Nigerian Research Journal of Engineering and Environmental Sciences 2(2) 2017 pp. 478-486

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

RJEES

Original Research Article

THE EFFECT OF MICROSTRUCTURAL CHANGES ON THE CORROSION RESISTANCE OF WELDED AISI 1036 STEEL IN CHLORIDE ENVIRONMENT

***Awheme, O., Unueroh, G.U. and Onyekpe, B.O.**

Mechanical Engineering Department, Faculty of Engineering, University of Benin, Benin City, Nigeria
*oghenerobo.awheme@uniben.edu; georgina.odin@uniben.edu

ARTICLE INFORMATION

Article history:
Received 13 July, 2017
Revised 11 September, 2017
Accepted 19 September, 2017
Available online 29 December, 2017

Keywords:
Annealing
Medium carbon steel
Microstructure
Welding
Corrosion
Chloride

ABSTRACT

This work investigated the effect of annealing temperature on microstructural changes and corrosion resistance of welded medium carbon steel in chloride environment. The samples were machined into cylindrical pieces of 20 mm diameter and 40 mm length for un-welded samples of 24 pieces and 60 mm length for welding samples of 24 pieces. The medium carbon steel samples were annealed at varied temperature of 860 ^{o}C, 920 ^{o}C and 1000 ^{o}C with a soaking time of one hour while some were not annealed and served as controlled samples. The samples were immersed in 1M NaCl solution for 60 days. The annealing temperatures used in this study yielded different microstructures which in-turn possibly affected their susceptibility to corrosion. The result showed corrosion attack on the annealed steel, with the severity increasing with higher annealing temperature of the samples. The result showed that as the annealing temperatures increases, the cementite and ferrite grains are relatively segregated from each other for the welded samples than the un-welded samples resulting in an increasing corrosion attack. The annealed un-welded samples showed better corrosion resistance compared to the welded samples while the control (un-annealed) sample show better corrosion resistance compared to the annealed samples.

1. INTRODUCTION

Steel is essentially an alloy of iron and carbon or of iron; carbon and other alloying elements (Onyekpe, 2002). Steel continues to gain wide use as prospective functional and structural material because of its good soft-magnetic properties, high strength, good corrosion, and wear resistance coupled with relatively low cost (Tokaji et al., 2004). Medium carbon steel has between 0.25% to

0.5% carbon, and it is heat treatable to achieve the desired property. This material has found various application in many engineering industries and it is used in almost all environments. Some of its uses are for the production of machine parts, bolts, crank shafts, gears and rail road's (Onyekpe, 2002).

Welding is one of the most employed methods of fabricating medium carbon steel components. It is basically a fusion of two or more pieces of metal by the application of heat and sometimes pressure (Agarwal, 1992). Thus welding involves a wide range of scientific variables such as time, temperature, electrode, power, input and welding speed (Jariyaben et al., 2007). Research findings have showed that failure do occur as a result of poor mechanical properties of the welded materials due to the presence of gases, irregular grain size and internal stresses in the heat affected zone of the welded material (James, 2000; Boumerzoug et al., 2010; Gemme et al., 2011). The cycle of heating and cooling that occurs during the welding process affects the microstructure and surface composition of welds and adjacent base metal (Nandan et al., 2008; Shi and Han, 2008). Consequently, the corrosion resistance of autogenous welds and welds made with matching filler metal may be inferior to that of properly annealed base metal because of: microsegregation, precipitation of secondary phases, formation of unmixed zones, recrystallization and grain growth in the weld heat-affected zone (HAZ), volatilization of alloying elements from the molten weld pool, contamination of the solidifying weld pool (ASM, 1987; Ayodele and Nenuwa, 2013).

Heat treatments are used to modify the microstructure and mechanical properties of engineering materials, particularly steels. Annealing is the type of heat treatment most frequently applied in order to soften iron or steel materials and refines its grains due to ferrite-pearlite microstructure. It is used where elongations and appreciable level of tensile strength are required in engineering materials (Kempester, 1984; Raymond and Higgins, 1985). Heat treatment which involves the application of heat to bring about modification in the microstructure, essentially alters mechanical and chemical properties based on the retained austenite, grain size and defects such as dislocation, twining, vacancies and so on (Rajan, 1993). One of the specific purposes of altering material properties is to improve their corrosion resistance characteristics. The relative limited service performance of welded steel materials as compared to non-welded parts under the same operating conditions is due to failure (Ayodele and Nenuwa, 2013).

