Effects of Gas Metal Arc Welding Parameters on the Corrosion Behaviour of Austenitic Stainless Steel in Acidic Medium

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Abstract-In this work, the effects of gas metal arc welding parameters on the corrosion behaviour of type 304 austenitic stainless steel (ASS) immersed in hydrochloric acid medium (0.5M) at ambient temperatures were studied using design expert software, Scanning Electron Microscopy (SEM) and Monsanto Tensometer. The design expert was used to determine the surface responses and interactions between the parameters, SEM was used to examine the test specimen's microstructural analysis after immersion in the corrosive medium while the Monsanto Tensometer was used to examine the materials optimum performance in hydrochloric acid medium in terms of strength and it was found that tensile strength increased with increasing welding parameters (from 120MN/m^2 to 133MN/m^2). It was also found that increase in welding current and speed at constant voltage gave the optimum performance of the ASS structure in HCl medium obtained at speed 40mm/sec and current 110Amp. This shows a corresponding minimal material deterioration. Surface corrosion deposit composition was analyzed with the SEM paired with energy dispersive spectrometer (EDS). It was concluded that relatively high speed and current at a constant voltage gave a satisfactory weldment with good integrity.

Keywords-Welding, Current, Speed, Austenitic Stainless Steel, Hydrochloric Acid**.**

1 INTRODUCTION

Austenitic stainless steels (ASS) are good corrosion resistance alloy steels. These steels mainly find their use in aggressive environments. ASS, general-purpose steel, are widely used in the industry for applications related to corrosion-resistance. Corrosion resistance of these steels depends on various metallurgical variables [1].

Hence, the importance of (ASS) in industrial applications and development cannot be over-emphasized. Its excellent properties which range from high tensile strength, good impact resistance, corrosion and wear resistances have found various applications in many engineering industries today. In addition, ASS sheets have gained wide acceptance in the fabrication of components, which require high temperature resistance and corrosion resistance such as metal bellows used in expansion joints in aircraft, aerospace and petroleum industries to mention but few. However, many research findings have proved that improper techniques employed in welding austenitic stainless steels may lead to serious consequences of the structures. Failures as a result of poor corrosion resistance have also found their places in annals of times, from household equipment to industrial structures [2-5].

Afolabi, [6] investigated the effect of electric arc welding (shielded metal arc welding) parameters (power input, weld geometry, welding speed, and post-weld heat treatment) on the corrosion behaviour of austenitic stainless steel in chloride medium. The results also show that the best electrode for welding stainless steel is a stainless steel-core electrode. Also, Iliyasu, et al [7] investigated the susceptibility and resistance of type 304 austenitic stainless steel exposed to sulphuric acids (0.3M to 1M concentration) at ambient temperatures and at higher temperatures. The susceptibility of type 304 austenitic stainless steel to stress corrosion cracking in the corrosive media and its high corrosion of below 0.1mm/yr was also observed.

The aim of this research is to investigate the effects of Gas metal arc welding parameters on the corrosion behavior of austenitic stainless steel immersed in 0.5M HCl medium using Design-Expert 6.0.6 software to determine the responses and interactions between parameters and also to examine optimum performance in terms of strength, of the sample in HCl acid using the tensile test machine.

2 MATERIALS AND METHOD

2.1 Materials/Equipment

Austenitic stainless steel was used for this research work which was sourced locally at Kakuri Market in Kaduna, Nigeria and its chemical composition was analyzed. Other materials that were used are: stainless steel electrode wire of 0.9mm, acetone, distilled water and paper grit of 120, 340, and 400 and the selected (HCl) medium. The equipment used during the course of this analysis were; Gas Metal Arc Welding machine, Digital Weighing Balance, Grinding Machine, Milling Machine, and scanning Electron Microscope.

2.2 Experimental Procedure

In this analysis, gas metal arc welding was used. A 50mm x 15mm x 3mm dimension of ASS sample was cut to produce a plain face sample for butt wedding, leaving a root opening of 2mm. The butt welding method was implemented as shown in the sample preparation in figure 1. A single pass was used in welding each of the specimen. Both welded and unwelded specimens were cleaned of dirt and oil using paper grit (120, 340, and 400) and acetone according to ASTM.

