

Combined Effect of Base Metal Dilution and Thermal Aging Conditions on the Corrosion Performance of Stainless Steel Claddings

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Abstract

Objectives: Present work investigates the effects of base metal dilution and the thermal aging treatments on corrosion performance and strength of stainless steel claddings, fabricated by gas metal arc welding process. **Methods/Statistical Analysis:** Austenitic stainless steel AISI SS 316L was selected as the cladding material and low carbon steel as substrate for the present study. Experimental conditions were selected to achieve a varying degree of base metal dilution of the deposit. Thermal aging treatment were given to specimens at 700°C, for 2 hours, 4 hours and 20 hours. The specimens were subjected to Double Loop Electrochemical Potentio Kinetic Reactivation (DLEPR), boiling nitric acid, and microhardness testing. **Findings:** Microhardness results of the clad deposits showed a continuous decrease in values from top of clad deposit to the base metal. However almost constant values of microhardness were observed when it was measured along the clad deposit. Moreover the deposits with high dilution showed low microhardness values than that of low dilution clad beads. The low dilution clad deposits also performed better under corrosion testing and sensitization measurement conditions as compared to high dilution deposits. Corrosion rate measured from boiling nitric acid test showed a significant growth with increase of thermal aging time due to carbide precipitation. The corrosion rate of specimens in the as clad condition was as low as 0.19 mm/month which increased to 3.64 mm/month when sensitized for 20 hours at 700°C. Degree of sensitization (DOS) found to be more significantly affected by the thermal aging treatment. The DOS values varied from as low as 2.47 % to high as 31% for the as clad and sensitized conditions respectively. **Application/Improvements:** The present study can beneficially be adopted for weld overlay fabrications as it suggests the processing conditions to forecast the adequate strength and corrosion performance of components in similar service conditions.

Keywords: Corrosion Rate, Dilution, Degree of Sensitization, Microhardness, Thermal Aging

1. Introduction

Cladding is a process of depositing one alloy of desired properties over the substrate in order to improve the properties of base metal like resistance to abrasion, corrosion, fatigue, strength or for achieving dimension control, and metallurgical needs. Though numerous cladding methods have evolved, all operate on the same basic principle of fusing corrosion-resistant alloys to carbon steel. Gas metal arc welding is found suitable for cladding due to its versatility and process capabilities. Austenitic stainless steels have been one of the most widely used cladding materials to counter the corrosive attacks on the surfaces.

Austenitic stainless steels find extensive applications in the surfacing industry due to its good weldability and corrosion resistance. While austenitic stainless steels are normally quite easily welded, there are a number of issues also when welding these materials. One of these issues is that these steels got tendency of grain growth. The higher is the exposure temperature and longer is the duration of expose, the bigger the grains become. This reduces both the strength and impact properties¹. Another problem is sensitization which may be defined as the loss of alloy integrity which results from chromium depletion in the vicinity of carbides precipitated at grain boundaries. This causes the steel or alloy to become susceptible to

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intergranular corrosion or intergranular Stress Corrosion Cracking (SCC). Sensitization occurs when these steels get exposed at the temperature range from 500° C- 850°C. However these problems may be minimized by the usage of L grades which stands for extra low carbon to a large extent. A number of researchers have made several attempts on studying various aspects related to the quality of the achieved clad deposit. Few studies have been reported on optimization of the welding process parameters so as to achieve good quality weld with appropriate dilution levels³. Dilution may be defined as the change in the chemical composition of a welding filler material caused by the admixture of the base material or previously deposited weld material in the deposited weld⁴⁻⁶. As shown in Figure 1 the percentage dilution is calculated from finding the A_p and A_r i.e. areas of penetration and reinforcement respectively.

$$\% \text{ Dilution} = (100) (A_p / (A_p + A_r))$$

Thus dilution becomes an important aspect to adjudge the quality of the clad deposit. Dilution reduces the alloying elements and increases the carbon content in the clad layer, which leads to a decrease in the corrosion resistance properties, percentages of delta ferrite content and other metallurgical problems. Also the economics of stainless steel weld cladding is dependent on achieving the specific chemistry at the highest practical deposition rate in a minimum number of layers⁷. Effect of carbide precipitation or sensitization has also studied by taking into account the pitting corrosion behavior by several researchers⁸⁻¹¹. But very scanty information is available which directly indicate the influence of dilution and that of carbide precipitation on the corrosion performance of the austenitic stainless steels weld overlays.

