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The Effect of Welding Process on Mechanical Properties and Pitting Corrosion Resistance of Aisi 316l Austenitic Stainless Steel Welds

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***Abstract:** The effect of welding process on mechanical properties and pitting corrosion resistance of AISI 316L austenitic stainless steel welds has been investigated using gas tungsten arc welding technique. The influence of the gas tungsten arc welding process on the toughness via the Charpy test, the hardness using Brinell hardness test, the tensile strength with the aid of a Universal tensile test machine and the pitting corrosion resistance by weight loss method were carried out on austenitic stainless steel 316L respectively. The welding process being a relatively high temperature process resulted in phase transformation in the weld and transition zone. Thereby culminating in observable differences in mechanical properties and pitting corrosion resistance between the parent material, transition zone and the weld. Higher concentration of austenite phase accounted for better mechanical properties in the transition zone and weldment. The weldment and HAZ being areas with lesser amount of Chromium and Molybdenum are the most probable for the initiation of corrosion pits and hence lesser pitting corrosion resistance compared to the parent material.*

***Keywords:** Austenitic Stainless Steel, Gas Tungsten Arc Welding, Pitting Corrosion, Mechanical Properties.*

1. INTRODUCTION

Engineering materials that are selected for specific uses are designed to perform satisfactorily against corrosion and in the aspect of strength throughout their designed life, which are criteria for high performance and reliability [1]. Austenitic steels contain Chromium, Nickel

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and low Carbon; are mainly austenitic at all temperatures and may contain some delta-ferrite [2]. The Austenitics make up the biggest share of stainless steels production because of their high corrosion resistance, retained strength at high temperatures, stability at very low temperatures and weldability [3], [4], [5], [6], [7], [8]. Austenitic stainless steel is widely used in the petroleum industry because of its excellent corrosion resistance and high strength [9], [10].

The industrial use of any steel depends heavily on the ease of its welding for fabrication [11]. Concerns have arisen over welds of austenitic stainless steels due to weld decay and its deleterious effects they might have on their mechanical properties and resistance to corrosion [12]. In the process of welding, parts of the transition zone are heated in the range in .which $Cr_{23}C_6$ precipitates at the austenite grain boundaries; thereby locally depleting chromium, such that the chromium-depleted zone is preferentially corroded; otherwise called weld decay [13]. This often happens due the heat supply is too much or the inter-pass temperature is too great. [14], [15].

Austenitic steel weldment usually has a tree-like and heterogeneous microstructure, containing a little amount of delta-ferrite, sigma, $M_{23}C_6$ carbides, and substantial segregation of the main alloying elements at the phase interfaces [13]. In order to prevent micro fissures and hot cracking of welded components of austenitic steels, a ferrite number (FN) of not above 10 is the requirement for delta-ferrite formation [16].

The formation of pits in austenitic steels in industries; and its progression is suppressed by chromium reacting preferentially to iron by the formation of a passive film [17], [18]. The breaking down of protective passive film naturally formed on the surface of stainless steels by halide ions resulting in the initiation of pits which serve as sites for cracks to initiate and propagate, thus shortening the lifespan of stainless steel components during service [19].

GTAW (gas tungsten arc welding) or tungsten inert gas (TIG) welding as it is otherwise termed, which is a fusion welding process, utilises helium or argon for the protection of the transition zone from the atmospheric conditions, whereby an electric arc between a non-consumable tungsten electrode and the metal produces welding heat; and a filler material is also used if needed [20]. A particular steel grade will not be utilised widely used except it is easily weldable, and austenitic steels meet this requirement [1]. However, austenitic stainless steels as with other grades of stainless steels are prone to severe localised corrosion such as crevice in addition to pitting under service conditions impacts negatively on the mechanical properties of the steels, thereby resulting in the ultimately in the failure of the materials to perform optimally [21], [22], [23], [24], [25]. Welding being a high temperature process invariably affects the constitution of steel especially in the heat affected zone (HAZ) and fusion zone (FZ) with its likely implications on the mechanical properties and corrosion behaviour of steel. Hence, this present study seeks to investigate how the GTAW welding process affects the pitting corrosion resistance and mechanical properties of austenitic stainless steels.

