

The Effect of Dilution on Electrochemical Properties of Stainless Steel Clad Layer

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Abstract:

The effect of dilution on clad-stainless steel layers type (SS309L & SS308) deposited by Gas Metal Arc Welding technique was studied. The dilution effect was investigated by metallographic, and corrosion (both weight and electrochemical) techniques. The metallographic test showed that the first layer SS309 L has pitting corrosion and also some indications of brittle sigma phase at the interface between SS 309L & SS308 layers. The corrosion tests both weight loss and electrochemical tests were conducted in a solution of 4.5% NaCl and their results were in agreement with the metallographic results. In the electrochemical test the passivity region was lesser in SS 309L layer than that in SS 308 layer indicating the better corrosion resistance of SS 308 layer than that of SS309L. All tests results approved that SS 308 layer has superior corrosion resistance than SS 309L despite that the SS 309L is the thicker layer and has more Cr & Ni content but apparently these excellent properties were damaged due to the dilution effect.

Key Words: SS 309L & SS308 stainless steel, Gas Metal Arc Welding, Dilution Effect, Corrosion, microstructure.

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Introduction:

A clad- metal or alloy is a composite material consisted of a thin layer of a metal deposited on lower cost substrate. The main purpose of this process is to produce at low cost a combination of desired properties of a composite material. (J.R.Davis,1994). In case of clad-stainless steel composite metal, the desirable properties required are the high corrosion and abrasion resistance of clad stainless steel with good strength of the substrate material such as low carbon steel. (JFE, 2013).

There are many types of cladding alloys such as stainless steel, nickel-copper based alloys, and also tin and aluminium based alloys which can be cladded in many applications. Despite the importance of cladding technique in the industry to decrease the overall cost there are many limitations that control the cladding technique regardless the technique used. One of the most important limitation factors which determine the quality of the cladding process is dilution factor. (Acton, 2013). The dilution is the percentage of the filler metal to the sum of filler metal and base metal content. When the high dilution takes place in the cladded layer that means the cladded layer contains a high amount of substrate metal. The high amount of substrate metal in the clad layer will lead to considerably decrease in the desirable properties especially the corrosion resistance in case of the stainless steel clad layer. (Smith, 2012). The high dilution value obtained in this study can be interpreted in this case as the increase in the amount of iron that take place from the base metal and moved up to the stainless steel clad layers.

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

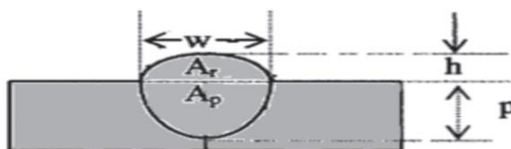


Fig. (1.1) illustration of dilution calculation (Kumar, 2012)

To decrease the effect of dilution the clad layer normally is made with a thick layer. The thinnest layer with the required

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properties (which should be in perfect conditions exactly the same as the filler metal chemical composition) can be achieved by controlling all the parameters that have an effect on dilution and this demands sophisticated technology. The factors that affect dilution are:

1) Amperage. 2) Travel speed. 3) Polarity. (J.R. Davis, 1994).

Generally speaking the welding parameters that lead to high penetration should be avoided and the manufacturers should be very cautious to use the parameters that achieve less penetration but not on expense of interface adhesion between the clad layer and the substrate surface.

Cladding using Gas Metal Arc Welding (GMAW):

GMAW is very accepted method used in weld-cladding and it has got the following advantages:

- (1) High reliability,
- (2) All positions capability,
- (3) Easy to use,
- (4) Low cost,
- (5) Good productivity. (P. Seeraj, 2013)

In GMAW the mechanical properties of clad metal and dilution are influenced by many factors such as wire feed rate, voltage, welding speed...etc. (J.R. Davis, 1994). In this study these factors were studied to optimize the properties quality of the achieved work.

Experimental Procedure:

plates of low carbon steel cut to dimensions of (300*200*60 mm) were used in this study as a base metal to be clad. The plate surfaces were grinded in order to remove the oxide layer and any other dirties.

Table (2.1) Chemical composition of the base metal
using spectrometer analysis

element	Fe	C	Si	Mn	N
percentage	99.1	0.066	0.026	0.513	0.017

The welding machine used in this study is GMAW welding machine type Miller. The Filler materials used are stainless steel SS 309L and SS 308. The work was carried out in such way that the SS309 L layer first deposited and followed with SS 308 layer on top. The gas used was 100% argon. The depositing process was conducted by using the settings and parameters shown in table (2.2).