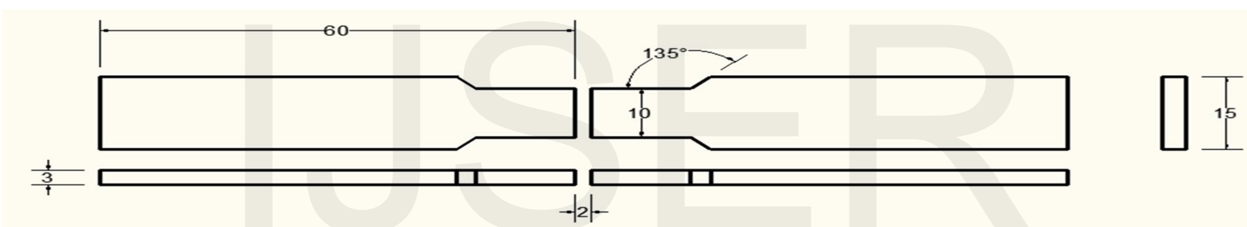


Figure 1: Standard Joint Preparations for plain face sample for welding

2.3. Factorial Design of Experiment for the Welding Parameters

Three factors which are important variables in welding of metals were selected to study the corrosion behaviour of ASS in HCl medium. The variables are; Speed (S), Current (I) and constant Voltage (E) which are represented as A, B and C respectively. The interactions between these factors were studied and optimization was done using three dimensional plots and cube plots according to Okibe [8]. Design Expert software 6.0.6 was used to generate the experimental runs and for the statistical analysis of weight loss in milligram of the ASS in the HCl in an interval of eight days for forty (40) days as shown in figure 2 and figure 3.

Table 1: Design matrix for the welding parameters of ASS in HCl medium

Std	Run	A: Speed (cm/min)	B: Current (Amp)	C:Voltage (volts)
1	1	20	90	230
3	2	20	110	230
5	3	30	100	230
4	4	40	110	230
2	5	40	90	230
6	6	30	100	230

2.4 Weight Loss Measurement

The initially weighed samples were immersed in $1dm^3$ of volumetric flask containing solution of 20.89 $cm^3$of HCl as prepared in accordance with Yawas, [9] for 40 days. The test specimens were taken out of the corrosive medium after every 8 days, wash with distilled water and acetone, air dried and re-weighed. The weight loss of the austenitic stainless steel samples were assessed using the digital weight balance machine of sensitivity of 0.0001g at the end of these intervals for 40 days.

2.5 Tensile Test

The samples were subjected to tensile tests in accordance with ASTM E8 Standard Method. These tests were carried out using the Monsanto Tensometer, Type "W" with a capacity of 20kN. Here, the ASS of 3mm thickness was cut into 120mm and a width of 15mm from a flat bar and was machined on a milling machine into a standardized shape of the sample with a central reduced section for tensile test.

2.6 Scanning Electron Microscope

The welded and the unwelded austenitic stainless steels were viewed using Phenom ProX scanning electron microscope (SEM) with a magnification of 5000x. The samples for investigation were prepared in accordance with the specifications of the machine.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition of Research Material

The X-ray florescence (XRF) test was used. Table 2 below shows the results.

Table 2: Chemical Composition (wt %) of ASS sample

Composition	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Co	Fe
ASS	0.122	0.540	1.360	0.030	0.019	20.120	8.340	0.188	0.257	0.106	Bal

The result in table 2 shows that the material is an austenitic stainless steel type 304. This is due to the high percentages of chromium (Cr) 20.12% and nickel (Ni) 8.34% as major alloying elements in the base material iron (Fe) 68.7%, low percentages of Carbon (C) 0.12% and other elements in accordance with the AISI standard grade.