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2. EXPERIMENTAL METHOD

2.1 Materials and Samples Preparation

The metal employed for this study was 316L austenitic steel obtained from a local steel vendor. The elemental chemical composition as supplied by the manufacturer is as shown in Table 1.

The tensile samples were prepared for tensile test in the longitudinal (rolling) direction. Rectangular test samples, as specified by ASTM for the as- received as well as for the as – welded samples respectively. The measurements of the prepared samples were 180 mm in full length, 80 mm in gauge section length and 15 mm in width [26].

Samples were prepared for hardness test. Rectangular test samples, each of 30 mm and length 10 mm as specified by ASTM International, ASTM E10-18 standard.

Impact strength test samples were then prepared. Rectangular test samples, each of 10 × 10 × 55 mm as specified by ASTM International, ASTM E23 standard.

The environment, a solution of iron (III) chloride ($FeCI_3.6H_2O$), was prepared using analytical grade $FeCI_3.6H_2O$.

2.2 Methods

2.2.1 Welding Process Procedure

Standard welding process procedures according to ASTM G48-76 were adopted to weld the 316L austenitic steel using GTAW utilising ER316L filler whose composition is as shown in Table 2.

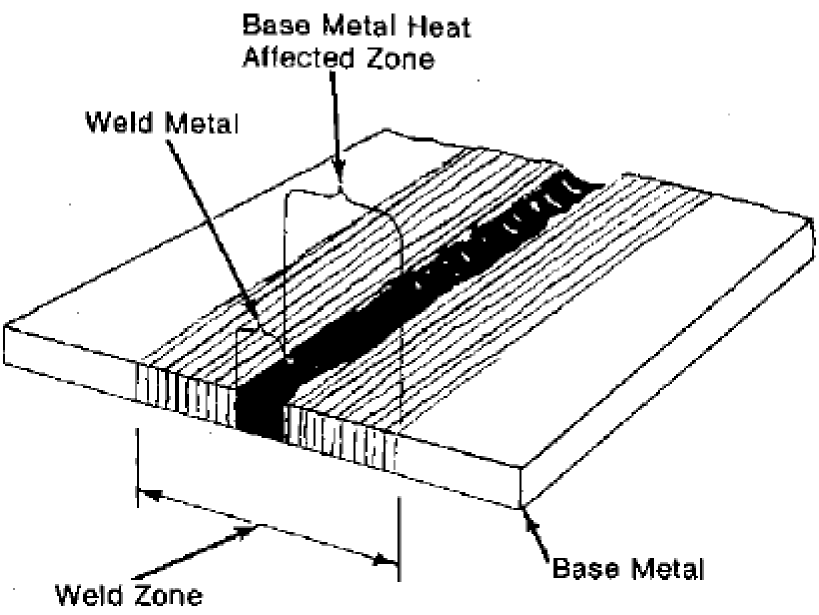

Figure 1: Heat affected zone of metal resulting from welding

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2.2.2 Evaluation of Mechanical Properties

The Mechanical properties of the as-welded including the base metal samples were evaluated employing established methods respectively. After the samples had been subjected to welding processes respectively, the evaluation of the tensile, impact and hardness tests were carried out on the samples to determine their mechanical properties and compare them with those of the base metal samples which were also subjected to the same tensile, impact and hardness tests.

Figure 2: GTAW welded section of AISI 316L Austenitic stainless steel sample

2.2.2.1 Tensile Test

The austenitic steel samples were cut to length with the use of a cutting machine. The tensile samples were tested using the UTM. Prior to samples being subjected to tension, the original gauge length and diameter were measured. The two parts of each of the fractured samples were fitted and the new gauge length together with the smallest diameter of the sample's neck had been measured. Results got from this testing were recorded as displayed in Table 4.

