[1.]A. O. AKINOLA, [2.]A. OYETUNJI

EFFECTS OF DIFFERENT ENVIRONMENTS ON THE CORROSION PROPERTIES OF WELDED MILD STEEL PLATE

[1.]Department of Mechanical Engineering, The Federal University of Technology, Akure, NIGERIA
[2.]Department of Metallurgical and Materials Engineering, The Federal University of Technology, Akure, NIGERIA

Abstract: The study on the effects of different environment on the corrosion properties of welded mild steel was evaluated using the weight loss analysis method. Chemical analysis was done on the mild steel plate using ARX spectrometer. Three sets of samples were used; two samples were not subjected to any corrosive environment. Two other samples were immersed in 0.3 M NaCl and the last two samples were immersed in water. Results showed that the un-welded samples exhibited greater loss in weight compared to the welded samples; the rates of corrosion of welded samples were observed to be lower in comparison with their un-welded counterparts in their corresponding corrosive environment, and the maximum values of corrosion rates of the samples were obtained for un-welded steel sample immersed in 0.3 M NaCl (1.924344 mg/mm^2/yr.); welded steel sample immersed in 0.3 M NaCl (0.509108 mg/mm^2/yr.); un-welded steel sample immersed in water (0.001821018 mg/mm^2/yr.); and welded steel sample immersed in water (0.000780731 mg/mm^2/yr.).
Keywords: environments, corrosion, weight loss, welded and un-welded samples

INTRODUCTION

Mild steel is a type of steel alloy that contains a low amount of carbon as a major constituent. Its carbon content falls within the range 0.10 – 0.25% of low carbon steel. Mild steel is the most common form of steel and it is the major material used in construction industry due to its low cost. Mild steel have good strength, hard and can be bent, worked or can be welded into an endless variety of shapes for from vehicles to building materials. Its unique properties such as low cost, high strength, hardness and easy availability, made it to have wide range of applications in many areas such as vehicle parts, truck bed floors, automobile doors, domestic appliances, nut bolt, chains, hinges, knives, armour, pipes, magnets and military equipment (Kumar and Yadav, 2013; Talabi, *et al*., 2014).

The interaction of these materials with their immediate environment results in the deterioration of the mechanical properties (such as hardness, toughness, ductility and strength) and physical properties of the materials. In metals, there is actual material loss either by dissolution or by the formation of non-metallic scale or film (Callister, 2007). This material loss is as a result of corrosion. Corrosion can therefore be regarded as the gradual degradation, destruction or deterioration of a material, usually metals, by chemical reaction with its environment. This is done as a result of the electrochemical oxidation of metals in reaction with an oxidant such as oxygen. A common example of electrochemical corrosion is rusting, which is the formation of iron oxides. This type of oxides typically provides oxide(s) or salt(s) of the original metal. All environments are practically corrosive to some degree. Some examples are air and moisture; fresh, distilled, salt, and other gases such as chlorine and ammonia (Fontana, 2007).

Corrosion is a multifaceted phenomenon that adversely affects and deteriorates metals through oxidation. Corrosion degrades the useful properties of materials and structures including strength, appearance, and permeability to liquid and gases. Katundi *et al*., (2012) characterized the corrosion resistance in the steel sheets (Hot dip galvanizing of steel sheets) used in automotive industry. They carried out simulated corrosion tests, wet/humidity test and hot dust/dry cycle talk test in laboratory conditions. They tested dynamic behaviour of the corroded specimens dynamically to simulate under the crash test conditions. They exposed the samples to changing climatic conditions in terms of humidity. It was also observed that pitting corrosion damage and crack initiation sites were developed and propagated.

This research focuses on the evaluation of the effects of different environments on the corrosion properties of welded mild steel plate for automobile body service application using the weight loss analysis method.

MATERIALS AND METHOD

— Materials and equipment

The materials used for the experiment include: low carbon steel alloy of known chemical composition, emery paper of the following grades (60, 120, 180, 220, 320, 400, 600, 800, 1200 grits), tong, plastic containers, diamond paste, and zinc rod. The chemicals used for the experiment are sodium chloride (NaCl) and distilled water.

