Study of corrosion behaviour of SS-316 cladding deposited by shielded metal arc welding

Vedant Singh[1] , Virender Singh[2], Narender Anand Mohan[3]
[1]Assistant Professor, Department of Mechanical Engineering, DR. B. R. Ambedkar, National Institute of Technology, Jalandhar -144011 (PB), India
[2]Assistant Professor, Mechanical Engineering, Abhilashi University, Mandi-175028 (H.P.), India
[3]M. Tech. Scholar, Mechanical Engineering, Abhilashi University, Mandi-175028 (H.P.), India

*Corresponding Author:er.vedu@gmail.com

Abstract. The present work deals with the study of microstructure and to examine the effect of sensitization on the corrosion resistance of the Stainless Steel 316 cladding deposited by using SMAW process. Literature explains the susceptibility and resistance of SS316L at ambient temperatures and higher temperatures to examine the corrosion rate of the steel after immersion in the corrosive media. This work reveled that with one layer have less amount of precipitated chromium carbide as compared to the specimen B and C. The result shows that the Austenitic Stainless steel has the best layer thickness to highest corrosion resistance rates. Huey‘s test gives the microstructure results and through that we have concluded the corrosion rate goes at the maximum value of 2.88 mm by boiling the fresh nitric acid at 67 percentile. By focusing on the future various grades like SS309L, SS304L and materials such as cobalt alloys, copper alloys, manganese alloys, alloy steels, ceramics and composites are employed for weld cladding applications.

1. Introduction

SS-316L material is used in various industries for gas drilling, oil rings for removal and protection against corrosion. SS309L has also, been used in such applications but due to more percentage of carbon present in the material composition (0.03-0.08%) as compare with 316L (≤ 0.03) affects the corrosion resistance [4, 16] . The main purpose behind this study is to check the corrosion resistance of various thicknesses of SS316L claddings deposited by SMAW. Researchers [6, 10, 13, 7, 8, 17] also used other welding processes such as tungsten inert gas (TIG), metal inert gas (MIG), friction stir welding (FSW) and LASER welding but less work has processed on SMAW. In addition, Shen [15], Leitch [9], Navaneethakrishnan & Loganathan [12], Wang et al. [16], Bohatch et al. [1], Ettefagh & Davoodi [2], Rao et al. [14], Keller et al. [5], Ghosh et al. [3] and Muthupandi et al. [11] studies the corrosion behavior of cladding on steel using different welding techniques. However, to best of our knowledge, none of the study are available on the corrosion behaviour of SS316L cladding deposited by shielded metal arc welding (SMAW) and the microstructure of this welding has less investigated after corrosion.

The principle of the operation state that SMAW is a labour-intensive arc welding process with the intention of uses a consumable electrode which is enclosed with a flux to place the weld [15]. The process is used to weld steel, iron, nickel, aluminium, etc. but SMAW is employed extensively in the construction of heavy steel structure and in industrial fabrication. It takes over other welding processes in the maintenance and repair. It is used all-inclusive because of its simplicity of its operation and its equipment's.

The main objectives of this study is to analyse the effect of corrosion on microstructure and micro hardness of SS316L claddings and effect of sensitization on the corrosion life of SS316L claddings. In reality, Corrosion rate indicate the prevention and weight loss factor so that it can be remove with the impurities and the SS316L should satisfy the required conditions.

2. Research Methodology

Experimentation is to be conducted in two phase, in the first phase trial run is to be conducted to find out the best suited welding parameter for cladding in terms of moderate dilution level and corresponding better mechanical and metallurgical properties. In the second phase, the best suited results obtain from the first phase where further use for experimental studies.

