RESEARCH ARTICLE

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Resisting Corrosion under Chloride Environment by Providing Duplex Stainless Steel Cladding Through FCAW

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Abstract

Cladding is one of the solutions usually resorted to protect a structure from the detrimental effect of its surrounding environment. This investigation concerns with covering of duplex stainless steel on low carbon steel through flux cored arc welding (FCAW) under different parametric settings. Microstructure is observed and corrosion test under chloride environment is undertaken to find out resistance to corrosion of cladding. Corrosion becomes quite low at 0.38 kJ/mm heat input. At this condition, welding speed was also at a higher side. Therefore, the corresponding combination of parameters would be adopted for getting extended service life of a structure.

Keywords: Welding, FCAW, cladding, duplex stainless steel, corrosion

1.0 Introduction

For protecting a structure open to corrosive atmosphere, a wear-resistant covering is usually employed [1-4]. This covering resists corrosion wear to enhance life of operation and reduces maintenance cost remarkably [5-10]. Apart from different techniques used, weld cladding employing an arc is quite common. Clad material is superior in nature than the base material in terms of its alloy content. Therefore, weld cladding is essentially a dissimilar welding process. While some solid state welding can be employed for weld cladding, many arc welding processes are employed to have been popularly used for this [2,7,8,11] and Gas Metal Arc Welding (GMAW) equipment can be put to use [1,6-8,12-14] for cladding effectively.

Saha and Das [1] discussed extensively the effect of process variables on the characteristics, microstructure and corrosion resistance properties of clad parts made using GMAW. They also stated GMAW to be easily employed for cladding. Weld bead geometry is important to set the process towards deposition of an appropriate clad layer [12-21]. Clad layer was employed for repairing [5, 8]. Investigation on bead geometry was carried out by many [6, 12-18, 22, 23]. Kannan and Yoganandh [6] carried out an experimental investigation, and proposed a mathematical model to predict bead profile with GMAW process parameters satisfactorily. Low carbon steel clad with Austenitic stainless steel was done at different conditions effectively [12]. Murugan and Parmar [14] predicted successfully geometry of stainless steel weld bead while, optimal geometry of bead was obtained [16] in a work done using tungsten inert gas (TIG) welding of stainless steel. Shape of weld bead is the result of selection of heat input and duplex stainless steel was deposited [17] on low carbon steel effectively at a condition. To predict dilution and bead profile made through GMAW, models were successfully developed by Palani and Murugan [18].

Saha et al. [22] found minimum corrosion rate at 0.49 kJ/mm heat input. Increased heat input results in reduction of ferrite phase exhibiting more corrosion. On the other hand, Bose and Das [23] investigated on corrosion resistance of γ-stainless steel cladding and 0.6 kJ/mm heat input provided quite low corrosion. A number of research groups [24-41] performed deposition of different materials to retard corrosion. Nitrogen, etc. were added in a related work group also [26-35]. Duplex stainless steel showed better resistance to corrosion than that of austenitic stainless steel [37-44]. In the experiments conducted by Das and Saha [31], nickel plated medium carbon steel was covered with austenitic stainless steel to report improved resistance to corrosion. Bose and Das [32] employed PTIG (pulsed TIG) welding and recommended 0.594 kJ/mm heat input as the appropriate condition for minimum corrosion rate.

Weld deposit with higher heat input showed more impact toughness in another work [41]. With increased heat input, reduction in the corrosion resistant was observed. Again, corrosion resistance increased with increased percentage of argon in the shielding gas. Saha and others [42, 43] used duplex stainless steel filler material for depositing single clad layer to report high corrosion resistance of them. Kannan and Murugan [44] carried out an experimental work to report dilution, penetration, reinforcement and bead width to have increased with an increase in weld current.

In this work, characteristics of duplex stainless steel cladding was investigated under a set of varying process parameters. The clad specimens would next be subjected to immersion-type corrosion test under chloride environment to facilitate choose the suitable set of process parameters giving the least rate of corrosion.

2.0 Materials and Method

An ESAB, India manufactured AutoK400 MIG / MAG welding machine is used in this work as shown in **Fig. 1**. Pure CO_2 gas is employed for shielding the weld region. The torch has been fitted on a speed controllable vehicle. Straight linear motion is obtained as it follows a guided path. Velocity of it can be set at different values within a range. Shielding gas discharge is kept constant at 18 l/min. Low carbon steel base plates having the composition detailed in **Table 1** have the size of 100mm× 50mm× 6mm. Successive beads have 50% overlap. 6 passes are made to cover the sizeable portion of the specimen. Weld voltage and weld current are chosen suitably to determine heat input (HI) following standard relationship [24, 25]. Duplex Stainless Steel (**Table 2**) is taken as the clad material. Four experimental runs are conducted in this work at four values of heat input as detailed in **Table 3**.