The following equipment were used for the research: universal polishing machine; metallurgical microscope; mass spectrophotometric analyzer; universal hardness tester; cutting machine; grinding machine; digital multi-meter; pH meter; welding machine (electric-arc and oxy-acetylene); calibrated cylinder; digital vernier caliper and digital weighing balance.

— Methods

≡ Sample preparation

The mild steel plate was sectioned into six samples each of equal sizes (20 mm length by 20 mm thickness). The first three samples were un-welded while the remaining three samples were further sectioned into two each and welded (using electric-arc welding). The six samples were then separated in pairs (each pair containing a welded sample and an un-welded sample) resulting into three pairs. The three pairs are M_1 and M_2 as un-corroded samples, S_1 and S_2 as samples immersed in the chloride environment and lastly W_1 and W_2 as samples immersed in water. Samples M_1 and M_2 were purposely set aside just to examine the pre-corrosion microstructure of the steel sample. The sample description is presented in Table 1.

Table 1: Sample Description

Sample	Description
M_1	Control sample for pre-corrosion microstructural analysis for un-welded samples
M_2	Control sample for pre-corrosion microstructural analysis for welded samples
S_1	Un-welded steel sample immersed in 0.3 M NaCl
S_2	Welded steel sample immersed in 0.3 M NaCl
W_1	Un-welded steel sample immersed in water
W_2	Welded steel sample immersed in water

≡ **Chemical analysis:**

The chemical analysis was done on the mild steel plate using ARX spectrometer (Oyetunji, *et al.* 2013). Corrosion rate determination was done by weight loss method. In order to effectively calculate the corrosion rate of the samples, the initial weights of the samples were taken using the digital weighing balance. Two samples (M_1 and M_2) were not subjected to any corrosive environment for proper comparison. Two other samples (S_1 and S_2) were immersed in 0.3 M NaCl and the last two samples (W_1 and W_2) were immersed in sea water. The corrosion exercise lasted for 61 days and weighed at intervals of 4 days for the samples immersed in the chloride environment and samples immersed in sea water. The corrosion exercise was undertaken at room temperature, and the weight loss of each sample was obtained by calculating the difference between the initial weight and the obtained weight at each interval.

The corrosion rate of each sample is then calculated using equation 1 in accordance to (Fontana, 2007; Seifedine, 2008) and the results are presented in graphic form and depicted as Figures 1, 2, 3, and 4.

$$\text{Corrosion Rate; } R = \frac{KW}{\rho AT} \quad (1)$$

where:

K, a constant,

W, the weight loss of the metal in gram

T, time of exposure (hours)

A, the surface area of the metal exposed (cm^2),

P, the density of the metal (kg/m^3).

RESULTS AND DISCUSSION

— The chemical analysis result

The result of the chemical analysis of the as-received mild steel plate is as presented in Table 2.

Percentage of alloying elements = Mn 0.82 + Cr 0.080 + Ni 0.102 + Nb 0.0054 + W 0.0001 + Ti 0.0003 + V 0.0016 = 1.0094 %

From the above calculation, it can be deduced that the steel pipe is a plain carbon steel and definitely not an alloy steel because the percentage sum of all alloying elements is less than 2%. This implies that there is no inherent element to prevent or reduce the corrosion rate of the steel. The carbon content falls within the range 0.1 – 0.25%, therefore the steel is a low carbon steel (Degarmo, *et al*, 2003).

Table 2: Elemental Composition (wt %) of the As-received Mild Steel Plate

Elemental composition	Weight percent (wt%)
C	0.133
Si	0.307
Mn	0.820
P	0.0061
S	0.0081
Cr	0.080
Ni	0.102
Mo	0.038
Al	0.0036
Cu	0.178
Co	0.0085
Ti	0.0003
Nb	0.0054
V	0.0016
W	<0.0001
Pb	<0.0001
B	0.0007
Sn	0.0063
Zn	0.0042
As	0.0005
Bi	0.0010
Ca	0.0010
Ce	0.0023
Zr	0.0006
La	<0.0001
Fe	98.300

— Effects of distilled water and chloride environment on the cumulative weight loss of low carbon steel samples

Samples S_1 and S_2 were immersed in a chloride environment and Figure 1 show the cumulative weight loss of both samples. Generally, cumulative weight losses of these two samples were said to increase with increasing exposure time.