2.1 Experimentation for cladding

Cladding is to be done by using shielded metal arc welding, in which mild steel is taken as base metal having dimensions of 200x75x12 and SS316 is taken as cladding material which will be in the form of welding electrode. Three layers of different cladding thickness are formed on base metal. After that three specimens from each layer is cut means total of nine specimens are made. These specimens are tested by using weight loss method. Comparisons are done between specimens and base on these comparisons results should be made. The cladding deposited on the layer under the different specimens A, B and C. for weight loss test is necessary for the given specimens. The final testing gives the vulnerability of stainless steel cladding in the direction of corrosion attack boiling nitric acid test is used.

Base metal preparation includes the stepwise procedure like cleaning the top surface of the base metal to remove the dust, oil, rust and other foreign particles. The pre cleaning was done with the help of wire brush and hand surface grinder (as shown in "figure 1") so that proper fusion at top surface could be achieved, and to save the cladding layer from the impurities and weld defects.

Figure 1. Grinding of base metal to remove impurities

Welding equipment used for the cladding was DC rectifier type. Purpose of using DC power source is that it gives more stable arc as compare to AC power source; also, the amount of spatter produced is comparatively less. So the quality of cladding achieve will be better. For cladding entire plate and to achieve desired cladding layer thickness, welding performed was multi-pass and multi-layer type. "Figures 2-5" given below shows the way how it was carried out actually. Cladding layers were applied in horizontal and transverse direction one after another to maintain even surface finish. Procedure for different layer of welding of different thickness is given below:
Firstly, the specimen is kept on the table connected to earth. The specimen is kept horizontally for the first cladding layer and the welding is done from upside down layer by layer up to the end of specimen i.e. 200mm.

Figure 2. First layer of cladding on base metal

Secondly, after that we cut a piece of 70mm from this specimen using hand cutter and plain or give it surface finishing using surface grinder. This is our first specimen name as A. Now place the remaining piece on the welding table in vertical direction and deposit the second layer upside down. Cut 70mm from this specimen using hand cutter and plain or give it surface finishing using surface grinder. This is our second specimen name as B.

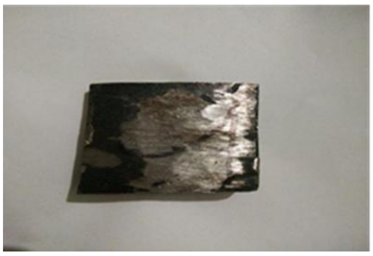

Figure 3. Specimen A

Figure 4. Specimen B

Figure 5. Specimen C

2.2 Preparation of the test specimen and test solution

After doing cladding of different thickness on different specimen the next step is to prepare specimens for weight loss test.

1. For weight loss test we prepare three specimens from each piece of different cladding thickness (A, B, C).
2. Prepare each specimen into same dimensions of 10*7*15 mm.
3. Name the each specimen as _A‘,_B‘,_C‘ for piece of single cladding layer _D‘,‘E‘,‘F‘ for the piece having two layer of cladding _G‘,‘H‘,‘I‘ using punch and the process of naming specimen is known as specimen coding.

2.3 Boiling nitric acid test (Huey’s test)

Huey‘s test as shown in “ figure 6” is employed for finding the susceptibility of stainless steel cladding in the direction of inter-granular corrosion attack and performed as per ASTM A-262-Practice-C. This test is carried for finding the vulnerability of inter-granular corrosion attack in stainless steel claddings. This test can also be employed to examine the fruitfulness of the stabilizing elements and the impact of carbon content in minimizing the susceptibility to inter-granular corrosion attack in Cr-Ni stainless steel.