Figure 3: Tensile Samples

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2.2.2.2 Hardness Test

For hardness testing, the mean Brinell hardness number values were obtained by using several measurements, with the hardness test machine applying a load of 1500 kg. The indenter was brought in contact with the samples for a dwell time of 15 seconds. Results from these tests are displayed in Table 5.

Figure 4: Hardness Samples

2.2.2.3 Impact Test

For impact testing, a Charpy V- notch test sample of austenitic stainless steel was laid on parallel jaws in the impact testing machine with the dial of the machine set up to its highest reading of 300 J. The hammer from its set height, let free on a downward motion towards the sample. Results obtained from this test were recorded and tabulated as shown in Table 6.

Figure 5: Impact Test Samples

2.4 Pitting Corrosion Test

Commercially available AISI 316L stainless steel plate samples of 10 mm thickness, with nominal composition given in Table 1, were used for the pitting corrosion test.

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ASTM G48-A standard procedures where employed in the determination of the pitting corrosion of the steel samples [27]. The average loss of mass per unit area was 0.0040 gcm^{-2} for the weld and 0.0036 gcm^{-2} for the base metal respectively were observed.

2.5 Test Procedure

From the samples used, each sample of 172 mm length was machined into tensile test sample according to ASTM E8-06 standard, samples, each of diameter 30 mm and length 10 mm were machined into hardness samples according to ASTM E10-17 standard, samples each of 10 × 10 × 150 mm were machined into impact test samples according to ASTM E2248-15 standard and the remaining samples were prepared for pitting corrosion test according to ASTM G48 E. Tensile, impact and hardness tests for the base samples were also carried out. The various tests were carried out in duplicates.

3. RESULTS AND DISCUSSION

Table 1: Elemental composition by percentage weight of AISI 316L steel

Element	Cr	Ni	Mn	S	Mo	C	Si	N	P	Fe
316L	18.000	14.000	2.000	0.030	2.500	0.030	1.000	0.10	0.045	Bal

Table 2: Elemental composition by percentage weight of electrode ER316 steel

Electrode	C	Cu	Mn	P	Si	S
ER316L	0.080	0.180	1.530	0.009	0.880	0.010

Table 3: Welding process parameters

Passes	Welding current [A]	Welding voltage [V]	Flow rate [L/min.]	Filler wire diameter [mm]
Root run	95	25	2.25	3.2
Hot pass	105	27	4.75	3.2
Fillet pass – multiple run	90	24	8.00	3.2

Table 4: Tensile properties of 316L austenitic stainless steel GTAW welds

Sample	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	% Elongation	Fracture Location
Parent Metal	175	564	48	centre
Gtaw Metal	223	598	52	Weld

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Table 5: Brinell Hardness (BHN) Values of 316L austenitic steel parent metal and GTAW weld metal