So it was decided to undertake the present work to study the effect of varying dilution and carbide precipitation on

the corrosion resistance properties of SS 316 L claddings by gas metal arc welding process.

2. Experimentation

Low carbon steel flats of selected size were taken as the substrate material for cladding by GMAW process and SS316L solid wire electrode with diameter 1.2 mm was used as the filler. Table 1 shows, chemical composition of the filler wire and the base material used in the present work.

Base metal plate surfaces were subjected to thorough cleaning prior to cladding by filing and grinding etc. to avoid any foreign material to react with the weldment. First screening experiments were conducted using a simple bead on plate experimental approach so as to decide the parametric window^{12,13} for the actual cladding operations.

Dilution characteristics are mainly dependent upon the heat input given to the base metal and the composition of filler and base metal⁷. Since the composition for the present work was fixed, it was the heat input parameters which governed the heat input and thus dilution of the clad deposit. Heat input is given by the equation

$$\text{Heat input} = \eta_a (\text{arc voltage} \times \text{welding current} \times \text{powerfactor}) / \text{welding speed}.$$

Power factor assumed to be unity, and at constant welding speed, arc voltage and welding current were taken as the controlling parameters whereas the welding current is represented by the wire feed rate. To study the effect of varying dilution the following experimental conditions were selected which are shown in the Table 2.

The specimens were cladded as per the experimental conditions mentioned in the Table 2, multi-layer and multi-pass welding was carried out maintaining the overlap between the clad beads and inter pass temperature.

After overlaying each deposit, clad bead was thoroughly cleaned making it suitable for the overlap or the next clad bead. The thermal aging treatment given to

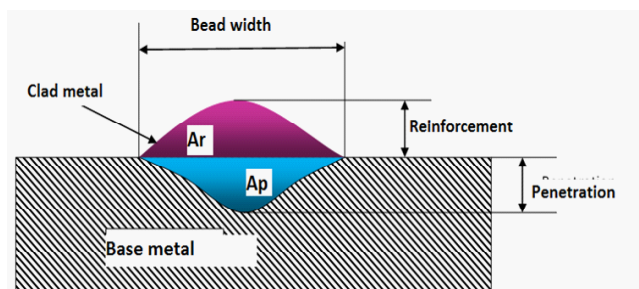


Figure 1. Representation of bead deposit and dilution calculation.

Table 1. Chemical composition of the filler wire and the base material

Elements	C	Mn	P	S	Si	Ni	Cr	Mo	Fe
SS 316L	0.015	1.4	0.02	0.02	0.4	10	17.8	2.5	Bal
Low carbon steel	0.27	0.51	0.04	0.032	0.19	0.046	0.089	0.04	Bal

clad specimens was decided on the basis of the literature reviewed. The sampling of specimens selected for further study is shown in Table 3. The clad specimens were categorized according to the dilution obtained by given set of welding parameters viz. low dilution and high dilution.

2.1 Post Clad Thermal Aging of Clad Deposits

In order to induce carbide precipitation or sensitization in the clad specimens post clad thermal aging treatment was given by heating each sample at 700° C for 2 hrs., 4 hrs., and 20 hrs followed by cooling in still air i.e. normalizing. The specimens were cut to different sizes to carry out further investigation of microhardness and corrosion testing in the as clad condition as well as after giving thermal aging treatment.

