

- Corrosion resistance of 316 austenitic stainless steel cladding on Cu coated E350 low alloy steel is found to be significantly more than that of ordinary 316 austenitic stainless steel cladding on low alloy steel without copper coating.

- Within the experimental domain, corrosion rate is the highest in $CuCl_2$ solution and lowest in H_2SO_4 solution, whereas it is moderate at $FeCl_3$ solution.

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REFERENCES

[1] Saha MK and Das S (2016); A review on different cladding techniques employed to resist corrosion, Journal of the Association of Engineers, India, 86(1-2), pp. 51-64.

[2] Saha MK, Mondal A, Hazra R and Das S (2016); On the variation of the hardness of duplex stainless steel clad layer deposited by flux-cored arc welding, Reason- A Technical Journal, 15, pp.1-6.

[3] Saha MK, Mondal J, Mondal A and Das S (2017); Influence of heat input on corrosion resistance of duplex stainless steel cladding using flux-cored arc welding on low alloy steel, Indian Welding Journal, 51(3), pp.66-72.

[4] Chakraborty B, Das H, Das S and Pal TK (2013); Effect of process parameters on clad quality of duplex stainless steel using GMAW process, Transaction of the Indian Institute of Metals, 66(3), pp.221-230.

[5] Mondal A, Saha MK, Hazra R and Das S (2015); Influence of heat input on weld bead geometry using duplex stainless steel wire electrode on low alloy steel specimens, Cogent Engineering, 3(1), pp. 1-14.

[6] Davis JR, Davis & Associates, Stainless steel cladding and weld overlay, ASM Specialty Handbook: Stainless Steels, 06398G, 1994 extracted on 31.10.2015.

[7] Verma AK, Biswas BC, Roy P, De S, Saren S and Das S (2013) Exploring quality of austenitic stainless steel clad layer obtained by metal active gas welding, Indian Science Cruiser, 27(4), pp.24-29.

[8] The effects of alloying elements, Outokumpu, 2016, extracted from http://www.outokumpu.com/en/products-properties/more-stainless/the-effects-of-alloying-elements%E2%80%8B/pages/ default.aspx

[9] Shen Z, Chen Y, Haghshenas M, Nguyen T, Galloway J and Gerlich AP (2015); Interfacial microstructure and properties of copper clad steel produced using friction stir welding versus gas metal arc welding, Materials Characterization, 104, pp. 1–9.

[10] Jiangnan Y, Lichang W and Wenhao S (1992); The effect of copper on the anodic dissolution behaviour of austenitic stainless steel in acidic chloride solution, Corrosion Science, 33(6), pp. 851-859.

[11] Savage WF, Nippes EP and Mushala MC (1978); Copper-contamination cracking in weld heat affected zone, Welding Journal, 5, pp. 145-152.

[12] Banas J and Mazurkiewicz A (2000); The effect of copper on passivity and corrosion behaviour of ferritic and ferritic–austenitic stainless steels, Materials Science and Engineering A, 277, pp. 183–191.

[13] Chen W, Wu Y and Shen J (2004); Effect of copper and bronze addition on corrosion resistance of alloyed 316L stainless steel cladded on plain carbon steel by powder metallurgy, Journal of Material Science & Technology, 20(2), pp. 217-220.

[14] Tomio A, Sagara M, Doi T, Amaya H, Otsuka N and Kudo T (2014); Role of alloyed copper on corrosion resistance of austenitic stainless steel in H2S–Cl environment, Corrosion Science, 81, pp. 144–151.

[15] Lee J, Kim S, Lee I, Kim G, Kim J and Park Y (2012); Effect of copper addition on the active corrosion behavior of hyper duplex stainless steels in sulfuric acid, Materials Transactions, 53(6), pp. 1048 -1055.