

## Studies on Effects of SMAW Variables on Corrosion Resistance of Austenitic Alloy Welded Joints in Hydrochloric Acid (HCl) Medium

A. U. Iwuoha<sup>1</sup> and I. A. Ezenugu<sup>2</sup>

<sup>1</sup>Department of Mechanical Engineering

<sup>2</sup>Department of Electrical and Electronic Engineering

<sup>1&2</sup>Imo State University, Owerri, Nigeria.

E-mail: [nmatoha@yahoo.com](mailto:nmatoha@yahoo.com)

**ABSTRACT:** This paper studied the effects of Shielded Metal Arc Welding (SMAW) variables (welding current, welding speed, electrode diameter and electrode coating type) on corrosion behaviour of austenitic alloy (stainless steel [SS]) welded joints in hydrochloric acid medium. A grade of AISI 300 series SS specimens in the cast state were welded with different welding variables and the specimens subjected to corrosion studies in electrolyte of 1 molar solution of hydrochloric acid (HCl) freely ventilated at 30°C. The study adopted electrode potential (critical corrosion potential) measurements with zinc rod reference electrode as the index. The zinc rod potentials were converted to Saturated Calomel Electrode (SCE) potential values. The critical corrosion potential dropped as the electrode diameter increased. One possibility for this is that the “extended” welding time brought about by large diameter electrodes created convenient window for microstructural change and sensitization of base metal Heat Affected Zone (HAZ); in this state, weld decay cannot be ruled out. The reducing reactions caused by release of hydrogen in rutile coated electrodes compromised the metallurgical homogeneity of the weld with respect to the base metal; this lowered the critical corrosion potential of welded joints produced with this type of electrode. Higher welding current matched with workpiece thickness and geometry produced joints that were more resistant to corrosion in HCl medium.

**Keywords:** Austenitic alloy, SMAW Variables (welding current, welding speed, electrode diameter, electrode coating), Corrosion Resistance, Hydrochloric acid (HCl).

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## INTRODUCTION

Austenitic Stainless Steel (ASS), being the widest in use of all the stainless steel groups finds application in the beverages industry, petrochemical, petroleum, food processing and textile industries amongst others. It has good tensile strength, impact resistance and wear resistance properties. In addition, it combines these with excellent corrosion resistant properties (Dillon, 1994). Extensively it is the material of choice in the kitchen. In Nigeria emerging natural gas liquids (NGLs) and liquefied natural gas (LNG) plants, it is increasingly being

used in the cryogenic (very low temperature) service (James, 2000).

Welding is one of the most employed methods of fabricating ASS components. ASS is largely highly weldable; the higher the carbon content, the harder the SS and so the more difficult it is to weld. The problem commonly encountered in welded ASS joints is intergranular corrosion, pitting and crevice corrosion in severe corrosion environments. Weld metals of ASS may undergo precipitation of  $(CrFe)_{23}C_6$  at the grain boundaries, thus depleting Cr and

making the SS weldment to be preferentially susceptible to corrosion at the grain boundaries. There may also be the precipitation of the brittle sigma Fe-Cr phase in their microstructure if they are exposed to high temperatures for a certain length of time as experienced during welding. High heat input welding invariably leads to slow cooling. During this slow cooling time, the temperature range of 700 - 850°C stretches in time and with it the greater formation of the sigma phase (Pickering, 1985). The different variables involved in welding affect the weldment and correspondingly the chemical and mechanical properties earlier listed (Robinson, 1979). Some of the variables are: welding power input, electrode type, electrode coating, pre-heating and welding speed (Khanaa, 1990).

Failures of weldments as a result of reduction in mechanical-chemical properties (strength, corrosion resistance) have been reported in the industry (pipes, road bridges, storage tanks, boilers, etc). In Nigeria, failures have been reported in ASS weldments deployed in offshore installations for NGLs liquefaction / extraction (Hooi Too, 2002).

SMAW is one of the commonest arc welding processes employed for the welding of these SS, it is important to study the influence of the welding variables (welding current input, welding

speed, electrode diameter and electrode coating) in the corrosion resistance of ASS in different media.