2.2 Microhardness Testing

Microhardness measurements were carried out in the manner as shown in the Figure 2, (a) along the weld

Table 2. Experimental conditions

Cladding operation	Multi-pass, multi-layer cladding by GMAW process with overlap of 25%
Cladding position	Flat
Filler wire	SS 316 L (1.2mm), solid
Base metal	Low carbon steel (12mm thick)
Shielding gas	Industrially pure Argon
Gas flow rate	20 Lit/min
Arc voltage	24 V- 26 V
Wire feed rate	4 m/min- 5 m/min
Nozzle to plate distance	15 mm
Inter pass temperature	150°C

Table 3. Sampling of specimens

Sample name	Cladding condition	Post clad thermal aging treatment (Temperature(°C)/ Time(hr))
A1	Low dilution	As clad
B1	Low dilution	(700/2hr)
C1	Low dilution	(700/ 4hr)
D1	Low dilution	(700/20hr)
A2	High dilution	As clad
B2	High dilution	(700/2hr)
C2	High dilution	(700/4hr)
D2	High dilution	(700/20hr)

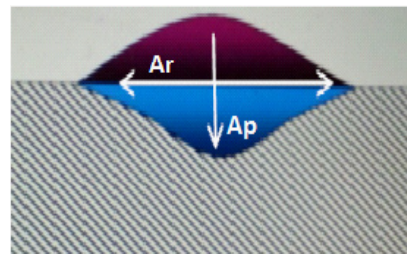


Figure 2. Illustration of readings taken for microhardness.

centreline and (b) across the cladded from top of the layer towards base metal metal using Vickers hardness testing machine. The specimens in the as clad condition as well as after thermal aging were tested for microhardness as well as corrosion studies. The readings of microhardness obtained were repeated and the average values have been reported. The results are discussed in the following section.

2.3 Corrosion Testing

As already discussed specimens both as clad and thermally aged was subjected to two types of corrosion studies- boiling nitric acid test and DLEPR testing. The boiling nitric acid or Huey's test is used for detecting the susceptibility of stainless steel cladding towards inter-granular corrosion attack which was conducted as per ASTM A-262-Practice-C. It is conducted for detecting the susceptibility of inter-granular corrosion attack in stainless steel claddings. This procedure can also be used to check the effectiveness of the stabilizing elements and the effect of carbon content in reducing the susceptibility to inter-granular corrosion attack in Cr-Ni stainless steel. The entire lateral surfaces of the eight prepared test specimens were finely grounded and polished to facilitate better surface exposure to the corrosive test solution. A 65 % by weight nitric acid solution was prepared by adding distilled water to concentrated nitric acid (HNO_3) of reagent grade with specific gravity 1.42 at the rate of 108 ml of distilled water per litre of concentrated nitric acid as per ASTM standards^{14,15}. The solution was considered appropriate because of the effect of HNO_3 being more pronounced and aggressive in the environments that could formulate inter-granular corrosion. Inter-granular attack in nitric acid is associated with the inter-granular precipitation of chromium carbides. The specimens were polished with 120 grit abrasive paper and weighed initially. They were placed in a glass cradle and kept

inside the round bottom boiling flask fitted with condenser to dissipate the heat developed during boiling of the acid. The flask was filled with sufficient quantity of the test solution to cover the specimen and to provide a volume of 20 ml/cm² of the specimen surface. Cooling water was passed through the condenser for dissipating the heat generated and the flask is electrically heated and maintained at 60°C thereby keeping the test solution boiling throughout the test period. The test period was of 48 hours duration and after the end of each test period the specimen was rinsed with water and scrubbed with a nylon brush under running water to remove any adhering corrosion products. Then the specimens were dried by dipping in acetone and weighed in an analytical balance. The difference in weight is recorded for estimating the corrosion rate. This test procedure was repeated for five consecutive boiling periods with duration of 48 hours for each period for every specimen. Fresh test solution was used every time during the entire testing period.

2.4 DLEPR Testing

The double loop electrochemical potentio kinetic reactivation test (DLEPR) is a quasi-non-destructive test to describe the corrosion resistance of stainless steels. This test was carried out according to ASTM G-108 to evaluate the degree of sensitization of the specimens. The double loop EPR-test shows a cyclic polarization curve consisting of a forward scan followed by a reverse scan starting at active VOC (open circuit voltage). The test comprising of three stages, which are:

1. A 5 min delay at VOC.
2. An anodic polarization scan from 50 mV below VOC to 300 mV for cladded specimens and sensitized samples scan rate of 100 mV/min i.e. 1.67mv/s.
3. A cathodic reactivation scans from 300 mV (for cladded and sensitized specimens) to VOC at the same scan rate.

