

## INVESTIGATION ON THE CORROSION SUSCEPTIBILITY OF WELDED SOLUTION ANNEALED AISI 1036 STEEL IN 1.0M NaCl SOLUTION

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### *Abstract*

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*The aim of the paper is to investigate the corrosion susceptibility of welded solution annealed 0.36%C steel in chloride environment. The steel samples were subjected to solution annealing heat treatment at a temperature of 990 °C and held for 2hrs for homogenization after which the samples were immediately cooled in water. The heat treated and controlled samples were immersed in sea water for a period of 100 days. The weights of the samples were taken before immersion and were weighed subsequently at an interval of 20 days using the electronic weighing balance. Corrosion rate were investigated for at the parent metal (PM), heat affected zone (HAZ) and welded zone (WZ) using the gravimetric method (GM) and optical metallography microscopy (OMM). The results obtained revealed that the solution annealed samples at the parent metal (PM), heat affected zone (HAZ) and welded zone (WZ) showed better corrosion resistance than the control samples. The susceptibility of the samples was found to decrease from the parent metal (PM), to the heat affected zone (HAZ), and the welded zone (WZ) the least, with peak corrosion rate of 63.253 (mg/cm<sup>2</sup>/yr), 75.301 (mg/cm<sup>2</sup>/yr) and 99.398 (mg/cm<sup>2</sup>/yr) respectively on the 20<sup>th</sup> day. The microstructure also varied from the parent metal, to the heat affected zone and to the welded zone. From the results obtained, the welded solution annealed steel samples appeared to be more suitable for application in the chloride environment since they show better resistance throughout the exposure period.*

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**Keywords:** Solution Annealing, Carbon steel, Microstructure, Corrosion susceptibility, Chloride Solution

### **1. Introduction**

Steel is an alloy of iron and carbon. The uses of steels for engineering components require a complete understanding of material properties and design requirements. Thus, steels known as medium carbon steels have undergone constant research [1]. Medium carbon steel is steel with 0.3 to 0.7%C and approximately 0.8%Mn [2]. Medium carbon steels are broadly used for many industrial applications and manufacturing on account of their low cost and easy fabrication [3]. Most steel parts such as gears, precision gauges, bearings, tools and dies produced today are heat treated before being put into service. Parts are heat treated to enhance particular properties, such as hardness, toughness and corrosion resistance, and to improve uniformity of properties. The exact heat treatment applied depends on both the type of alloy and the intended service conditions [4]. Research have shown that failure of welded steels can result from irregular grain size and internal stress in the heat affected zone of the welded material [5]. Sequentially, to forestall these failures, the properties of the steel can be changed as desired by heat treatment. Heat treatment is defined as a controlled process of heating and cooling a metal or alloy in its solid state to change its metallurgical and mechanical properties [6]. The findings of [7] revealed that amongst various heat treatment processes (hardening, annealing, normalizing, tempering, etc.), solution annealing causes the material to be in its most corrosion resistance condition.

Chloride is reported to play a significant role in corrosion reactions, products and kinetics of ferrous metals. Corrosion of ferrous metals in chloride environment is one of the major causes of durability problems of water, sewage, oil and gas distribution systems. Corrosion of steel in chloride environment is a multiscale process initially induced by the localized electrochemical reactions [8]. The electrochemical process is highly influenced by the development of rust oxide layers as well as the film/droplet formation on the metal surface, which are in turn controlled by local environments, i.e. moisture,

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oxygen, temperature, soluble salts and so forth [9]. Chloride ions, minor in radius, may be adsorbed or penetrate easily through the passive film even the oxide layer thus damaging the integrity of the steel material and accelerating the electrochemical reactions afterwards [10]. Besides, the abundant chloride concentrations, conducive to reducing resistivity, also indirectly facilitate the electrochemical reactions. A great number of investigations have demonstrated that chloride ions remarkably influence the composition and protective efficiency of rust layers on ferrous metal surfaces. High concentrations of chloride were reported to induce the production of akaganite ( $\beta$ -FeOOH) [11,12,13], which was able to exhibit high reduction reactivity. The major accumulation of  $\beta$ -FeOOH in the thick parts of rust layers that served as a Cl<sup>-</sup> container was verified by [14];  $\beta$ -FeOOH made the layer more porous and accelerated the corrosion process as well. Further, as chloride concentrations increased, the  $\beta$ -FeOOH increased simultaneously [15]. High chloride deposition was speculated to lead to the formation of  $\beta$ -FeOOH, and it is also reported that low chloride facilitated the accumulation of lepidocrocite ( $\gamma$ -FeOOH) [16]. The following transformation from  $\gamma$ -FeOOH to  $\alpha$ -FeOOH was more stabilized thus protecting the metal against further corrosion.