Table (2.2) welding parameters used to achieve best results according to visual inspection.

Sample	Voltage V	Feed Rate M/min	Amperage A
S 309L	27	3.5	165
	26	4	180
	29	4	210
S 308	27	4	185
	26	3.5	160
	29	4	210

The gas flow rate is 20 L/min, 100bar and the gas used is argon. And the relationship between the feed rate and amperage was formulated in this equation:

$$A = 60 * \text{feed rate} - 45$$

The welding process were carried put according to the manufacturer of the electrodes but the visual inspection showed that the range of parameters given was far away from achieving the acceptable results. Therefore the four parameters used in this study were the best of the parameters used according to the visual inspection. The visual inspection was based on the geometry of the weld and the distortion which takes place after using different parameters.

First, the four layers of SS309L were deposited on the low carbon steel substrate. The second layers of SS 308 were deposited using the same parameters on only two of the samples. This strategy applied in this study is meant to compare the results between the samples of two layers and the sample of one layer and

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weather the thicker thickness is necessary to ensure better results or the extra costs are not justified.

The use of filler metals 309L as first layer is to reduce the possibility of forming chrome carbide as 309L has tiny amount of carbon content furthermore SS 309L has high content of chromium about 23% which can compensate any depletion of chrome in the welding zone due to the dilution effect.

Two tests were carried out in this study:

1. Weight loss
2. Electrochemical test
3. Surface characterization.

The samples which used in all tests were undergone to the same preparation and grinded using silicon carbide papers graded 80, 120, 360, & 600. The solution used for both weight loss and electrochemical tests was 4.5 % NaCl. This solution represents the environment of sea water where the stainless steel finds many applications. In the weight loss measurement test, the immersion intervals are shown in table (2.3). The corrosion rate was calculated in millimeter per year units and the electrochemical test was conducted by Potentiostat device used in Petroleum Institution.

Table (2.3) Samples immersion intervals in 4.5% NaCl solution.

Sample	Exposure Time (hrs.)
SS 309L	72
SS 309L	145
SS 309L	265
SS 309L	365
SS 308	72
SS 308	145
SS 308	265
SS 308	365

Results:

Metallographic Characterization (Before Exposure)

A) SS 308 (Top Layer)

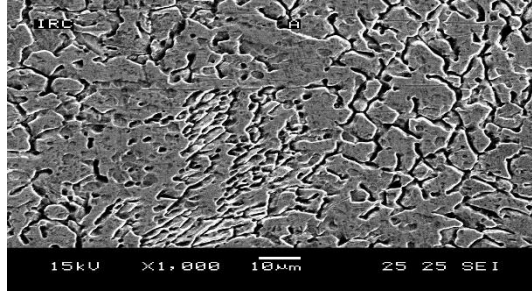


Fig. (3.1) Microstructure of SS 308 before Immersion using SEM.

B) SS 308 –SS 309 L

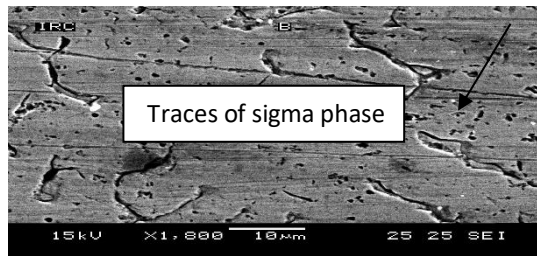


Fig (3.2) Microstructure of SS 308 – 309L interface Before immersion using SEM.

C) SS 309L

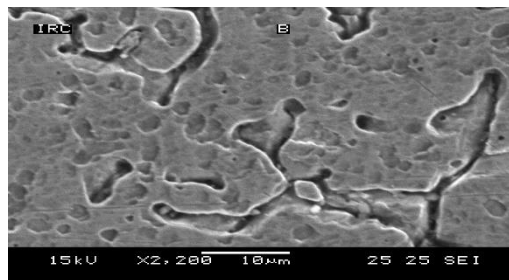


Fig (3.3) Microstructure of SS 309 before exposure

Corrosion Morphology (After exposure)

A) SS 308

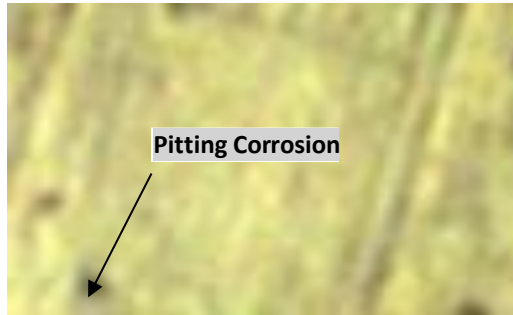


Fig (3.4) pitting corrosion after 265 hrs.in NaCl solution, (500X).