## METHODOLOGY

The chemical composition of the ASS used for the study is given in Table 1. The steel plate (10 mm thickness) was obtained in the cast state. Seventy five specimens of dimensions 100 x 50 x 10 mm were cut from the plate. Seventy two specimens were paired into single V-groove joints and welded with different welding variables to produce thirty six welded specimens. The elemental composition of the welding electrode is given in Table 1. The general welding conditions are stated in Table 2. The different welding variables used are detailed in Tables 3 to 6. The welding procedure specification (WPS) used was prequalified for ASS acid basin used for washing in a soft drink bottling plant. AWS B2.1: *Standard for Welding Procedure and Performance Qualification* is the reference standard for welding procedure specifications. Welded specimens were partially dissolved in 10% HCl-methanol mixture to remove slag particles trapped in the weldments. All the specimens were then ground and polished to fine diamond grade after which they were pickled and rinsed with demineralized water. This was done to remove fully the oxide and chromium-depleted layers in the specimens (Maiya, P. S., 1989).

**Table 1: Chemical Composition of Austenitic Stainless Steel and Electrode Material.**

Element	ASS Material (% by weight)	SMAW Electrode Material (% by weight)
Carbon	0.032	0.028
Chromium	18.50	19.00
Nickel	12.00	11.50
Manganese	1.85	1.95
Silicon	0.90	1.15
Molybdenum	2.20	2.00
Vanadium	0.085	0.00
Copper	0.00	0.25
Phosphorus	0.040	0.04
Sulphur	0.03	0.005
Iron	Remainder	Remainder

**Table 2: Specimens Welding (SMAW) Conditions.**

Welding Parameter	Setting
Welding technique	Direct Current Straight Polarity (DCSP)
Welding position	Horizontal-Right
Joint configuration	Single V, 60°, 2 mm Root Face
Electrode movement	No Weaving
Metal transfer technique	Gravity Transfer
Root opening	1.0 mm
Electrode type	E318 (AWS A5.4, A5.9 and A5.22)
Electrode diameter	4, 5 and 5.8 mm (5 mm Fixed setting)
Pressure of gas (Argon)	Not Applicable
Arc voltage	20 V
Welding current	190 A (Fixed setting)
Baking temperature	160 °C for 1 hr.
Inter-bead temperature	150 – 200 °C
Number of beads	2-3

Under welding current variable, welding currents used were 170, 190 and 210 Amps. Three specimens were welded for each current setting. The speed of the weld was achieved by fixing the workpiece on a motion slab which derives its linear motion from a gearing system driven by electric motor. The electrode was fixed (motionless) after the arc was manually established. The device was

designed and constructed in the welding shop specific for this study. From practice and welding literature, speed of 10mm/second is the average (Agarwal, 1992). From welding tables, voltage of 20–25V is the optimum for the combination of material thickness and electrode diameter (Khanaa, 1990). Three passes (beads) were made to completely

fill the weld groove. All welded samples were cooled in free air.

For welding speed variable, welding current was set at 190A. With the same electrode and electrode diameter (5mm), the speed of the motion slab was adjusted to achieve welding speeds of 4mm/second and 18mm/second;

corresponding to “slow rate” and “fast rate” respectively. The specimens were welded in turn with these speeds. To vary the electrode diameter setting, electrode diameters of 4mm and 5.8mm were used in addition to 5mm. All other parameters were set as shown in Table 5.

**Table 3: Welding Current Input Variable**

Variable	Setting
Electrode	E 318-15 (Basic Coated)
Electrode diameter	5 mm
Speed	10 mm / second
Voltage	20 V
Current	170 Amps, 190 Amps, 210 Amps
Number of beads	3
Number of specimens welded	9 (3 specimens per current setting)

**Table 4: Welding Speed Variable**

Variable	Setting
Electrode	E 318-15 (Basic Coated)
Electrode diameter	5 mm
Speed	4, 10, 18 mm / second
Voltage	20 V
Current	190 Amps
Number of beads	3
Number of specimens welded	9 (3 specimens per speed setting)

**Table 5: Electrode Diameter Variable**

Variable	Setting
Electrode	E 318-15 (Basic Coated)
Electrode diameter	4, 5, 5.8 mm
Speed	10 mm / second
Voltage	20 V
Current	190 Amps
Number of beads	2 for 5.8 mm electrode, 3 for the others
Number of specimens welded	9 (3 specimens per electrode diameter setting)