3.1.2 Results of factorial design

Table 3: Design matrix and responses of welding parameters of ASS in HCl environment

Std	Run	A: Speed (cm/min)	B: Current (Amp)	C: Voltage (volts)	WL_8 (mg)	WL_{16} (mg)	WL_{24} (mg)	WL_{32} (mg)	WL_{40} (mg)
1	1	20	90	230	0.0608	0.0699	0.0795	0.1103	0.1073
3	2	20	110	230	0.0708	0.0767	0.1047	0.1309	0.1880
5	3	30	100	230	0.0485	0.0752	0.0901	0.1005	0.0971
4	4	40	110	230	0.0470	0.0546	0.0970	0.0974	0.0759
2	5	40	90	230	0.0631	0.0988	0.1356	0.2151	0.3498
6	6	30	100	230	0.0480	0.0786	0.1412	0.1016	0.1181

Table.4: ANOVA for the factorial model for speed and current at a constant voltage for HCl environment.

Source	Sum of Squares	DF	Mean Square	F Value	Prob>F	Remark
Model	$1.011X10^{-3}$	3	$3.372X10^{-4}$	63.66	0.0155	Significant
A	$1.156X10^{-5}$	1	$1.156X10^{-5}$	2.18	0.2776	Not Significant
B	$3.497X10^{-4}$	1	$3.497X10^{-4}$	66.02	0.0148	Significant
AB	$6.502X10^{-4}$	1	$6.502X10^{-4}$	122.77	0.0080	Significant
Residual	$1.059 X10^{-5}$	2	$5.297X10^{-6}$			
Lack of Fit	$4.813X10^{-6}$	1	$4.813X10^{-6}$	0.83	0.5291	Not Significant
Pure Error	$5.780X10^{-6}$	1	$5.780X10^{-6}$			
Cor. Total	$1.022X10^{-3}$	5				

Presented in table 3 is the variation of the selected welding parameters (factors) affecting the behaviour of ASS in 0.5M concentration of HCl medium and the corresponding weight loss in milligrams obtained after each experimental run was performed on the welded ASS immersed for 40 days in an interval of 8 days. The results show that experimental run four (4) gave the least weight loss values for eight (8) days and forty (40) days as 0.0470mg and 0.0759mg respectively at a welding speed of 40cm/min, welding current of 110 Amperes at a constant voltage of 230 volts. This implies that experimental run four (4) gave the least average weight loss value. This further shows that in a corrosive HCl medium, ASS is susceptible to corrosion. While experimental run five (5) and two (2) gave the highest average weight loss values. This implies that at low current and low speed, poor weldment was achieved.

The analysis of variance (ANOVA) values are presented in table 4. From the results of the ANOVA, model F-value of 63.66 implies that the model is significant. There is only 1.55% chance that a "Model F-Value" could occur due to error terms. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B, AB are significant model terms while A is not significant. The “Curvature F-value” of 63.66 implies that there is significant curvature in the design space.