B) SS 309L

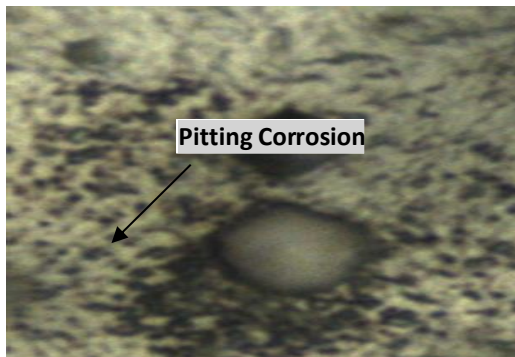


Fig. (3.5) SS 309L samples after 265 hrs. of Exposure in NaCl showing traces of pitting corrosion. 1000X.

Corrosion Test: Weight Loss

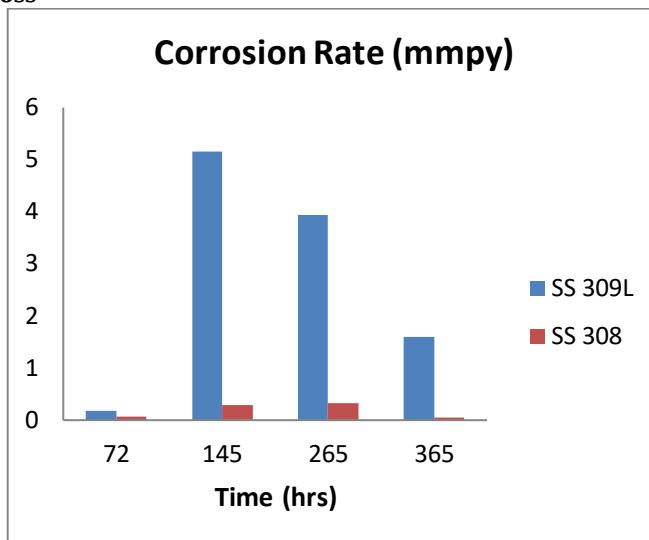
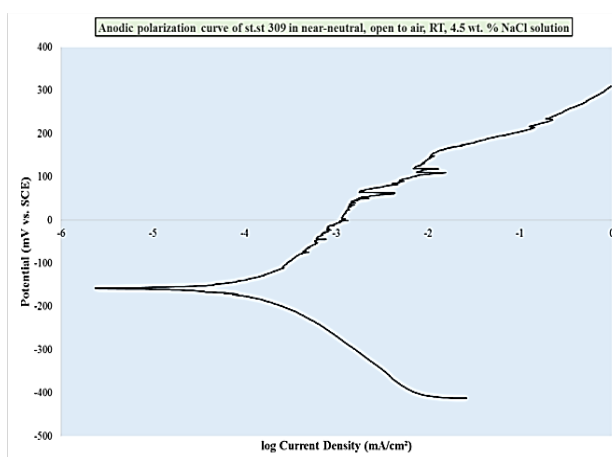


Fig. (3.6) Corrosion rates of SS 309L & SS 308 layers in 4.5% NaCl solution.

Electrochemical Test:

Fig. (3.7) Potentiodynamic polarization behavior of st.st 309L in near-neutral, open to air, RT, 4.5 wt. % NaCl solution.



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Fig. (3.8) Potentiodynamic polarization behavior of st.st 308 in near-neutral, open to air, RT, 4.5 wt. % NaCl solution.