**Table 6: Electrode Coating Variable**

Variable	Setting
Electrode	E 318-15 (Basic coated), E 318-16 (Rutile [Lime + TiO <sub>2</sub> ] coated), E 318-17 (Lime + Silica coated)
Electrode diameter	5 mm
Speed	10 mm / second
Voltage	20 V
Current	190 Amps
Number of beads	3
Number of specimens welded	9 (3 specimens per electrode coating type)

### CORROSION POTENTIAL MEASUREMENT

Electrode (Metal) voltage measurement with reference to another electrode in a given corrosive medium is an indication of the tendency of the metal of interest to corrode in that particular medium. This voltage is usually measured in millivolts (mV). Numerous research findings (experimental) (Cottis, Al-Ansari and Pettiti, 1997; Jariyabon, Davenport, Ambert, Connolly, Willians and Price, 2007) have shown that high values of electrode potential of a metal in a given corrosive medium indicates high resistance of that metal to corrosion in that particular medium (i.e. the metal is passive or said to be passivated in that medium) while low values (usually negative values) of this voltage show that the metal has low resistance to corrosion in that environment (Afolabi, 2008; Karadeniz, Ozsarac and Yildiz, 2007; ASTM 1991).

All the welded samples (with three pieces un-welded specimens) were carefully designated and completely immersed separately in an electrolyte of one molar solution of hydrochloric acid according to the parameters variables. The electrolyte was formed with distilled water and freely ventilated at 30°C. With digital multimeter coupled with zinc rod reference electrode, the electrode potential of each sample was measured every five days for duration of seventy days. The average of the readings in each specimen variable

group was taken. The electrode potential values were converted to Saturated Calomel Electrode (SCE) with the formula:

$$\text{Electrode Potential } E_{ccp}(SCE) \text{ mV} = (E_{zn} - 1030) \text{ mV} \text{ (Afolabi, 2008; Hilbert and James, (1984).)}$$

Where;

$E_{ccp}$  = Critical corrosion potential

$E_{zn}$  = Electrode potential from zinc rod reference electrode.

### RESULTS AND DISCUSSIONS

#### Effect of Current Input

The effect of the different welding current inputs on corrosion resistance of the welded specimens in HCl is graphically shown in Fig. 1. The as-received (un-welded) specimens showed the highest electrode potential value followed by the specimens welded with current of 210 Amps. Progressively, the potential decreased for lower welding currents of 190 and 170 Amps. It follows that the un-welded specimens have the highest resistance to corrosion in this environment followed by joints welded with current of 210 Amps. This pattern is explained by the fact that low current required longer heating time for weld action. The longer time stretched the sensitization of HAZ weldment with formation of chromium carbide

precipitates along grain boundaries (depletion of Cr in the grain boundaries) (Iwuoha, Isiohia, Onyeka, and Atanmo, 2012). The Cr depletion results in loss of corrosion resistance (Le, and Ghali, 1993).

Comparatively, the thermal expansion of ASS is high (about 50% higher than that of plain carbon steels) (Khanaa 1990), for prolonged weld heat cycles, there is tendency for greater expansion with tendency of warpage and geometry distortion. These could create weld cracks and regions of alloy loss with weakening of corrosion resistance (Llewellyn 1992). The higher the current, the deeper the weld penetration and the narrower the weld breadth HAZ zone; it is equally established that too high welding current may cause excessive weld spatter in addition to weld cracking. This is supported by the works of Lothongkum, Viyanit, and Bhandhubanyong, 2001.

#### **Effect of Welding Speed**

Again, with electrode voltage measurement (Corrosion potential), the relationship between different welding speeds and corrosion resistance of the welded specimens in HCl is graphically shown in Fig. 2. The lowest weld speed (4 mm / second) produced lowest corrosion potential measurement in the medium, i.e. low speeds produce welded joints that are relatively prone to corrosion in HCl environment. The explanation is linked to the already described thermodynamics of metal fusion and kinetics of elements in solid solution in the HAZ due to longer weld heating cycles caused by “welding drag or welding delay” at low speed. The longer time created “convenience” for Cr to combine with carbon and emerge as precipitates along grain boundaries. This also widens the grain boundaries breadth and thus leads to accommodation of chloride ions and subsequent yielding to corrosion attack. However, the weld bead cools faster as a result of lean deposits occasioned by fast weld speed. This in turn

has the possibility of slag inclusion and weld porosities and such weld sites are active spots for corrosion attack (Karadeniz, et al., 2007).