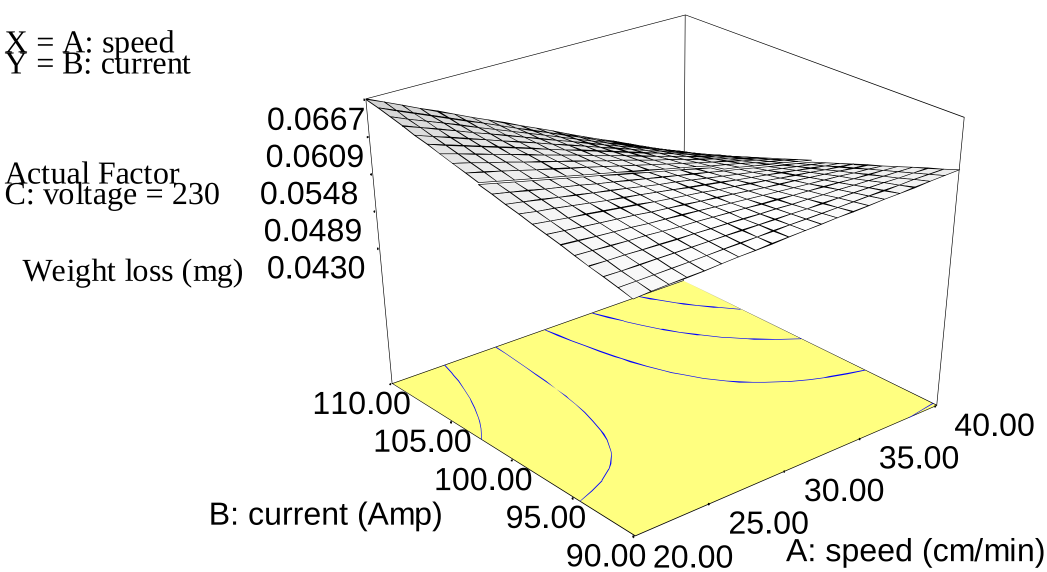


Figure 2: Response surface plot for ASS immersed in HCl for 8 days and the interaction between speed and current at constant voltage.

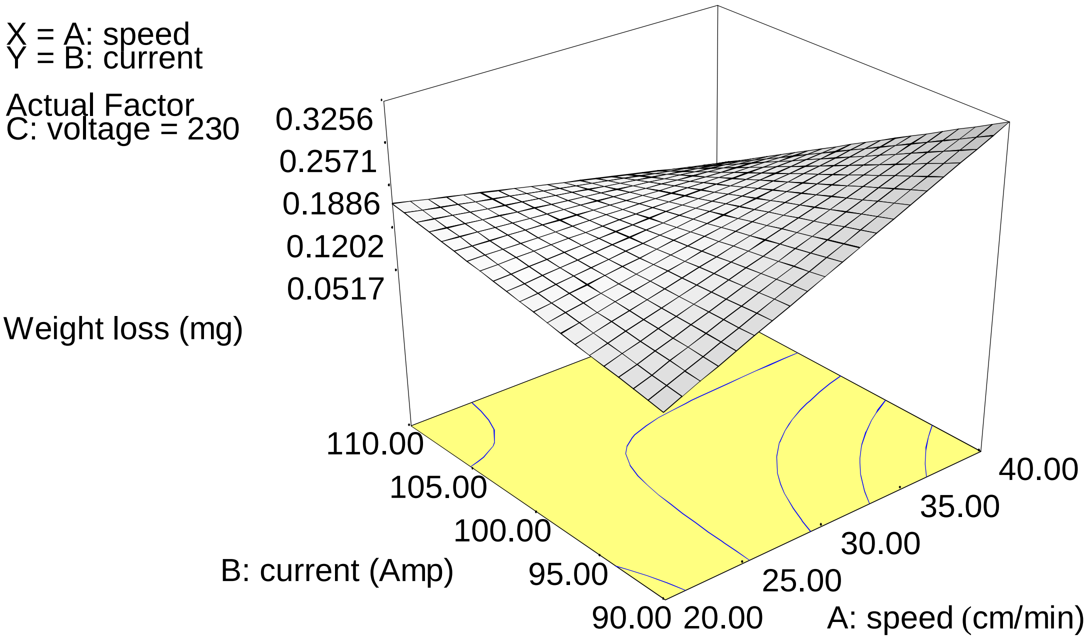


Figure 3: Response surface plot for ASS immersed in HCl for 40 days and the interaction between speed and current at constant voltage.

` Figures 2 and 3 are the response surface plots to show the interactions between the speed and current at constant voltage on the ASS immersed in 0.5M concentration of hydrochloric acid for eight (8) days and forty (40) days. From the results obtained, the interactions of these two variables on the ASS were clearly shown. Increase in welding current and welding speed at constant voltage gave the optimum performance of the ASS in this environment since the materials' deterioration was minimal (that is, at speed of 40cm/min and current of 110Amp).