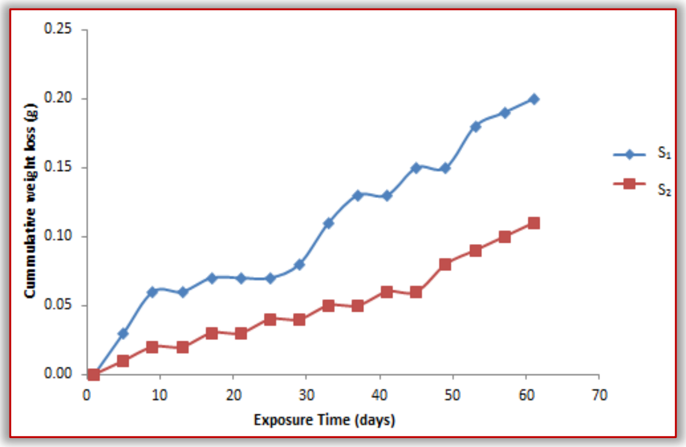

Figure 1: Variation of Cumulative Weight Loss with Exposure Time of Samples Immersed in 0.3 M NaCl

Sample S_1, being an un-welded sample, has a higher cumulative weight loss as the exposure time increases. This means that the weight lost by sample S_2 over the specified number of days were much lesser than the weight lost by sample S_1. It can be inferred from the graph that the welded sample (S_2) exhibits a better resistance to weight loss compared to un-welded sample (S_1), because the graph shows that the rate at which sample S_2 loses weight is not as high as the weight loss rate of sample S_1, (Chinwko, *et al.*, 2014).

As shown in Figure 2, the cumulative weight loss of samples W_1 and W_2 with reference to the exposure time was analyzed with the two samples immersed in sea water. The cumulative weight losses of these two samples increased with increasing exposure time. Figure 2 shows that sample W_2 (welded) did not lose much weight as sample W_1 (un-welded). This implies that the overall cumulative weight loss of sample W_1 is lower than that of sample W_2 which is an indication that the un-welded sample shows a better resistance to the loss of weight when immersed in water. The reason for this can be traced to the action and effect of welding on the steel sample, which had positively, affected the microstructural arrangement of the atoms (Oladele, *et al.*, 2014).

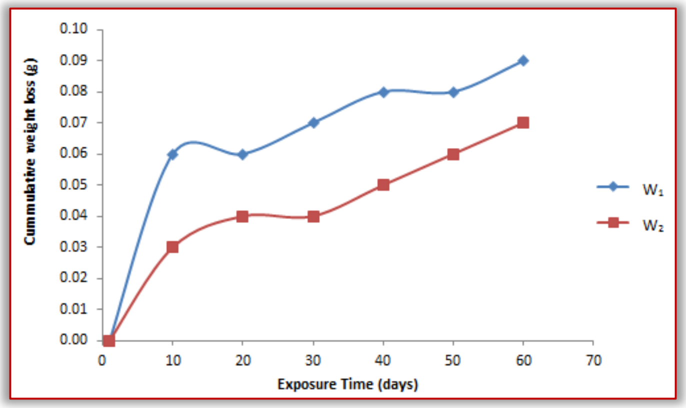

Figure 2: Variation of Cumulative Weight Loss with Exposure Time of Samples Immersed in Distilled Water

Figure 3 shows the comparison among the cumulative weight loss of all samples with distinctive difference between the cumulative weight loss of samples immersed in the chloride environment and samples immersed in distilled water, including welded and un-welded samples.