Table 1 and **Table 2** show composition of substrate and filler wire respectively. Carbon, silicon, manganese, chromium, molybdenum and nickel content of duplex stainless steel filler wire (E2209T0-1) is remarkably higher than that of the base plate. The electrode wire contains nitrogen (0.125%) to boost precipitation of austenitic phase and also to stabilize it, thus improving mechanical properties of stainless steels [27-35]. Ferrite phase of this steel offers better corrosion resistance than the γ-phase.

Fig. 1 : The MIG/MAG welding set up

Table 1 : Contents of substrate

%C	%Si	%Mn	%P	%S	%As	%Zn	%Ni	%Ta
0.076	0.138	0.343	0.128	0.063	0.068	0.015	0.012	0.011

Table 2 : Contents of filler wire (E2209T0-1)

% C	% Cr	% Ni	% Mo	% Mn	% Si	% N	% P	% S
0.020	22.52	9.09	2.91	1.01	0.76	0.125	0.018	0.009

Test for hardness at the surface of the base plates is carried out before and after cladding by using a Fine Testing Machine, Miraj made Rockwell Hardness Testing Machine. Hardness value has been found in Rockwell hardness B scale by applying a load of 100kg. The geometry of the weld bead is then determined as it affects mechanical property of the weld, and thus, affecting its quality [16]. Clad plates are cut at different sections for preparing samples to observe under a tool makers microscope (Mitutoyo, Japan made). First, cut samples are filed and surface ground. Then they are ground/polished on a belt grinder/polisher and ground and polished on a disc grinder/polisher. Final stage is to undertake buffing operation using a velvet cloth and alumina paste on disc grinder/polisher to make the surface mirror finished. Respective values of reinforcement and penetration for each specimen are noted, and percentage dilution (D% = (B/(A+B)) x 100%) is calculated when, B is area of the weld pool, and A= area of the weld above the surface of the base metal. With some assumptions, dilution may also be computed as ({P/(P+R)} x 100%), when P is depth of penetration and R is height of reinforcement. In this work, it is used to compute dilution.

Metallographic study is carried out on the clad specimens by etching using Kalling's No. 2 reagent. It is prepared by mixing 100ml ethanol, 100ml HCL, and 5gm $CuCl_2$. Microstructures are observed using a Metzer, India made metallurgical microscope at 200x magnification. Corrosion test is next performed on different samples of polished clad components. Samples are weighed with a precision of 1μg. Hydrochloric acid, anhydrous ferric chloride, and distilled water mixture is used as a solution for the corrosion test. Only clad portions of the test specimens are made exposed to the solution and the remaining portion is masked with Teflon tape. Samples are put inside the solution for a day for accelerated corrosion test. Thereafter, they are taken out and washed under running water and put under ethyl alcohol. After taking out, they are dried and their weights are measured to calculate corrosion rate per unit area per time.

3.0 Results and Discussion

Detail of four experimental runs can be seen in **Table 3**. Radius of curvature of the weld cladded flats and distortion value are also shown. Angular distortion increases with heat input. Higher the heat input, larger will be the melt volume of the weld zone and this would cause larger shrinkage upon solidification and have larger distortion. Hardness of clad region has higher hardness than the unclad portion as expected (**Table 4**). This hardness increment in cladding is likely to be due to the presence of alloying elements like Cr, Ni, Mo, Mn, Si and N which increase hardenability of steels. Reinforcement, penetration and dilution are listed in **Table 5**.

Table 3 : Heat input used for weld cladding with 6 passes

Sl. No	Weld Voltage (V)	Weld Current (A)	Torch travel speed (mm/min)	Heat input, (kJ/mm)	Radius of curvature (mm)	Distortion angle (°)
1	28	145	540	0.36	347.29	7.1
2	28	145	516	0.38	265.87	8.2
3	28	145	468	0.42	257.49	10.5
4	26	145	402	0.45	135.15	15.5

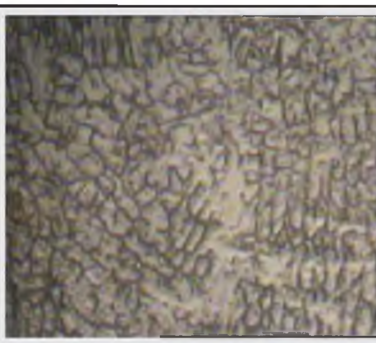
Table 4 : Hardness values measured before and after cladding