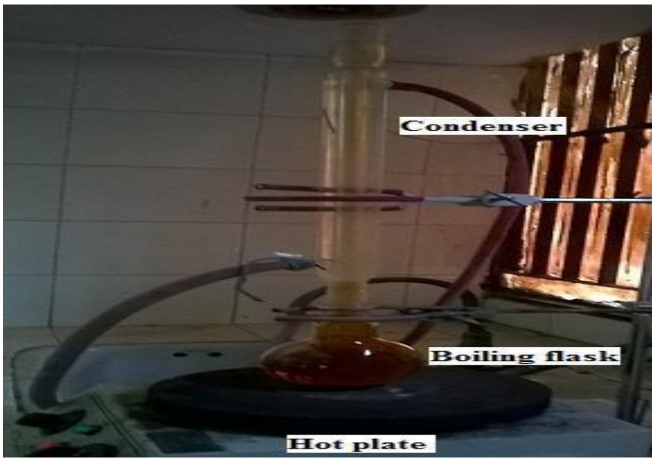

Figure 6. Boiling nitric acid test (Huey's test) arrangement

2.4 Preparation of the test specimen and solution

The whole surfaces of the four prepared test specimens are grinded to offer better surface exposure to the corrosive test solution. A 67 % by weight HNO_3 solution was made by adding distilled water to concentrated HNO_3 of reagent grade with specific gravity 1.45 at the rate of 109 ml of distilled water per liter of concentrated nitric acid as per ASTM standards. The solution was examined appropriate because of the impact of HNO_3 being more noticeable and assertive in the environments that might formulate inter-granular corrosion.

2.5 Experimental method

Intergranular attack in nitric acid is related with the inter-granular precipitation of chromium carbides. The specimen was buffed with 122 grit abrasive paper and weighed. Then, this specimen was put in a glass cradle is shown in figure 3.6 and placed inside the round bottom boiling flask fitted with condenser to disappear the heat generated during boiling of the acid. To mask the specimen, the flask was then filled with sufficient quantity of the test solution and to give a volume of 20 ml/cm^2 of the specimen surface. Cooling water was moved through the condenser for dissipating the heat developed and the flask is electrically heated and retained at 60°C thereby keeping the test solution boiling through the test period. The test time was of 50 hours duration and after the completion of each test period the specimen was cleaned with water and scrubbed with a nylon brush under running water to detach any sticky corrosion products. Then, the specimen was baked by immersing in acetone and weighed in an analytical balance. The dissimilarity in weight is noted for estimating the corrosion rate. This test method was restated for six successive boiling periods with the time of 50 hours for each period for every specimen. After this, the new test solution was employed every time.

3. Result and Discussion

The results elaborate about the metal deposition behavior of SS 316L claddings deposited by SMAW process under various testing conditions. In addition, these results give us a practical frame for describing the corrosion and fatigue behaviour of claddings under actual working conditions. The graph shows the weight loss after test (g) and corrosion rate (mm/month) under the eight samples.

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3.1 Boiling nitric acid test (Huey's Test) results

In nitric acid test ASTM A-262 Practice C, a fresh 67% nitric acid was boiled and specimens were kept at this condition for five 50 hours periods. Specimens were cut into equal dimension (10×10×4) mm and weight of every the specimen was measured before test. Specimens were weighed on a scale with least count of 0.00001 g analytical balance before and after these experiments. The corrosion rate was estimated as the loss in weight as inch per month (mm/month) according to ASTM A-262 as follows:

$$mm/month = 278 \times W / A \times t \times d$$

Where t is the time of exposure in hours, A is the total surface area in cm^2; 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/cm^3. Results obtained from the weight loss test is given in the "Table 1". It is clear from the "figures 7 and 8" that the specimen with one layer of thickness have high corrosion rate as compared to the specimens with two and three cladding layers.

Table 1. Weight losses and corrosion resistance rate

Specimen coding	Specimen weight before wt. loss test	Specimen weight after wt. loss test	Weight loss after test (gm)	Corrosion rate (mm/month)
A	8.990	4.800	4.14	2.88
B	7.940	4.050	3.89	2.85
C	8.610	4.430	4.18	2.68
D	8.550	8.160	0.39	0.93
E	7.070	6.420	0.65	0.44
F	7.120	5.770	1.35	0.26
G	7.380	7.340	0.04	0.027
H	6.850	6.810	0.04	0.027