This established the fact that, the best welding parameters' values to obtaining an optimum performance of an ASS occurs when the current and the speed were relatively high. The least weight loss values for eight (8) days and forty (40) days were 0.0430mg and 0.0517mg at a welding speed of 40cm/min and welding current of 110 Amperes at a constant voltage of 230 volts as shown in figure 2 and 3 respectively. While the highest weight loss value for eight (8) days and forty (40) days were 0.0667mg and 0.3256mg respectively this shows a significant difference in the deterioration of the material.

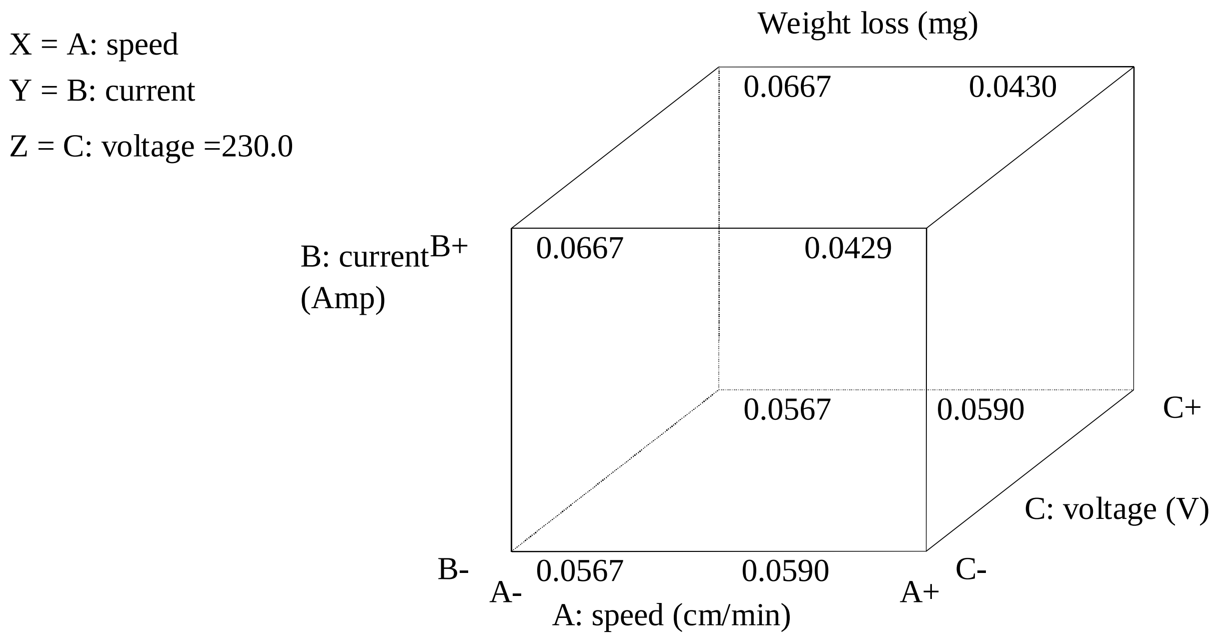


Figure 4: Cube plot for weight loss of ASS in HCl for 8 days and interaction between speed, current and voltage.