#### **Effect of Electrode Diameter**

The critical corrosion potential falls as the electrode diameter increases (see Fig. 3), this is an indication of lowered corrosion resistance of weldments produced with larger electrodes. More welding current is required by the large diameter electrodes to melt within the required welding time compared with small diameter electrodes. This introduces “extended” welding time; cooling of the weld pool is also slow as a result of large weld bead and, HAZ final metallurgical microstructure is influenced (Hooi Too, (2002). Sensitization, which will adversely result in weld decay, cannot be avoided. The influence of sensitization promotes carbon diffusion to grain boundaries in this state (Munoz, Anton, Nuevalos, Guinon, and Herranz, 2004; Karadeniz, et al., 2007).

#### **Effect of Electrode Coating Type**

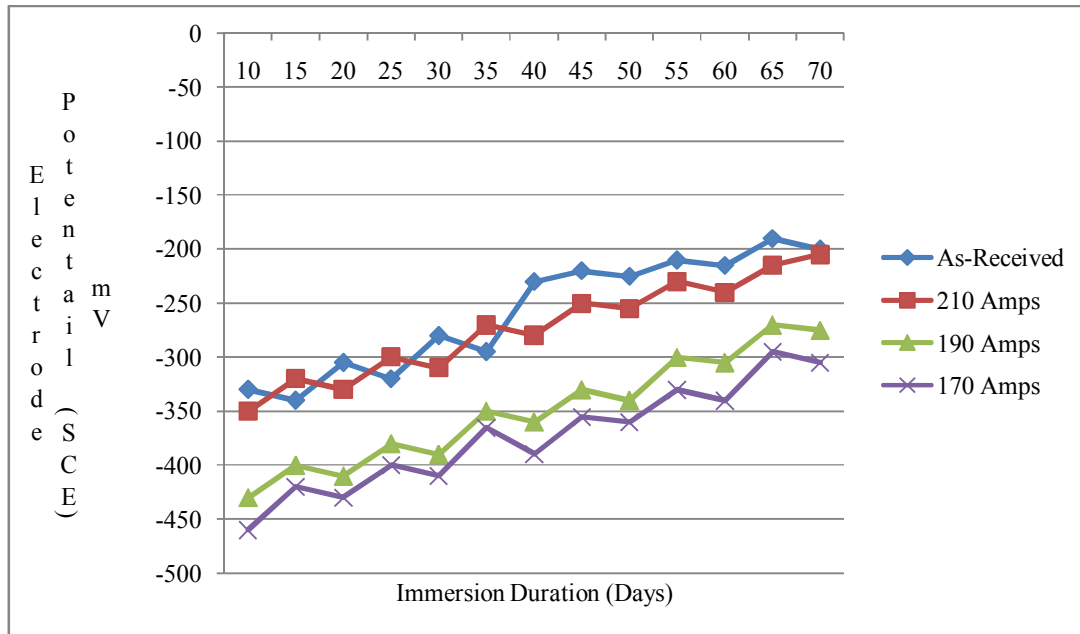
Basic coated electrode type (E 318-15) showed the highest critical corrosion potential compared with rutile (E 318-16 [Lime + TiO<sub>2</sub>]) and silica coated (E 318-17 [Lime + Silica coated]). Figure 4 is graphical display of corrosion resistance measurement pattern (critical corrosion potential) in relation to electrode coating type. This implies that welded joints produced by basic type electrodes are comparatively stable in HCl medium than the rutile and silica type electrodes. The combined CO and CO<sub>2</sub> gases evolved during welding combustion add to the shielding effectiveness of the coating, thus ambient incursion to the weld pool is reduced and the weldment retains much of the metallurgical properties of the base metal. The weld heat cycle is further reduced and the HAZ is narrower (Parijslaan, 2002). Rutile coating evolves

H<sub>2</sub> and CO gas mixture on combustion of the cellulose lime; this also serves additional shielding support to the weld pool but with the danger of hydrogen embrittlement of the welded joint. The reducing reactions caused by release of hydrogen compromises the metallurgical homogeneity of the weld with respect to the base metal. The introduction of silicon into the welded joint by the silica coated electrode type create weld fusion inhomogeneity.