Corrosion is the destructive attack of a metal by chemical or electrochemical interactions with its environment [17]. Corrosion failure and perforation leakage events of steel materials happened repeatedly due to the presence of Cl<sup>-</sup>. Especially in acid environment and in the presence of Cl<sup>-</sup> with higher concentration, corrosion failure and serious damage of steel materials can be seen everywhere [18, 19]. Despite the usefulness of steel in the field of engineering and other related industrial fields. When steel is present in a marine environment, it encounters catastrophic failure [20]. It is on this basis that this project has been conducted to investigate the corrosion susceptibility of welded solution annealed 0.36%C steel in chloride environment with a view to obtain a more suitable steel material that is less susceptible to corrosion and also to contributing additional knowledge to existing literature.

## 2. Material and methods

### 2.1 Material

The material used in this investigation is a medium carbon steel substrate of 16 millimeter diameter. The chemical composition of this material were analyzed for by a mass spectrometer analyzer. The result of the analysis is shown in Table 1.

### 2.2 Methods

#### 2.2.1 Preparation of samples

The 0.36%C steel were machined into welding specifications. The welding samples were cut into two equal halves by power hacksaw. The V-edge design was adopted with a bevel angle of 30° in preparation for butt welding which is in line with American Welding Society [21]. This welding geometry was selected based on the submission of [22] that acceptable welding penetration could easily be achieved by butt sample preparation.

#### 2.2.2 Welding Procedure Specification

The edges of the samples were firmly clamped together on a welding table with a root gap of 2mm between them in accordance to literature. The samples were manually welded together in pairs. The shielded metal arc welding (SMAW) technique was used for the welding operation. During the welding operation electrode was made to run through the butt until penetration of the weld pool were achieved to the thickness level of the rod. After the welding operation, iron brush was used to remove the slag and welded samples were allowed to cool in air. All the sample including the butt welded samples and the un-welded samples were divided into two groups, for the purpose of post weld heat treatment.

#### 2.2.3. Post Weld Heat Treatment

The welded samples were stress relieved to remove internal stresses that were induced on them in the course of welding [23, 24]. The solution annealing heat treatment were performed for some samples using a muffle furnace and heated to austenitic temperature of 990 °C and held for 2 hrs for homogenization after which the samples were water cooled. Ten (10) samples of the welded specimen and the un-welded specimen were subjected to solution annealing heat treatment. Ten (10) samples of the welded samples and the un-welded samples were used as control samples, without heat treatment so as to see the effect of corrosion and to compare with the treated samples.

#### 2.2.4 Environmental Preparation

In order to be able to have a good assessment of the corrosion of the materials, the corrosion medium was prepared by weighing 58.44g of sodium chloride salt dissolved in 1000ml of deionized or distilled water in accordance with literature and stored in a 20 litre gallon and labeled.

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**2.2.5 Gravimetric Measurement and Determination of Corrosion Rate**

Five samples each from each group were fully immersed in 1.0M NaCl environment with appropriate labelling. The samples were immersed in the corrosion environment for 100 days. The samples were first weighed before immersion using electronic weighing balance. Weight losses of the samples were determined at an interval of 20 days. Corrosion rates were determined from the weight loss in accordance with the American Society of Testing and Materials (ASTM) standard using the relation in Equation (1) as obtained from [25].

$$CPR = \frac{W}{A \left(\frac{T}{365}\right)} \quad (\text{mg/cm}^2/\text{yr}) \tag{1}$$

Where,  $W = W_0 - W_f$

$W$  = Weight loss (mg)

$W_0$  = Initial weight

$W_f$  = Final weight of each day of monitoring

$T/365$  = Exposure time in days extrapolated to a year

$A$  = total surface area ( $\text{cm}^2$ )

$A = 2\pi r(r+L)$  due to the cylindrical shape of the samples

Where:  $r$  = Radius of samples (cm)

$L$  = Length of samples (cm)

The result of the corrosion rate is presented in Fig. 1 - Fig. 3

**2.2.6 Metallography and Microscopy**

All the steel samples were prepared for optical microscopy using standard metallographic practice. The surface of the specimens was etched using 2% Nital to reveal the grain boundaries. Microscopic examination was carried out with an optical metallurgical microscope fitted with a photographic device. The micrography was carried out with a magnification of  $\times 1000$ . The result is presented in Plate. 1 – Plate. 6

**3 Results and Discussion**

**3.1 Results**

Table 1: Chemical composition of the medium carbon steel

Elements	C	Si	Mn	P	S	Cr	Ni	Cu
Weight (%)	0.366	0.278	0.869	0.046	0.057	0.134	0.101	0.233
Elements	Nb	Al	B	W	Mo	V	Ti	Fe
Weight (%)	0.007	0.006	0.003	0.025	0.005	<0.0001	<0.0001	97.87