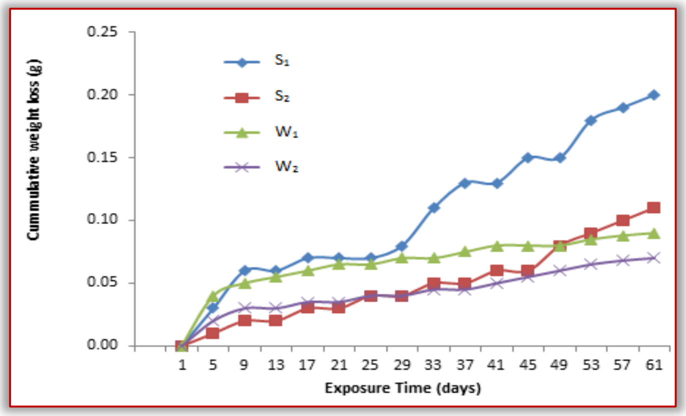

Figure 3: Variation of Cumulative Weight Loss of All Samples with the Exposure Time in Days

Generally, the welded samples (S_2 and W_2) lost lesser weight compared to their un-welded counterparts (S_1 and W_1). However, samples S_1 and S_2 which were immersed in the chloride environment lost much weight compared to samples W_1 and W_2 which were immersed in water. This is due to the fact that the chloride environment is aggressive and more corrosive than the natural water environment. The corrosive nature of the chloride was majorly due to the actions of the chloride ions on the steel sample, but the available oxygen in the water formed a corrosion cell until passive films were formed, and the rate almost became constant (Chinwko, *et al.*, 2014).

— **Effects of chloride environment on corrosion rate of low carbon steel plate samples**

Figure 4 shows the relationship between the corrosion rates of the samples immersed in chloride environment. It can be seen from the figure that both samples S_1 and S_2 exhibited a higher corrosion rate within the first 10 days compared to the remaining days. This is usually expected holding to the fact that the chloride environment, in which the samples were subjected, tends to decrease in potency over time. However, the corrosion rate of sample S_1 was far higher than that of sample S_2 because the weldment of sample S_2 undoubtedly acted against the corrosion reaction of the sample compared to the other sample S_1 which had no weldment. In addition, sample S_2 was observed to exhibit a more uniform corrosion than sample S_1 with increase in exposure time.

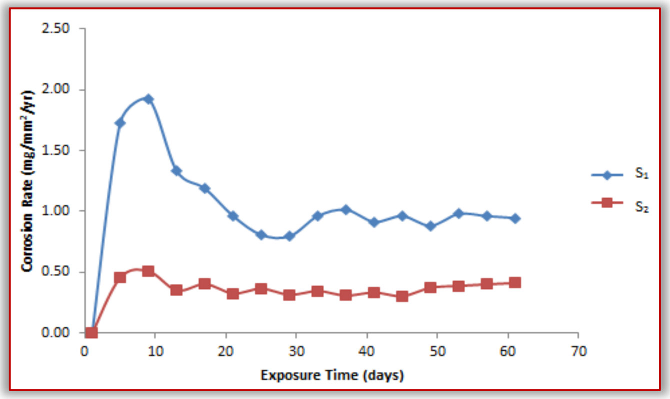

Figure 4: Variation of Corrosion Rate of Samples S_1 and S_2 with the Exposure Time in Days

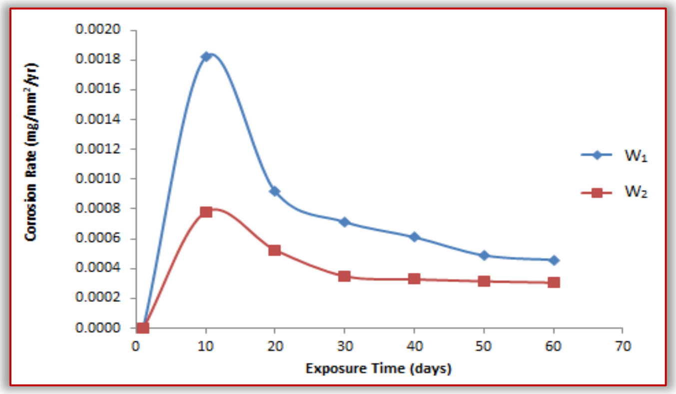

Figure 5: Variation of Corrosion Rate of Samples W_1 and W_2 with the Exposure Time in Days