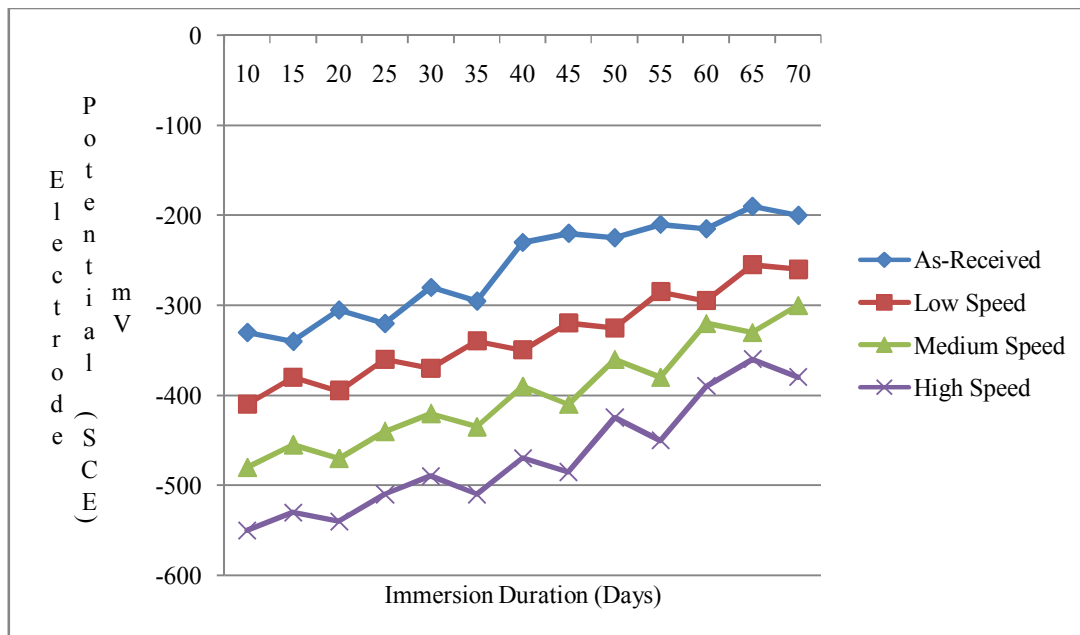
### CONCLUSIONS

From the results of this study, the following conclusions are made:

- i. Suitably selected high welding current (power input) matching workpiece thickness and electrode produce welded joints with better resistant to corrosion in hydrochloric acid medium than low welding currents. This suitable matching is very important to avoid “over high” welding currents that in turn led to excessive weld spatter in addition to weld cracking.
- ii. Considering the alloy thickness, geometric shape (configuration) and electrode diameter, medium welding speed (about 10 mm / second) gives the desired high resistance of welded joints to corrosion in HCl environment.
- iii. The critical corrosion potential falls as the electrode diameter increases. The “extended” welding time introduced by large diameter electrodes creates convenient window for microstructural change and sensitization of base metal HAZ; weld decay cannot be ruled out in this state.
- iv. Welded joints produced with basic coated electrode type are comparatively more stable in HCl medium than those produced with rutile coated and silica coated electrode types. The reducing reactions caused by release of hydrogen in rutile coated electrodes compromises the metallurgical homogeneity of the weld with respect to the base metal and this lowers the critical corrosion potential.