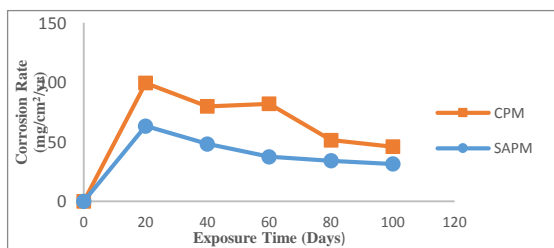


Figure 1: Plot of Corrosion Rate Against Exposure Time for The Control and Solution Annealed Parent Metal (PM) of The Samples Immersed in 1.0M NaCl Environment.

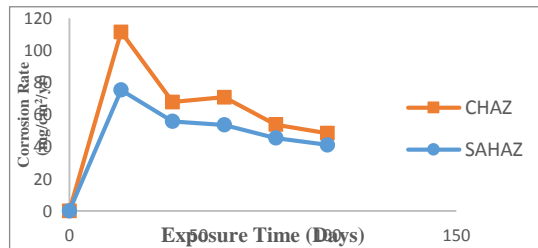


Figure 2: Plot of Corrosion Rate Against Exposure Time for The Control and Solution Annealed Heat Affected Zone (HAZ) of The Samples Immersed in 1.0M NaCl Environment.

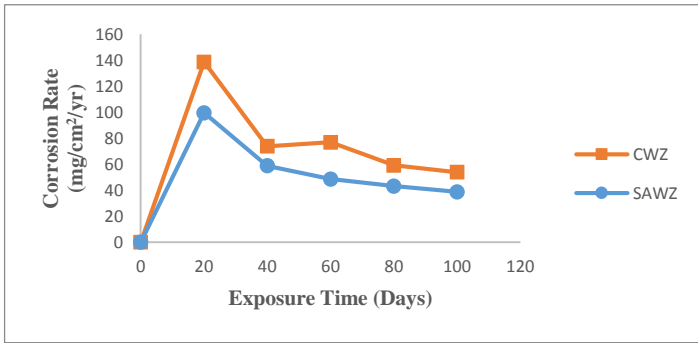


Figure 3: Plot of Corrosion Rate Against Exposure Time for The Control and Solution Annealed Welded Zone (WZ) of The Samples Immersed in 1.0M NaCl Environment.

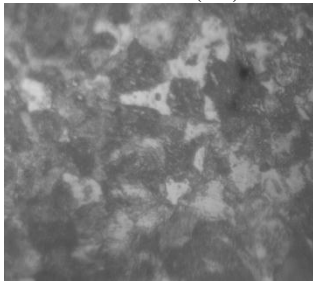


Plate 1: Optical Micrograph of the Control Un-Welded Zone of 0.36%C Steel at X1000.

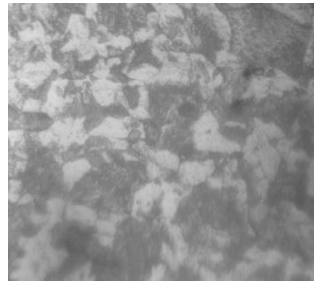


Plate 2: Optical Micrograph of the Control Heat Affected Zone (HAZ) of 0.36%C Steel at X1000.

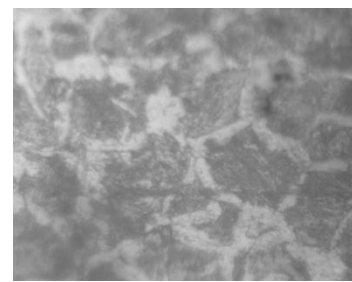


Plate 3: Optical Micrograph of the Control Welded Zone of 0.36%C Steel at X1000.

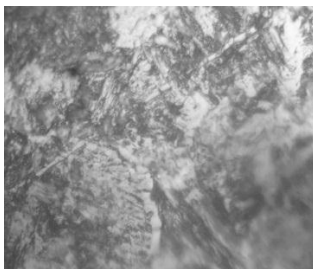


Plate 4: Optical Micrograph of the Parent Metal of 0.36%C Steel annealed at 990 °C for 2hr at X1000.

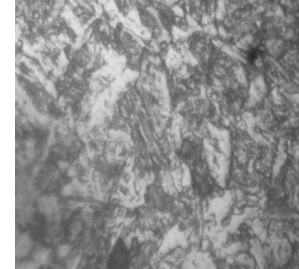


Plate 5: Optical Micrograph of the Heat Affected Zone (HAZ) of 0.36%C Steel annealed at 990 °C for 2hr at X1000.