Corrosion involves the interaction (reaction) between a metal or alloy and its environment. Corrosive environments include the atmosphere, aqueous solutions, soils, acids, bases, inorganic solvents, molten salts and liquid metals. These have found a wider influence on material strength and performance behaviour. Environment is a variable that can change with time and conditions, its effect on metal corresponds to the micro environmental conditions (Popoola and Fayomi, 2011). Marine atmosphere is highly corrosive because of the presence of sodium chloride. Seawater consists predominantly of sodium chloride, as well as some minerals and organic matters. Seawater is generally more corrosive than freshwater, frequently producing pitting and crevice corrosion (William and Callister, 1997). Failures as a result of poor mechanical properties and corrosion resistance have also found their places in the annals of times, from household equipment to industrial structures such as railways, road bridges, storage tanks and ocean liners (Afolabi, 2008). One of such failures is the corrosion cracking of a grade 304 stainless steel pipe improperly seam welded and meant for the conveying of glucose solution in Illinois USA (James, 2000). Many other failures have proved to be welding prone or propagated. It is therefore pertinent to investigate the influence of microstructural changes and its effects on corrosion resistance of welded medium carbon steel annealed various temperatures in sodium chloride environment.

2. MATERIALS AND METHODS

2.1. Materials

The material used in this investigation is a medium carbon steel substrate of 20 millimeter diameter. It was obtained from Delta Steel Company (DSC), Aladja, with heat number 1143567. The chemical composition of this material were analyzed for by a mass spectrometer analyzer at DSC and the result is shown in Table 1.

2.2. Methods

2.2.1. Preparation of samples

The medium carbon steel was used in as received condition. The samples were machined into cylindrical pieces of 20mm diameter and 40mm length for un-welded samples of 24 pieces and 60mm length for welding samples of 24 pieces. The welding samples were cut into two equal halves and then chamfered in preparation for butt welding. This welding geometry was chosen based on the suggestion of Agarwal (1992) that adequate welding penetration could easily be achieved using butt sample preparation.

2.2.2. Preparation of 1.0M sodium chloride solution

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 dissolving in 1000 ml of distilled water and stored in a 20 litre gallon.

2.2.3. Welding and post welding heat treatment

The edges of these samples were firmly clamped together with a root gap of 2mm between them. The samples were welded together in pairs with the aid of a manual electric arc welding. The pieces of medium carbon steel was butt welded. During welding, the electrode was to run through the butt until the penetration and development of the weld pool were achieved to the thickness level of the rod. Thereafter an iron brush was used to remove the covering slag and then the welded samples were allowed to cool in air. All the samples including the butt welded samples and the un-welded samples were divided into four groups, for the purpose of investigating the effect of annealing temperature. The first group comprised of six (6) welded samples and six (6) un-welded samples annealed at 860 ^{o}C with a soaking time of one hour. The second group comprised of six (6) welded samples and six (6) un-welded samples annealed at 920 ^{o}C with a soaking time of one hour. The third group comprised of six (6) welded samples and six (6) un-welded samples annealed at 1000 ^{o}C with a soaking time of one hour. The fourth group comprised of six (6) welded samples and six (6) un-welded samples that were not annealed. After the heat treatment, the samples were weighed and immersed in the corrosion medium to test for corrosion in the sodium chloride solution.

2.2.4. Determination of corrosion penetration rate from weight loss measurement

The investigation involves periodic weight loss measurement. The setup for the corrosion resistance of the samples in one molar solution of sodium chloride have twenty-four plastic containers for welded and control samples with each container labeled according to their annealing temperatures. The corrosion samples were removed from the corrosion environments (media) with the aid of a tong after which the samples were properly cleaned in distilled water and then dried with a cotton wool. The dried sample were weighed with a chemical weighing balance (Digital) and recorded and this continued at regular intervals of ten (10) days for the duration of 60 days. From the data obtained from the weight loss, the corrosion rates were calculated in accordance with ASTM-G31 standard using the relation in Equation (1) as obtained from Fontana (1986):

$$R = \frac{W}{A \times \left(T/365 \right)} \tag{1}$$

W = Weight loss (mg)
A = Total surface area (cm^2)
T/365 = exposure time in days extrapolated to a year

2.2.5. Hardness testing

Standard procedures and equipment were used to the measure hardness property of the samples. Surfaces of the samples were properly ground to make it a flat and stable using a hand grinder. Hardness measurement was made using Digital Rockwell hardness (HRA) Tester with 0.4064 m indenter and 0.6 N indenting load with a dwell time of 10 s. The hardness measurement was taken in five different locations and the average values of the best three results were considered (Seidu and Kutelu, 2013).

2.2.6. Metallography

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. The micrography was done with a magnification of x 50.

3. RESULTS AND DISCUSSION

The chemical composition of the steel substrate as presented in the Table 1 reveals that the material is a medium carbon steel as the carbon in this material is between 0.25% - 0.5%, while the others are alloying elements present in this material, as steel is basically an alloy of iron and carbon, and other alloying elements (Onyekpe, 2002). Results presented in Table 2 reavealed that there was a decrease in hardness value for the annealed samples with increase in annealing temperature. The 1000 ºC annealed samples displayed the least hardness with 860 ºC displaying the highest value compared with the control sample.