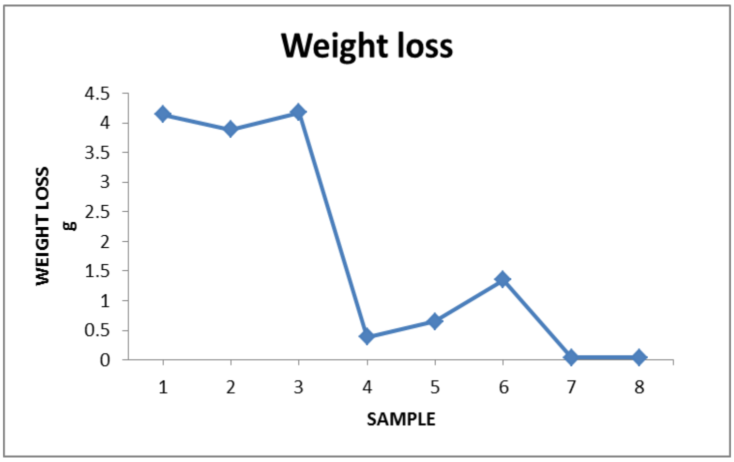


Figure 7. Graphical representation of weight loss in various samples

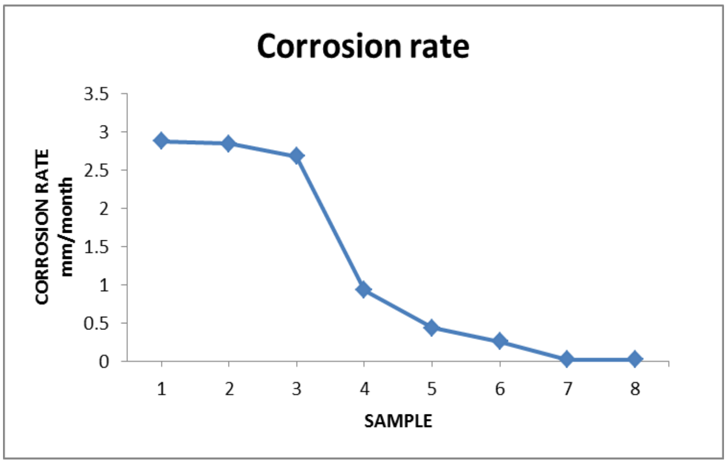
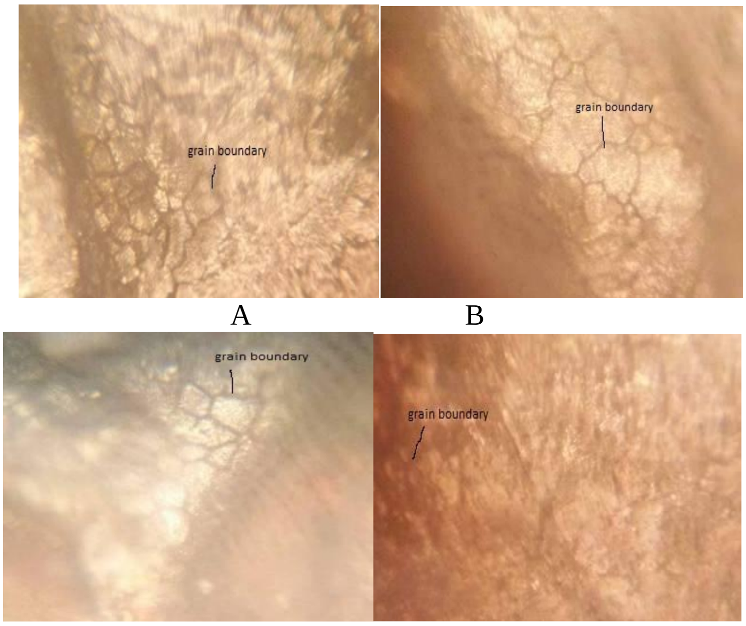