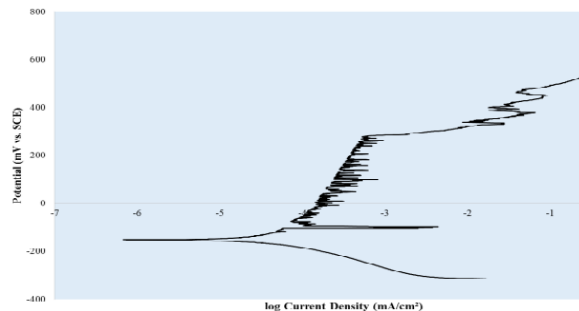
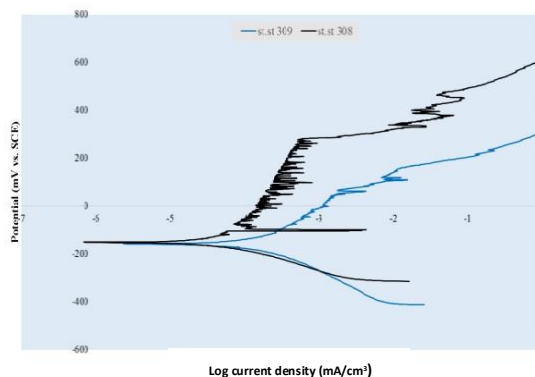


Table (3.1) corrosion potential and passivity range of Both SS 309L & SS308.

Parameter	Corrosion Potential (mV vs. SCE)	Breakdown Potential (mV vs. SCE)	Passivity Range (mV)
SS 309L	-159	271.68	176
SS 308	-151.35	570.5	374

Note: The breakdown potential is the applied voltage at which the anodic current density reached 0.5 mA/cm^2

Fig. (3.9) Comparison between the polarization behaviors of the 308 and 309 L stainless steels in near-neutral, open to air, RT, 4.5 wt. % NaCl solutions.



Discussion:

Metallographic Characterization:

Scanning Electron Microscope SEM in figures (3.1 & 3.3) showed the dendritic structure of deposited layers and it's a bit hard to tell a clear difference in all layers. Fig. 3.2 showed the formation of intermetallic compound at the interface between SS309L and the low carbon steel base metal. This intermetallic compound under the SEM looks like the sigma phase (44% Fe 29.2% Cr 8.3% Mo). Sigma phase normally forms in temperature 650~ 900°C during welding processes. Sigma phase is very brittle phase and decrease toughness of metals and can be represented in a gray region in Sheffler diagram as shown in fig (4.1). Welding heat and cooling rate should be considered and controlled to prevent the formation of sigma phase to avoid unexpected failure especially in application where the safety standards are very high such as space and airplane industry

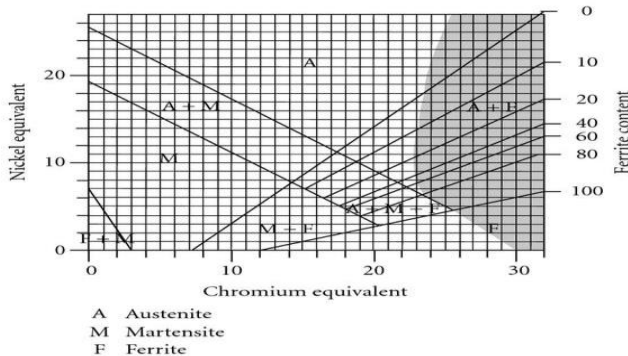


Fig (4.1) Sheffler diagram of stainless steel

Corrosion morphology:

Figures (3.4) and (3.5) showed the corrosion morphology of SS 308 and 309L samples immersed in 4.5% NaCl solution for 365 hrs. The SS308 layer showed insignificant traces of pitting corrosion while SS 309L showed many traces of pitting corrosion scattered on the surface of the sample. Fig. (3.6). And this another evidence to the effect of the dilution on the corrosion properties

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of the deposited layers as the thin layer of about 2mm is not enough to produce the same corrosion properties of pure SS 309 L alloy unless all the welding parameters are controlled with the cutting edge technology.

Corrosion:

Weight loss:

The weight loss shows that the corrosion rate of the first layer of SS 309L has higher corrosion rate than the top layer of SS 308. Although the SS 309L has higher chromium content but due to the dilution factor where the Iron from the base metal move up and mixed with SS 309L leading to increasing the iron content and decreasing the Cr and Ni amounts. The weight loss results will be viewed through the results of the electrochemical results as both tests results in agreement.