The surface preparations of the specimens were finished by polishing up to the desired level. The electrolyte solution used for the test was 0.5 M H₂SO₄ + 0.01 M KSCN.

Degree of sensitization was calculated by using following formula.

$$DOS(\%) = \frac{I_r}{I_a} \cdot 100$$

In the double loop test, specimen is first polarized anodically through the active region then the reactivation scan in the reverse direction is carried out. When it is polarized anodically at a given rate from the corrosion potential to a potential in the passive area, this polarization leads to the formation of a passive layer on the whole surface. Then when scanning direction is reversed and the potential is decreased at the same rate to the corrosion potential, it leads to the breakdown of the passive film on chromium depleted areas. A ratio of maximum current generated in the double loop test (I_r/I_a) is used as a measure for the degree of sensitization. The results obtained are discussed in the next section.

3. Results and Discussions

As per the sampling plan shown in Table 3, cladded specimens were given different set of treatments and the results obtained are discussed below.

3.1 Microhardness Results

The microhardness studies were carried out for both sensitized and non-sensitized specimens in the manner already discussed in the previous section 2.2 experimentation. The results obtained are shown in the graphs shown in Figure 3(a) and Figure 3(b). The following observations are made from the results obtained by microhardness testing:

The microhardness along the clad bead for as clad conditions i.e. for samples A1 and A2 showed almost constant trend. However the clad deposits under low dilution conditions showed marginally higher values of microhardness than that of high dilution clads. As specimens were thermally aged and the time of exposure was increased, the microhardness results showed a decreasing

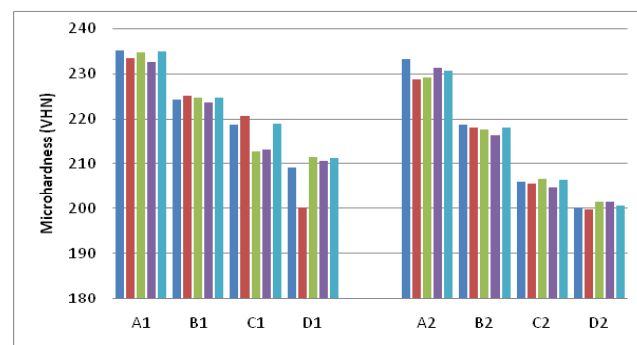


Figure 3 (a). Microhardness results along the clad bead.

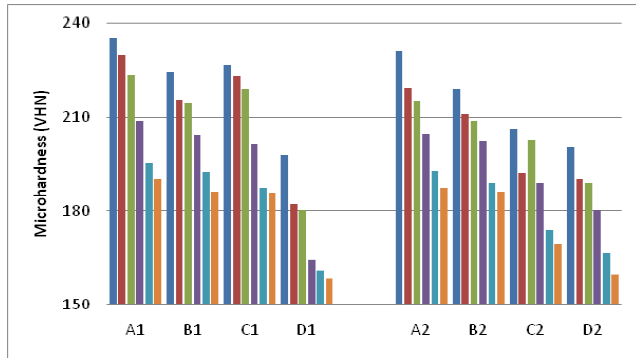


Figure 3 (b). Microhardness results from clad metal to base metal.

trend. Individual sample for condition B, C and D showed almost constant microhardness along the clad bead.

When microhardness was measured from clad to base metal i.e. across the clad bead, a continuous and significant decreasing trend in the microhardness results was observed. The decreasing trend in Figure. 3(b) can be attributed to the variation in the filler chemistry from richer to leaner due to dilution. As the time of exposure in thermal aging treatment was increased, microhardness values showed a significant drop. This may be due to the fact that availability of more time for the precipitates to grow during the carbide precipitation that occurred at the grain boundaries leaving behind the matrix depleted of both chromium and carbon which otherwise act as matrix strengtheners.

3.2 (a) Boiling Nitric Acid Test

The corrosion tests were conducted in accordance of ASTM standards. While conducting the boiling nitric acid test, specimens both sensitized and non-sensitized were weighed before and after the test to find the loss in weight of each sample due to corrosion. The corrosion rate was calculated by the following formula recommended for stainless steels according to ASTM A262 G1:

$$\text{Corrosion rate (mm/month)} = (2.87 \times 100 \times W \times 25.4) / (A \times t \times d)$$

Where 't' is the time of exposure in hours, 'A' is the total surface area in cm²; 'W' is the weight loss in grams and 'd' is the density, where for chromium–nickel–molybdenum stainless steels it is taken as 8 g/cm³. Results obtained from the weight loss and corrosion rate calculations are given in Table 4.