Sl. No.	Hardness in HRB	
	Before cladding	On the cladding
1	73	87

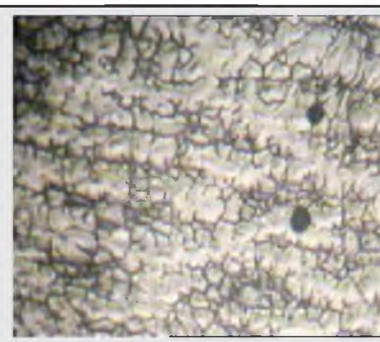
Table 5 : Dilution of base plate after cladding

Sl. No	Heat input, (kJ/mm)	Depth of penetration, P (mm)	Reinforcement, R (mm)	% Dilution $\left[\frac{P}{(R+P)}\right]$ x100
1	0.36	0.22	1.75	11
2	0.38	0.16	1.91	7.7
3	0.42	0.06	2.09	8.2
4	0.45	0.1	2.57	3.7

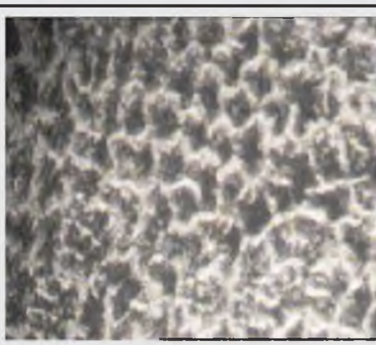
In **Fig.2**, microstructures obtained under different parametric combinations are depicted. The microstructure depicted in **Fig.2 (a),(b)** show the precipitation of single phase white ferrite (F) with secondary phase delta (δ) ferrite. The delta ferrite is responsible for the precipitation of sigma (σ) phase which reduces ductility and enhances hardness as reported by Gray et al. [34]. Thus, toughness may be reduced due to the presence of sigma (σ) phase [9, 10, 40, 41]. **Fig.2 (c)** and **(d)** show presence of austenite in white ferrite matrix



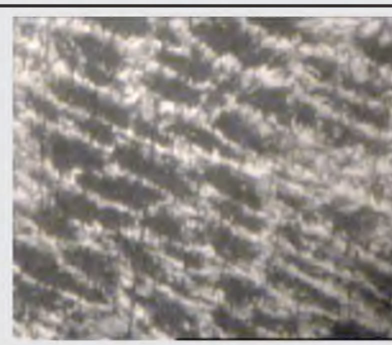
(a) At V= 28V, I= 145A, HI= 0.36kJ/mm, Exp. No.1



(b) At V= 28V, I= 145A, HI= 0.38kJ/mm, Exp. No.2



(c) At V= 28 V, I= 145A, HI= 0.42kJ/mm, Exp. No.



(d) At V= 26V, I= 145A, HI= 0.45kJ/mm, Exp. No.4

Fig. 2 : Microstructure of duplex stainless steel cladding

Table 6 : Observation of corrosion rate of the cladding

Sl. No.	Heat input, HI (kJ/mm)	Corrosion rate, C (gm/(m²hr))
1	0.36	0.458
2	0.38	0.282
3	0.42	0.353
4	0.45	0.499

Experimental run 2 gives lower corrosion rate than the other runs **(Table 6)**. **Fig. 3(a-d)** and **Fig. 3(e)** show micrographs of corrosion pits formed as a result of the corrosion test on clad portion and unclad specimens respectively. The intensive, large corrosion pits are clearly observed **(Fig. 3(e))** on bare, unclad plates showing the extent of corrosion taking place in the base plate under corrosive environment. Substantial reduction in corrosion pits is seen on duplex stainless steel clad specimens **(Fig. 3(a-d))** compared to that on the unclad specimens. This is likely due to the presence of corrosion resistant alloying elements in the clad portion, and the presence of dual phases on stainless steel existed in the cladding.