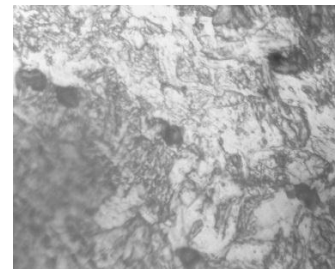


Plate 6: Optical Micrograph of the Welded Zone of 0.36%C Steel annealed at 990 °C for 2hr at X1000.

### 3.2 Discussion

#### 3.2.1 Effect of Solution Annealing on the Corrosion Resistance of Welded 0.36%C Steel in 1.0M NaCl Environment from Corrosion Penetration Rate Obtained from Gravimetric Measurement

Fig. 1 to Fig. 3 show the plot of corrosion rate against exposure time for the control and solution annealed parent metal (PM), heat affected zone (HAZ) and the welded zone (WZ) of the samples immersed in 1.0M NaCl solution for the period of 100 days. The graphs revealed that the corrosion rate were observed to increase with exposure time with peak corrosion rate on the 20<sup>th</sup> day for the investigated control and solution annealed parent metal (PM), heat affected zone (HAZ) and welded zone (WZ) of the samples. The rate of increase was observed to be higher for the control samples with peak corrosion rate of 99.398 (mg/cm<sup>2</sup>/yr) for the parent metal (CPM), 111.446 (mg/cm<sup>2</sup>/yr) for the heat affected zone (CHAZ) and 138.554 (mg/cm<sup>2</sup>/yr) for the welded zone (CWZ) than the solution annealed samples with peak corrosion rate of 63.253 (mg/cm<sup>2</sup>/yr) at the parent metal (SAPM), 75.301 (mg/cm<sup>2</sup>/yr) at the heat affected zone (SAHAZ) and 99.398 (mg/cm<sup>2</sup>/yr) at the welded zone (SAWZ). The higher corrosion rate observed for the control samples can be attributed to the presence of carbide at the grain boundaries. These carbides present at the grain boundaries are more susceptible to anodic dissolution. The decreased corrosion rate observed with the solution annealed samples can be attributed to the homogeneous dissolution of the carbides at the matrix of the steel, thus, resulting in the reduced presence of carbides at the grain boundaries of the samples and thereby making the solution annealed samples to be less susceptible to corrosion and these observations aligns with [26, 27].

### 3.2.2 Optical Evaluation of the Effect of Solution Annealing on the Microstructure and Corrosion Susceptibility of 0.36%C Steel in 1.0M NaCl Environment

From the results obtained from the investigation, it can clearly be seen that the solution annealing heat treatment process have varied effect on the microstructure of the 0.36%C steel which in turn affected its susceptibility to corrosion. **Plate. 1** shows uniform distribution of carbide in the matrix of ferrite. **Plate.2** shows coarse carbide in the ferrite matrix. **Plate. 3** shows coarser carbide dispersion in the ferrite matrix. **Plate. 4** shows uniform dispersion of martensite with more traces of retained austenite. **Plate. 5** shows martensite distribution with more traces of coarse retained austenite. **Plate. 6** shows martensite distribution with coarser retained austenite. It can be observed from the microstructure of the control samples in **Plate. 1 to Plate. 3**, that the major phase present were ferrite and cementite phase which ultimately may have brings about changes in cathodic to anodic area ratios with regard to the phases present, hence, resulted to its high susceptibility to corrosion. This is in agreement with [28]. They observed that the corrosion of medium carbon steel is not only governed by the electrolyte conditions, but can also be influence by its microstructure. It was observed from **Plate. 4 to Plate. 6** of the solution annealed samples that the major phases present were martensite and retained austenite. These observed phases could have possibly account for their low susceptibility to corrosion and this observation is in good agreement with [29], in their investigation reported that retained austenite had lower corrosion susceptibility damage. [30], observed from their investigation that the martensite phase had the least susceptibility to corrosion. The corrosion rate for both samples were observed to increase from the parent metal (PM), heat affected zone (HAZ) to the welded zone (WZ).

### 4. Conclusion

From the results of the investigation carried out, the following conclusions were made:

1. The solution annealed steel samples showed better corrosion resistance tendency than the control samples.
2. The control samples were more susceptible to corrosion than the solution annealed medium carbon steel samples in the chloride environment.
3. The corrosion rate for both samples were observed to increase from the parent metal (PM), heat affected zone (HAZ) to the welded zone (WZ).

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*Journal of the Nigerian Association of Mathematical Physics Volume 59, (January - March 2021 Issue), 191–196*

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