Table 1: Chemical composition of the medium carbon steel substrate

Elements	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Fe
Composition (w%)	0.36	0.52	0.18	0.036	0.050	0.17	0.13	0.33	0.002	98.22

Table 2: Hardness test values for un-welded medium carbon steel samples

Samples	Average Rockwell Hardness (HRA)
Control sample	43.4
860 ºC	38.9
920 ºC	29.4
1000 ºC	23.3

Table 3: Hardness test values for welded medium carbon steel samples

Samples	Average Rockwell Hardness (HRA)
Control sample	37.7
860 ºC	30.5
920 ºC	26.3
1000 ºC	21.3

Results presented in Table 3 showed that there was a decrease in hardness value for the annealed samples with increase in annealing temperature. The 1000 ^oC annealed samples displayed the least hardness with 860 ^oC displaying the highest value compared with the control sample. This is due to the fact that the higher annealing temperature favours grain growth due to the faster rate of diffusion (Rajput, 2004). The hardness value of the un-welded annealed samples presented in Table 2 showed higher hardness values compared to the welded annealed samples.

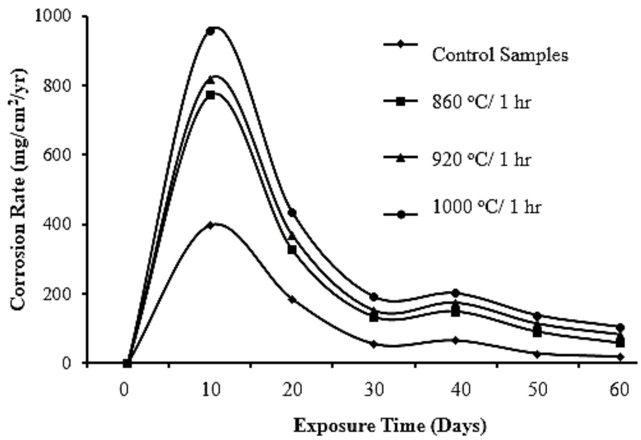

Figure 1: Plot of corrosion rate against exposure time for welded medium carbon steel samples annealed at 860 ^oC – 1000 ^oC

Figure 1 showed a rapid increase in corrosion rate up to the 10^{th} day before a sharp decline in corrosion rate up to the 20^{th} day and then a steady decrease in corrosion rate for both the welded annealed samples and control samples, followed by an increase in corrosion rate on the 40^{th} day for all samples and a progressive decrease in corrosion rate throughout the remaining exposure time. The 1000 ^oC annealed samples displayed the highest corrosion rate and the control sample displaying the least throughout the exposure period.

Figure 2a: Optical Microstructure of as-received un-welded AISI 1036 steel sample (x50)

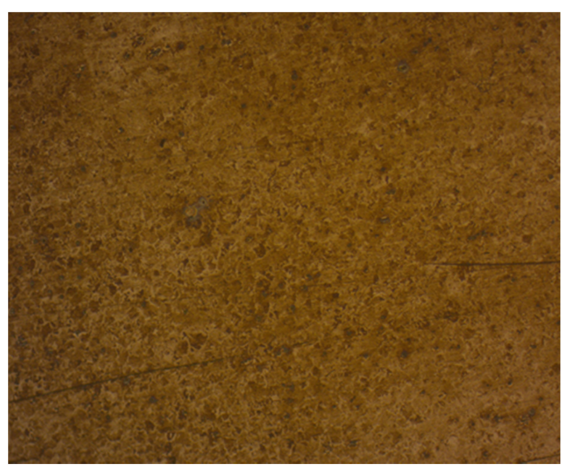

Figure 2b: Optical Microstructure of the (HAZ) of as-received welded AISI 1036 steel sample (x50)

Figure 3a: Optical Microstructure of 860°C annealed un-welded AISI 1036 steel sample (x50)

Figure 3b: Optical Microstructure of the (HAZ) of 860°C annealed welded AISI 1036 steel sample (x 50)

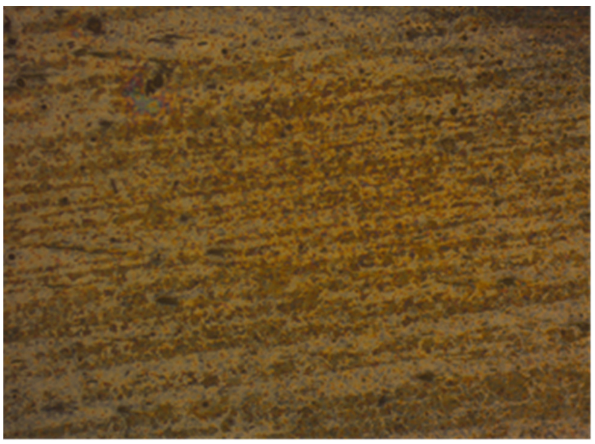

Figure 4a: Optical Microstructure of 920°C annealed un-welded AISI 1036 steel sample (x 50)