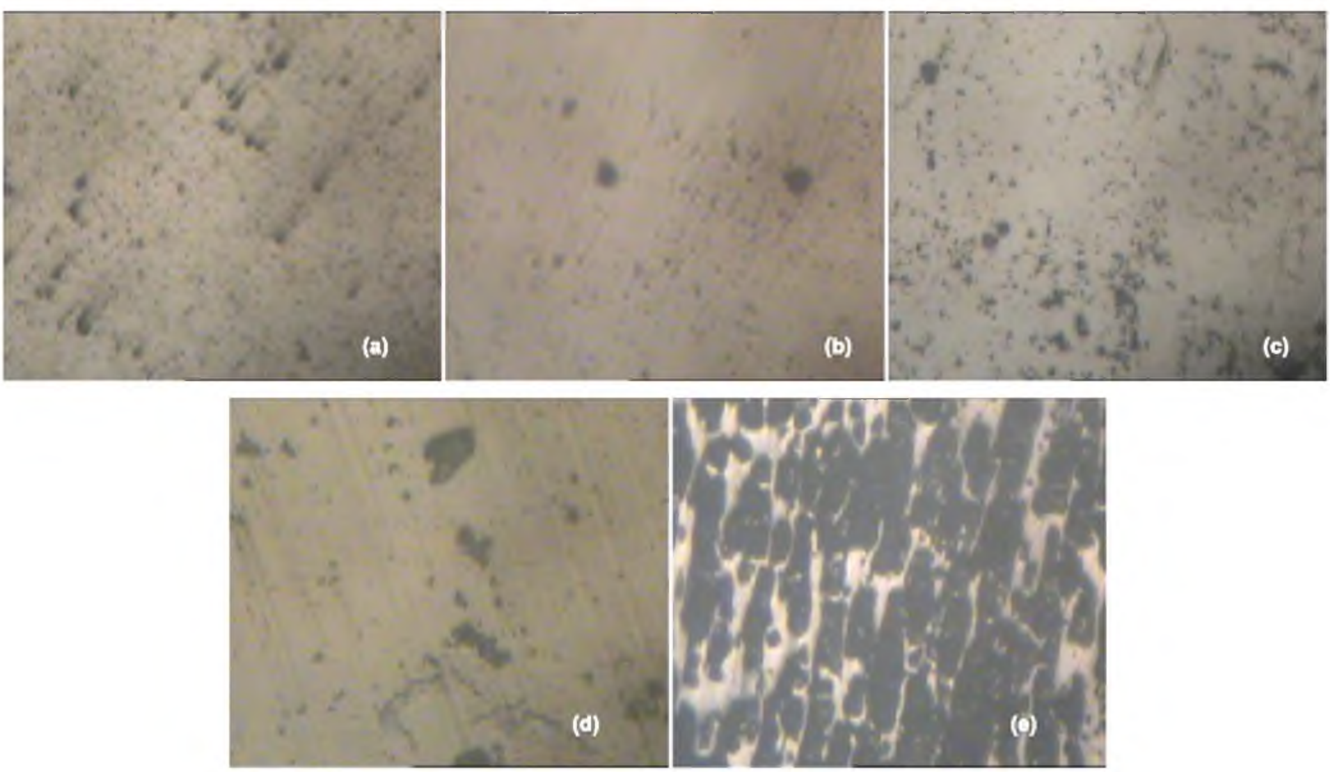


Fig. 3 : Micrographs depicting corrosion pits (200 X) [(a-d): corrosion on clad surface at experimental runs 1-4, and (e): corrosion on unclad specimen]

Among the four samples, the sample corresponding to experiment run 2, gives quite low corrosion rate compared to the other test samples as seen in Table 6. Nature of corrosion on this specimen is shown in **Fig. 3(b)**. This corresponds to a moderate heat input of 0.38 kJ/mm. At the heat input of lower and higher values than this, corrosion rate is observed to be higher. At 0.45 kJ/mm heat input, quite a high corrosion rate (0.499 (gm/m^{2}hr)) is observed. Overheating due to high heat input may have resulted in this low corrosion resistance than that at somewhat low heat input. Again, at a quite low heat input, there may be insufficient heating leading not to have favourable duplex phases of austenite and ferrite in the clad portion. Favourable microstructure as seen in **Fig. 2(b)** supports this. At higher heat inputs corresponding to samples as shown in **Fig. 2(c, d)**, predominant austenite phases are observed with low ferrite content thereby suppressing the favourable effects of duplex stainless steel.

4.0 Conclusion

Following inference can be drawn on the basis of the present experimental investigation on corrosion of duplex stainless steel clad on low carbon steel specimens using flux cored arc welding:

With 0.38 kJ/mm heat input, microstructure of clad surface shows presence of ferrite to a large extent. Correspondingly, quite a less rate of corrosion occurs. Therefore, this condition with 145A weld current, 28V weld voltage and 516 mm/min torch travel speed may be recommended to adopt in practice in similar situations.

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