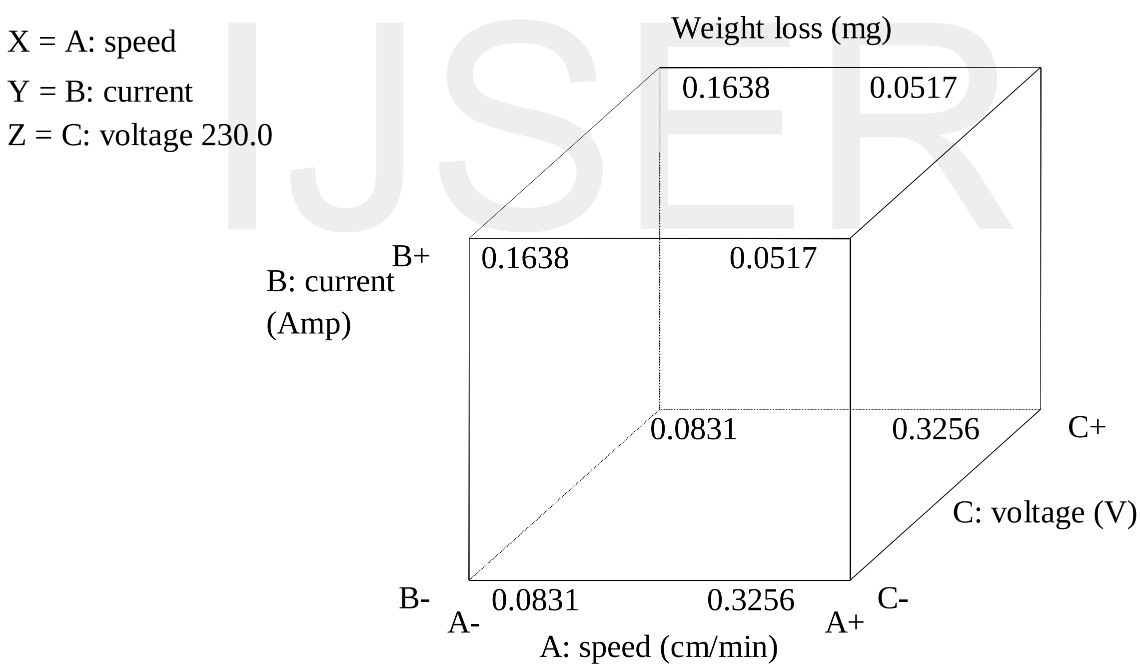


Figure 5: Cube plot for weight loss of ASS in HCl for 40 days and the interaction between speed, current and voltage.

From figures 4 and 5, the results show that at constant voltage of 230V, a varied speed from 20cm/min to 40cm/min and a varied current from 90Amp to 110Amp, weight losses for eight (8) days and forty (40) days were obtained as follows; For eight (8) days, these values were obtained; 5.90% (C+, B-, A+), 4.29% (C+, B+, A+), 5.67% (C+, B-, A-) and 6.67% (C+, B+, A-) while for forty (40) days, we have 32.56% (C+, B-, A+), 5.17% (C+, B+, A+), 8.31% (C+, B-, A-)

and 16.38% (C+, B+, A-). It was observed from the analysis that corrosion susceptibility of ASS is more pronounced at 40 days immersion than in 8 days as seen in the percentage corrosion of the metal.

3.1.3 Morphology of the samples

The micrographs of the samples, as taken by scanning electron microscope, are presented in figure 6 to 8

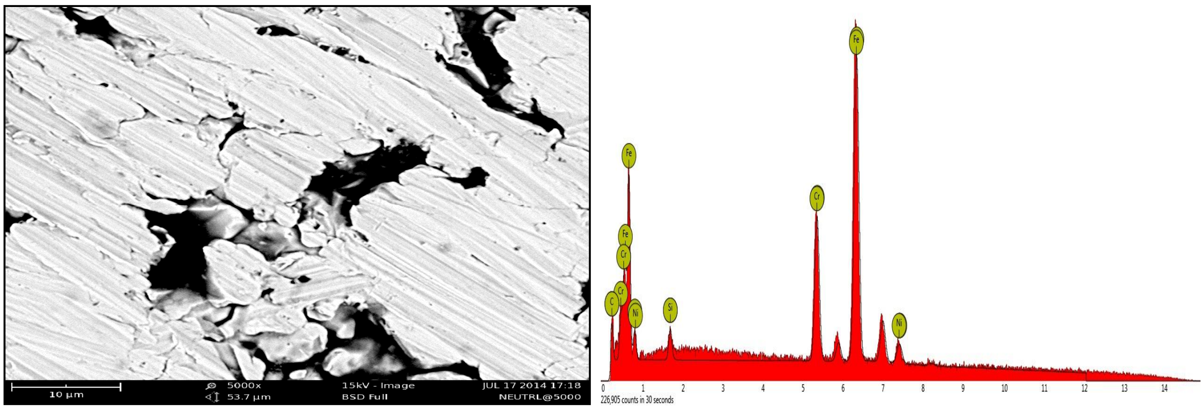


Figure 6: Micrograph of the control sample (as received) with EDS profile.