Electrochemical tests:

The potentiostat instrument setup was such that to take the open circuit potential (OCP) of both layers in one hour and started the measurement 150 mv more negative to polarise the samples anodically at a sweep rate of 0.001V/Sec. SS 309L showed more negative OCP than SS 308. When the applied potential to SS 309L alloy increased toward more positive value, the SS 309L alloy oxidation was dominant reaction till it reached (-151 mV). Above this potential, the cathodic reaction became the dominant reaction. When the applied voltage reached (-90 mV) the alloy showed partial passivity due to the formation of partial oxide film and the current density fluctuated and fell down into region ($3 \sim 10^{-3}$) amp/cm². The partial passivity range extended to 176 mV. At 271 mV the passive film broke down and more corrosion took place. SS 308 showed better behaviour as the passivity region started at lower potential and at lower current density and lasted longer till the sample pushed to a potential 570 mV where pitting corrosion took place. The lower corrosion properties of SS309L layer can be attributed to the dilution effect where the iron content

is increased on expense of chromium amount, while the top SS308 layer which basically has lower chromium content was less affected with dilution and had fewer changes in metallurgical properties. The electrochemical test is in agreement with the weight loss measurement particularly in this point.

Implication of the Study Results:

This study shows the engineers and auditors that the corrosion rate of both two clad layers lays in the accepted range of engineering applications criteria. This study also shows that using one layer with high content of alloying element such as SS 309L with thickness not less than 2mm will be enough to get a good product to be used in engineering application nevertheless commercial usage. Any way engineers and auditors should consider carrying out the microstructure tests to make sure the product is free from the brittle sigma phase especially where the clad product is subject to cyclic loads and the application demands high safety standards.

The dilution effect is highlighted in this study and it is clear that the thicker the clad layer the better corrosion resisting layer can be achieved.

Conclusion:

- Cautious should be taken when depositing thin layer less than 2mm as the dilution will affect the corrosion resistance properties of the deposited layer.
- Weight loss and electrochemical tests are in agreement that the dilution affects the corrosion resistance of stainless steel.
- Cladding low carbon steel with two stainless steel layers such that the less content alloy is at the top improves the corrosion properties of the product and decrease the cost of the product.
- More investigations regarding the formation of sigma phase in cladding stainless steel should be conducted to ensure no such harmful phases take place.

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تأثير التخفيف في مكونات طبقة الصهر على الخواص الكهروكيميائية لمعدني الصلب
الغير قابل للصدأ نوع SS 309L & 308

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المستخلص:

تأثير التخفيف في تركيز مكونات العناصر التسيكية على خصائص طبقة ترسيب الحديد الغير قابل للصدأ نوع (SS309L & SS308) كان موضوع الدراسة باستعمال تقنيات الفحص المجهرى واختبارات التآكل بنوعها الكهروكيميائية و معدلات التآكل باستخدام تقنية فاقد الوزن وذلك بوضع العينات في محلول ملحي 4.5%NaCl. اختبارات الفحص المجهرى أظهرت وجود تآكل نقري في طبقة الترسيب الأولى والمتكونة أساسا من معدن SS 309L وأثار لطور سيجما الهش في المنطقة الفاصلة بين طبقتي الترسيب SS309L & SS308. أما بالنسبة للطبقة SS 308 فنسبة التآكل النقري قليل جدا مقارنة بطبقة معدن SS 309L. اختبارات التآكل بنوعه كانت متوافقة الى حد كبير مع اختبار الفحص المجهرى حيث كانت معدلات التآكل أكبر في طبقة معدن SS309L منها في طبقة SS 308 وكذلك الحال في الاختبار الكهروكيميائي حيث كان جهد التآكل لطبقة SS 309L أكثر سالبية من طبقة SS 308. وكذلك بالنسبة لمدى الخمول للمعدن (Passivity Region) فقد كانت أصغر لطبقة معدن SS 309L من طبقة معدن SS 308. وهذا يؤكد على أن قابلية التآكل لطبقة SS 309L أكبر من قابلية التآكل لطبقة معدن SS 308. من نتائج هذه الإختبارات يتبين أن طبقة الترسيب لمعدن SS 309L والتي في التطبيقات العملية لها مقاومة تآكل أفضل من معدن SS 308 (تحتوي على اعلى نسبة Chromium) قد تضررت نتيجة لتأثير التخفيف والذي يفسر في هذه الدراسة بنسبة الحديد المساعد من معدن الأساس (الصلب منخفض نسبة الكربون) الى كل من طبقتي الترسيب SS 309L & 308.

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