Figure 8. Graphical representation of corrosion rate in various samples

3.2 Microstructure Studies

Microstructure obtained after the Huey's test for different specimens shows the effect of sensitization conditions produced at micro level. Following are the microstructure pictures obtained after the test for different batches of specimens. "Figure 9 (a, b and c)" ditch type microstructure. This ditch structure is the result of precipitation of chromium carbide at the grain boundaries. Microstructure for specimen ("Figure 9- d,e and f") are of specimen B. Microstructure obtained is also ditch type but in this case the amount of precipitation of chromium carbide is more when compared with specimen A. Grain boundaries are wider and clear in this case. "Figure 9 (h)"shows microstructure for specimen C. Sensitization in this case is even more than compared to specimen B. Grain boundaries are wider than obtained for specimens A and B.



A B

C D

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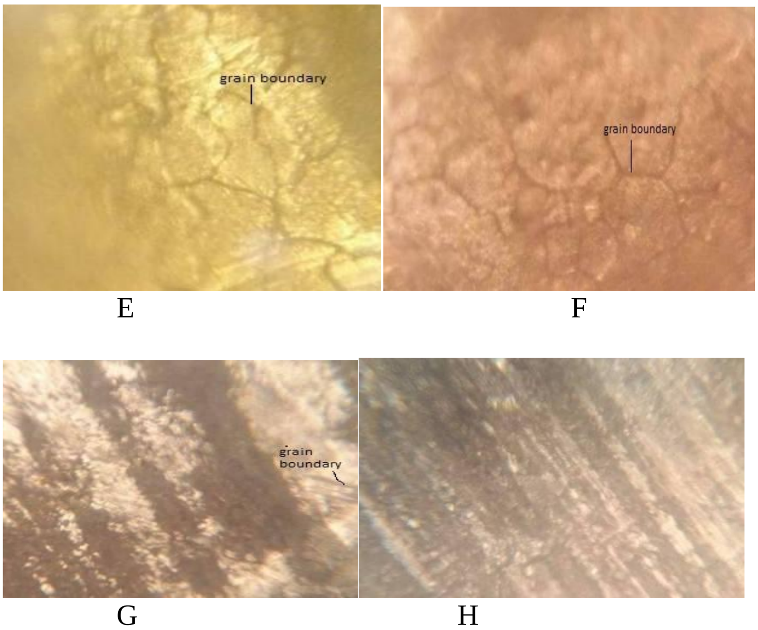

Figure 9. Microstructure of different specimens

3.3 Comparison of results

Comparison of result shows that how our experimental results contrast with other technique. It also helps to make the result more striking in such a way so that we can reach to a significant conclusion. Here, we discuss the results of stainless steel of grade 316L cladding with similar technique. Kumar et al. (2015) has studied the effect of sensitization on the metallurgical properties of austenitic stainless steel but we have done on SS316L type of grade SS316L steel have Nickel and Chromium as basic constituents. It has excellent corrosion resistance and very good weldability properties. Huey's test shows the more excellent result as compare with other properties of stainless steel. It is also clear from the table drawn that the specimen with one layer of thickness have high rate of corrosion rate as compare to the specimen with two or three cladding layer.

4. Conclusions

In this study cladding of three different layers of SS316L on a piece of mild steel has been studied with the concert of Huey's test on these different layer specimens. The result of this test shows that the piece with one cladding layer has low corrosion resistance rate as compared to the pieces having two and three cladding layers. The best result is shown by specimen having three layers of cladding on it having corrosion resistance rate about 0.027mm/month.

This study has shown that welding currents plays an important role on the cladding layer. So, current should be kept constant during cladding process and the Specimen with one layer have less amount of precipitated chromium carbide as compared to the specimen B and C. For future, In place of three cladding layers more layers can also be clad, their result could be tested, and apart from Mild Steel other base metal would be used by using some other base metal by which we can obtain high corrosion resistance rates at low prices.

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