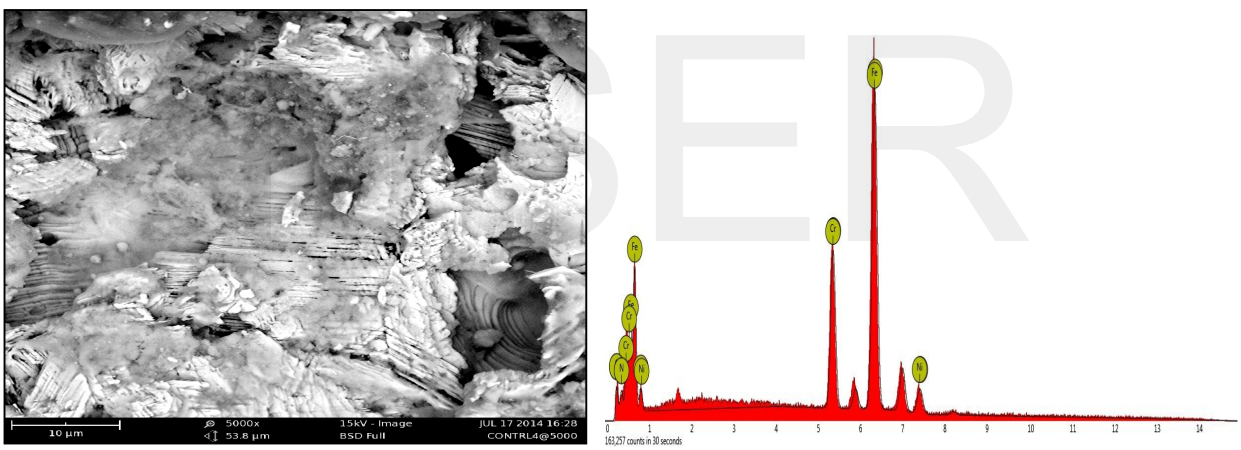


Figure 7: Micrograph of the control sample immersed in HCl for 40 days with EDS profile.

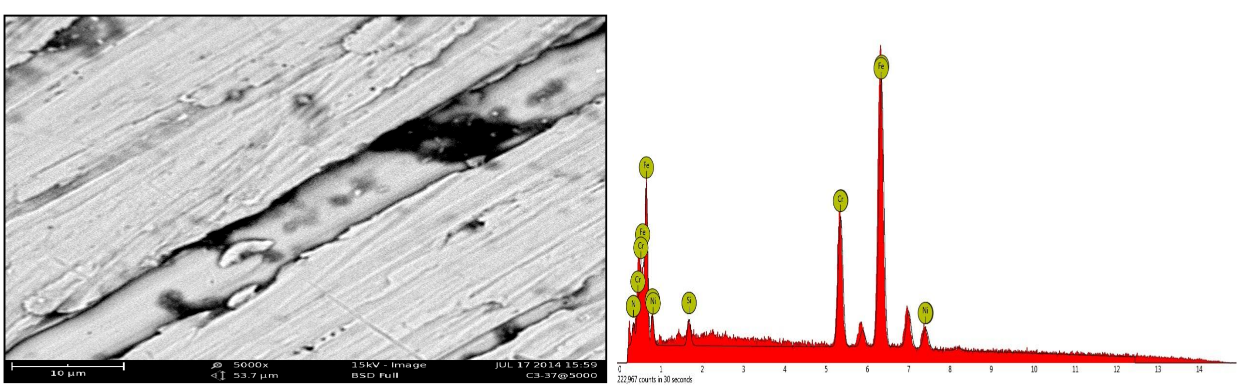
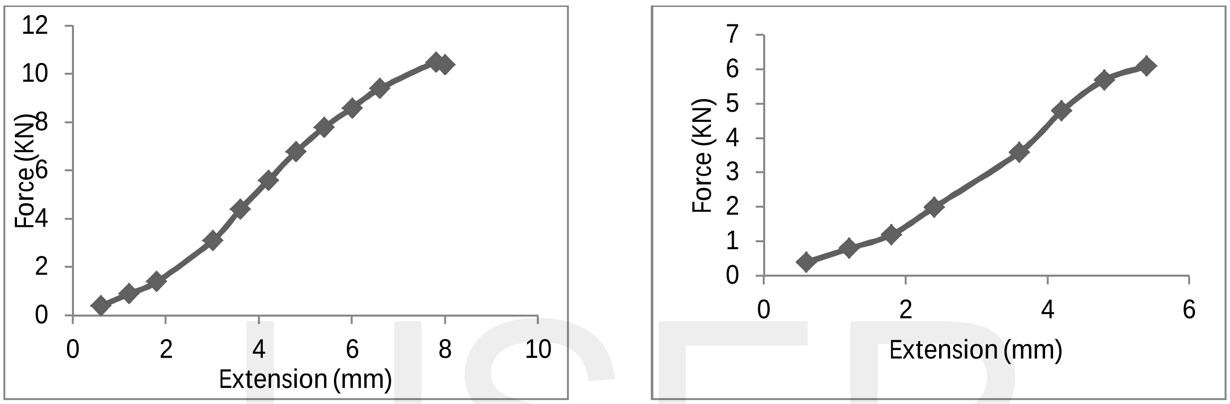