3.2 (b) DLEPR Test

The degree of sensitization (DOS) was calculated by DLEPR test which was carried out to check the level of sensitization induced in the specimen undergone different thermal aging treatments. DOS for as clad specimens did not show significant results. This means that low dilution as well as high dilution clads are not susceptible to sensitization until and unless they are given the thermal aging treatments. The DOS values obtained for the low dilution sensitized specimens vary from 2.47% to 23.8% whereas for high dilution sensitized specimens DOS varied from 2.81% to 31.7%. This indicates that the time of exposure for carbide precipitation has a significant effect on the DOS value. As the time of exposure is increasing more number of chromium atoms are diffusing at grain boundaries to form chromium carbide due to which corrosion resistance of grain other than grain boundary decreases. So it may be important to comment that as the time of exposure in post clad heat treatments is increasing, the material in particular at the grain boundaries become

Table 4. Corrosion rate and Degree of sensitization

Sample	Boiling nitric acid test results		DL EPR test results		
	Weight loss (g)	Corrosion rate (mm/month)	I _r (A/cm ²)	I _a (A/cm ²)	DOS=I _r /I _a ×100 (%age)
A1	0.036	0.193	3.64×10 ⁻³	146.9×10 ⁻³	2.47
B1	0.113	0.608	28.14×10 ⁻⁶	545.8×10 ⁻⁶	5.15
C1	0.157	0.845	0.512×10 ⁻³	4.99×10 ⁻³	10.26
D1	0.324	1.743	2.43×10 ⁻³	10.19×10 ⁻³	23.84
A2	0.043	0.231	24.26×10 ⁻⁶	862.1×10 ⁻⁶	2.81
B2	0.138	0.742	37.9×10 ⁻⁶	608.9×10 ⁻⁶	6.22
C2	0.177	0.952	0.268×10 ⁻³	1.97×10 ⁻³	13.6
D2	0.449	2.416	0.915×10 ⁻³	2.89×10 ⁻³	31.66

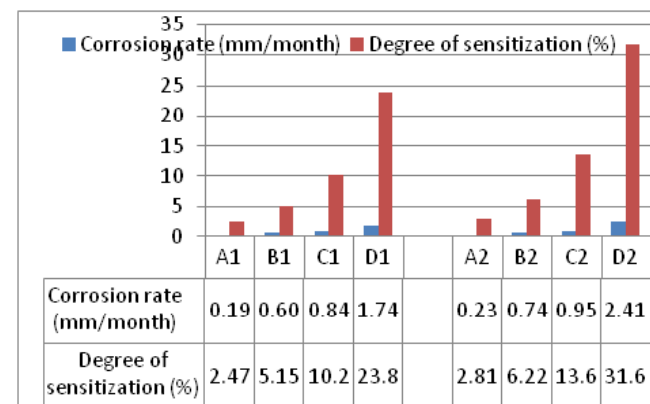


Figure 4. Corrosion performance of SS 316L claddings.

more sensitive to corrosion. Hence degree of sensitization is increasing or in other words the passivity of the protection layer has been decreased. The results of DOS are shown in Table 4 and the corrosion performance have been shown in Figure 4.

4. Conclusions

The following conclusion can be drawn on the basis of the present study conducted.

- Thermal aging treatments have less significant effect on the microhardness of SS 316L claddings as compared to that of base metal dilution. Low dilution claddings resulted in comparatively higher microhardness values than that of high dilution claddings.
- Corrosion rate is significantly affected by thermal aging treatment. Appreciable growth in the corrosion rate for both low dilution and high dilution depositions is observed with increase in aging time.
- Degree of sensitization is also affected significantly by the thermal aging treatment.
- Non-sensitized or as clad specimens show negligible values of DOS and corrosion rate implies the claddings to be highly corrosion resistant.

5. Acknowledgements

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