Sample	**Parent Metal**	**GTAW Metal**	**HAZ**
BHN	214	220	217

Table 6: Charpy V – notch Test Values at 25°C of 316L Austenitic Steel

Sample	**Parent Metal**	**GTAW Weld**	**HAZ**
Energy (J)	240	157	235

3.2 Discussion

3.2.1 Effect of Welding Process on Pitting Corrosion

The opposition to crevice and pitting corrosion is important in chloride environments, like salt water, in which the Pitting Resistance Equivalent Number, calculated using amount of chromium, molybdenum, tungsten and nitrogen, is used to predict the susceptibility of austenitic steel to pitting and crevice corrosion; and which is often marginally lesser in the welds than in the base material [2]. Obtaining the proper austenite/ferrite fraction in the process of welding is important by regulating the amount heat energy supply to the weld; so that evolution of detrimental phases is prevented. The rate of welding heat, the inter-run temperature, and the dimensions of the weldment, determine the cooling rate of a weld joint after welding; because excessive cooling rate leads to an increase in the delta ferrite content in the weld which decreases toughness and supports nitride precipitation. Consequent upon this, resistance to corrosion of the weld will be decreased. Similarly, too low cooling rates also cause the same problems, could likely lead to the production of brittle phases which may also detrimentally affect corrosion resistance. The choice of shielding gas and filler utilised in the protection the weld's root has a substantial impact on the amount of nitrogen in the weldment, as a deficient amount of N might decrease the weld's corrosion resistance, especially for GTAW. Acceptable pitting corrosion resistance is often achievable with fillers having equal proportions of Chromium, Molybdenum and Nitrogen as the base material [2] The weld face and HAZ regions are the most probable areas for the initiation of pits (areas with smaller amount of Chromium and Molybdenum) depending on the welding parameters. The highest value of corrosion resistance in the austenite (γ) phase is linked to the quantity of heat supplied during welding, possibly resulting from the presence of nickel which raises the pitting corrosion resistance, impact strength and stabilisation of the austenite phase. It has been suggested that austenite phase undergoes lower pitting compared with ferrite phase, and this was attributed to the amount of nickel in the austenite phase, which provides higher corrosion protection [27].

The mass loss due to pitting corrosion of the 316L steel weldment was 0.0040 g/ cm^2, compared to the parent metal mass of 0.0036 g/ cm^2. This slight difference in mass loss was probably due to the presence of comparatively more active sites of γ and δ interfaces in GTAW weld as opposed to that of the parent metal. Thus, lowered resistance to pitting was detected for GTAW weld and is credited to rise in galvanic interactivity amongst delta ferrite and austenite phases.

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3.2.2 Effect of Welding on the Mechanical Properties

Conventional GTAW welds of AISI 316L austenitic stainless steel produces comparatively higher tensile strength and yield strength compared to the parent metal, most likely with filler metal fortified with Ni, thereby improving the strength in the welds. Greater hardness actuated by welding could probably explain the observed higher strength in the ASS welds too. The application of welding on the AISI 316L steel produced high value of hardness in the HAZ, likely as a result of the higher concentration of γ -phase.

The impact strength tests of the welds were conducted on the heat affected zone, and on the base metal at temperature of 25^{o}C. The maximum value of Charpy V-notch impact strength was measured for the base metal at 240 J. The HAZ exhibited marginally lesser impact strength value of 235 J. The lowest impact strength value of 157 J was displayed by the weld. The findings of the study into the toughness of welds are compatible with previous studies [8], [27].

An excessive grain growth does not occur in the HAZ of the weldment in the course of welding, as a result of lesser amounts of welding energy input to the weld; thereby resulting in elevated levels of percentage elongation being sustained as indicated by tensile strength tests results. The existence of the secondary austenite structure γ_2 in the welds was harmful to the ductility and specifically to toughness. In the welds, the existence of the secondary austenite is majorly connected with the weld face zone. The heat affected zone and base metal exhibited appreciable impact strength at ambient temperature. Moreover, the impact strength at the weld face reduced substantially, in spite of the formation of austenite phase, as a result of ferrite grains coalescing into the formation of delta-ferrite phase.

4. CONCLUSIONS

This study was carried out to study the impact of welding on mechanical properties and pitting corrosion resistance of AISI 316L (UNS 31603) austenitic stainless steel welds. Samples of the steel were subjected to machining and welding processes; and exposure to corrosive medium. Then the steel samples were further subjected to Charpy V- notch impact test, tensile strength test, Brinell hardness test and pitting corrosion test respectively. At the end of the study, the findings indicate a 2.80% rise in hardness for the weld face over the parent metal; and 6.03% increase in the tensile strength for the weld over the base metal; 34.58% decrease in impact strength for the weld over the base metal; and 11.11% decrease in pitting corrosion resistance for the weld as compared to the base material.

1. The highest value of impact strength was obtained for the base material. The transition zone exhibited slightly lower impact strength while the lowest impact strength was displayed by the weld.
2. The GTAW weld had higher tensile strength and yield strength compared to the parent metal.
3. The weld's resistance to pitting corrosion was comparable but marginally lower than that of the parent metal.

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