Figure 8: Micrograph of HAZ and FZ of sample C_3 welded and immersed in HCl for 8 days with EDS profile.

Figures 6 to 8 show the SEM micrographs of the samples of 5000x magnification with their respective EDS profiles indicating iron to have the highest percentage as the base metal followed by chromium as the highest alloy element. Figure 6 shows the SEM micrograph of as received sample of ASS. It is observed here that the microstructure clearly shows a fine grain boundary and is an indication of a better blending of parent material and the alloying elements. Also, Figure 7 shows the SEM micrographs of unwelded ASS sample immersed in 0.5M of HCl for 40 days showing signs of dissolution of metallic structure and grain boundaries due to the aggressiveness of chloride ion (Cl^-) in the medium. Figure 8 shows the SEM micrograph of the heat affected zone and the fusion zone of ASS welded sample C_3 in 0.5M of HCl for 8 days. This micrograph shows a better weldment with the presence of pitting corrosion effect (dark area) along the grain boundaries of the parent metal. This actually supports the corrosion susceptibility of ASS in hydrochloric acid medium as posited by Claus, [10].

3.1.4 Tensile properties of the samples



(a) (b)

Figure 9: Load-Extension of tensile test on welded ASS ($C_1$and C_4) in HCl for 8 days and 40 days respectively

Figure 9 (a) and (b) show the variation of load against extension of the tensile test of the weld joint of the ASS. It can be observed generally that with a gradual increase in load, there is a corresponding increase in extension of the specimen, that is the extension produced is directly proportional to the load, this continues until the maximum load is reached. At this point of maximum load, a neck is formed. The reduced area was not able to sustain the load being applied, hence the specimen finally fractured at this new point which is called the breaking load point. The results obtained from the tensile test of the welded austenitic stainless steel are in agreement with those obtained by Grassel, et al [11]. This show that the tensile strength increases as the grain size decreases and also tensile strength depends on the integrity of welded joint.

4 CONCLUSIONS

The conclusions drawn from the study were;

(i) Corrosion susceptibility of ASS in HCl medium during the exposure time period studied could be attributed to the aggressive chloride ion which continuously breaks down the protective film on this metal.

(ii) The interaction effect of speed and current at constant voltage on ASS immersed in HCl medium was evaluated using factorial design of experiments which is not possible with the conventional univariate technique that is time-consuming, requiring a large number of experimental runs and is expensive.

(iii) Based on the work done, the tensile test shows that welding has a negative effect on the mechanical properties of this alloy.

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