Figure 4b: Optical Microstructure of the (HAZ) of 920°C annealed welded AISI 1036 steel sample (x 50)

The annealing temperatures used in this study yielded different microstructures (Figures 2 to 5), which in-turn possibly affected their susceptibility to corrosion. The un-welded sample not annealed in Figure 2a, showed fine dispersion of coalesced cementite and ferrite grain. However, the welded sample not annealed in Figure 2b, shows fine dispersion of coalesced cementite and ferrite grain with large cementite grain. Figure 3a shows that the un-welded sample annealed at 860 °C showed dispersion of coalesced cementite and ferrite grain. However, the sample welded in Figure 3b, showed dispersion of coalesced cementite and ferrite grain with ferrite becoming more visible. Figure 4a, for the un-welded sample annealed at 920 °C showed fine dispersion of cementite in an array of ferrite grains. However, the sample welded shown in Figure 4b, revealed dispersion of large cementite grain size in an array of ferrite grains. Figure 5a, for the un-welded sample annealed at 1000 °C showed directional aligned cementite and ferrite grain with less visibility of grain boundaries. The welded sample shown in Figure 5b, revealed directional aligned cementite and ferrite grain with larger grain sizes and visibility of grain boundaries.

Figure 5a: Optical Microstructure of 1000ºC annealed un-welded AISI 1036 steel sample (x50)

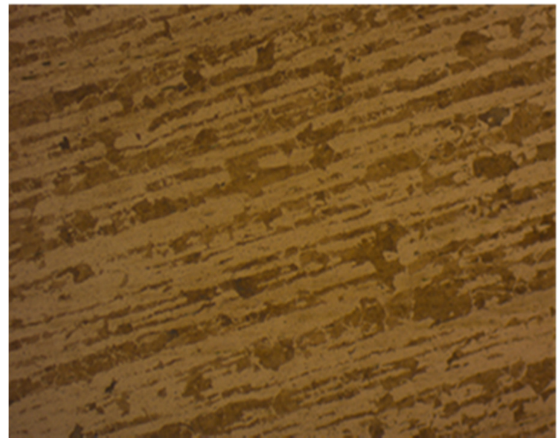

Figure 5b: Optical Microstructure of the (HAZ) of 1000ºC annealed welded AISI 1036 steel sample (x50)

It was also observed from Figures 2 to 5 that the average grain size of samples annealed at 1000 ºC appears to be the largest compared with the rest of the other samples with well relatively segregated grains. This is due to the fact that the higher annealing temperature favours grain growth due to the faster rate of diffusion (Rajput, 2004), and this is also evident in Tables 2 and 3 that there were slight decrease in hardness with increase in annealing temperature. Similarly, the sample annealed at 920 ºC has grain size that is larger and with relatively segregated grains compared to that annealed at 860 ºC and as-received. It was also observed that as the annealing temperatures increased, the cementite and ferrite grains were relatively segregated from each other for the welded samples than the un-welded samples. It was also observed that corrosion rate increased with increasing annealing temperature. This could be attributed to increase in grain size and relative segregation of the grains with increasing temperature as evident in Figure 2 to 5. The grain growth with increasing temperature also brings about changes in cathodic to anodic area ratios with regard to the phases present which can lead to susceptibility to corrosion. This is in agreement with Perez et al. (1996). 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. Shrier et al (1994) also observed that the driving force for corrosion in aqueous media is the difference in potential of small areas due to the heterogeneities in the material, which can arise from various factors such as defects in crystal structure of the metal, segregation of elements or phase etc. These findings are also in agreement with Symniotis (1990), who observed that the presence of two phases produces a galvanic effect between both phases and the selective dissolution of the ferrite phase take place so that a decrease in the ferrite may increase the galvanic effect due to the increase in the cathodic area (cementite) in comparison with the anodic one (ferrite). This phenomenon leads to decrease in the general corrosion resistance of the steel sample when immersed in the 1.0M NaCl solution with increase in annealing temperature.

4. CONCLUSION

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

1. The annealing temperatures gave different microstructures which in-turn affected their susceptibility to corrosion.
2. The cementite and ferrite grains are relatively segregated from each other for the welded samples than the un-welded samples as the annealing temperatures increases.

3. Corrosion rate increases with increased annealing temperature.
4. The welded samples annealed at 860 ºC and exposed to corrosion appears to be more suitable for chloride environment, since they show reasonable corrosion resistance tendency throughout the exposure period.

5. ACKNOWLEDGMENT

The author would like to thank Prof. B. O. Onyekpe for his contributions toward the success of this project.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work

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