The rate of corrosion of samples W_1 and W_2 in water can be seen on Figure 5. Sample W_1 (un-welded) exhibited a very low resistance to corrosion when compared to its counterpart (sample W_2 – welded). This is an indication of the fact that the welded sample exhibited a better corrosion resistance as a function of the action of the weldment with particular to the effect of the welding electrode. Although both samples shows a slightly noticeable uniform corrosion, however, their corrosion rate was very minimal and did not exceed 0.0018 mg/mm^2/yr. which implies that their rates of corrosion were within the passive extreme. To this end, the mechanical properties of the steels sample will only be slightly affected.

The corrosion rates of all samples were calculated and Figure 6 was plotted. Figure 6 therefore explains the corrosion relationship of all the samples immersed in different corrosive environments. Generally, the corrosion rates of the samples (S_1 and S_2) immersed in the chloride environment were distinctively higher than those (W_1 and W_2) immersed in water. This was mainly due to the actions of chloride ion on steel samples, which is more corrosive than water. These chloride ions react with the Fe^{2+} in the steel sample and hence, form passive corrosive films on the steel samples and these makes the corrosion of mild steel faster in the chloride environment than in water. Moreover, the welded samples were observed to possess a lower corrosion rate when directly compared with their un-welded counterpart immersed in the same corrosive environment (Seidu and Kutelu, 2013).

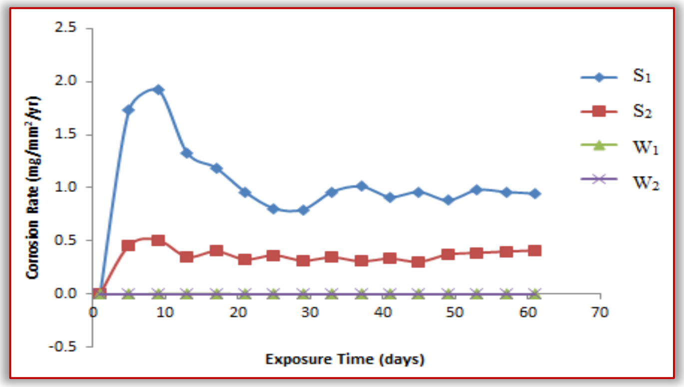

Figure 6: Variation of Corrosion Rate of all Samples with the Exposure Time in Days

CONCLUSIONS

The effects of different environments on the corrosion properties of welded and un-welded mild steel were investigated, and the following conclusions were drawn:

— The un-welded samples exhibited greater loss in weight compared to the welded samples. This is due to the fact that the weldment of the welded samples reduced the rate of weight loss in the steel samples.

— The rates of corrosion of welded samples were observed to be lower in comparison with their un-welded counterparts in their corresponding corrosive environment.

— The maximum values of corrosion rates of the samples are S_1 (1.924344 mg/mm^2/yr.), S_2 (0.509108 mg/mm^2/yr.), W_1 (0.001821018 mg/mm^2/yr.), W_2 (0.000780731 mg/mm^2/yr.). This implies that samples (S_1 and S_2) immersed in the chloride environment exhibited the higher corrosion rate than samples (W_1 and W_2) immersed in distilled water. The factor responsible for this can be traced to the actions of chloride ions which tends to form passive films on the on the steel samples (S_1 and S_2) unlike the other samples (W_1 and W_2) that corrode uniformly under the influence of water.

— The corrosion behaviour of all the steel samples were within the passive region even-though there was a noticeable discrepancy between the corrosion behavior of samples immersed in the chloride environment and the distilled water environment. This implies that because all the values of corrosion rate fell within 0.00030583 mg/mm^2/yr. to 1.924344 mg/mm^2/yr. (i.e. they did not exceed 5 mg/mm^2/yr. because active corrosion is known to be within the range of 10 mg/mm^2/yr. – 200 mg/mm^2/yr. or greater), the overall corrosion behaviour of the steel samples in the given corrosive environment can be regarded as being *Passive.*

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