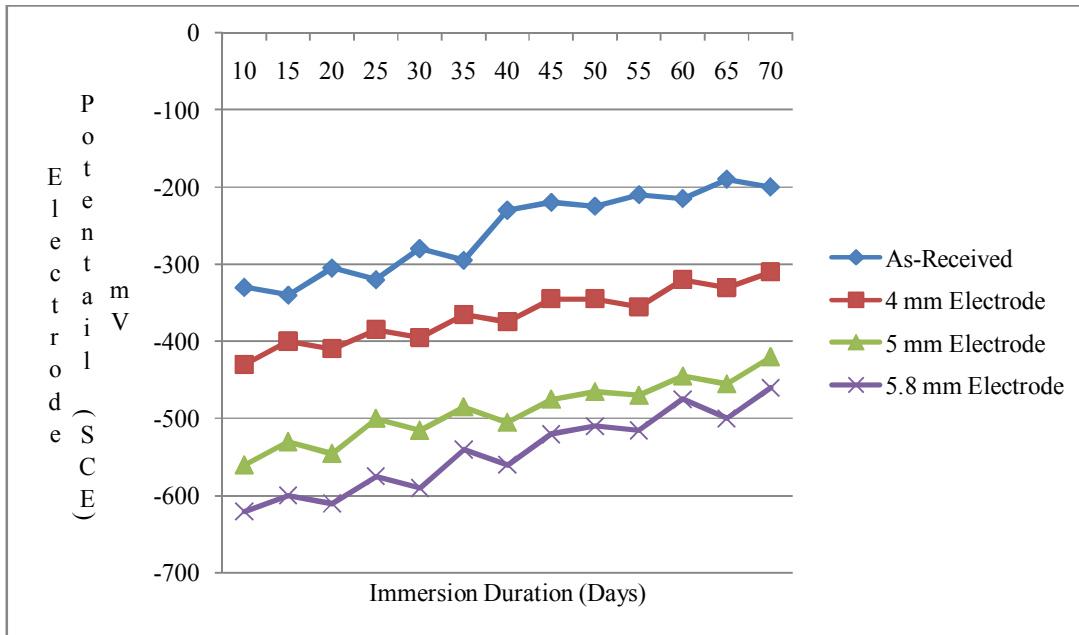


**Fig. 1: Electrode Potential (for different welding current inputs) against Duration of Immersion in 1M Solution of HCl**

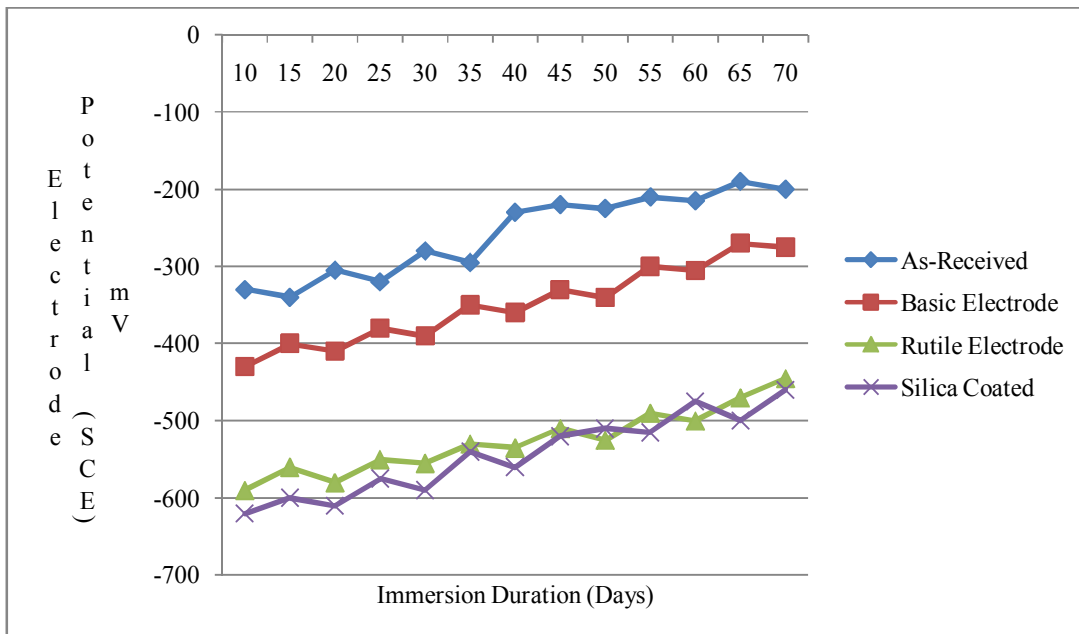


**Fig. 2: Electrode Potential (for different welding speeds) against Duration of Immersion in 1M Solution of HCl**





**Fig. 3: Electrode Potential (for different electrode diameters) against Duration of Immersion in 1M Solution of HCl**



**Fig. 4: Electrode Potential (for different electrode types) against Duration of Immersion in 1M Solution of HCl**

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#### ABBREVIATIONS

AISI	American Iron and Steel Institute
ASM	American Society for Metals
ASTM	American Society for Testing and Materials
AWS	American Welding Society

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**Biographical Note:** A.U. Iwuoha holds B.ENG and M.ENG and he is currently a Lecturer with Department of Mechanical Engineering, Imo State University, Owerri, Nigeria.

**Biographical Note:** I.A. Ezenugu holds B.ENG. and M.ENG. and he is currently a Lecturer with Department of Electrical and Electronics Engineering, Imo State University, Owerri, Nigeria.

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