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## Abstract

The susceptibility of austenitic (AISI 301) stainless steel to pitting corrosion was evaluated in sodium chloride (NaCl) solutions - 0.1M, 0.2M, 0.3M, 0.5M and 0.7M and 1.0M. Tensile tests and microscopic examinations were performed on samples prepared from the steel after exposure in the various environments. It was revealed that AISI 301 steel suffers from pitting corrosion in all the investigated solutions. This ultimately led to reduction in tensile properties with increased concentration as a function of time.

**Keywords:** Stainless steel, pitting, corrosion, chloride environment.

## Introduction

Pitting corrosion is a localized form of attack which produces holes in the metal. It is one of the most destructive and insidious form of corrosion and causes premature failure of equipment, with only a small percentage of weight loss [1, 2]. Among the halides, the most aggressive and thus, the most frequently investigated is the chloride ions, particularly its effect on pit formation in 18/8 stainless steel [1 – 3]. Chloride ions also aggravate stress corrosion cracking (SCC) failure of most martensitic stainless steels and high strength low alloy (HSLA) steels [4, 5, 6,].

Equipment / facility failure as a result of pitting corrosion is catastrophic especially those used to handle (process, transport or store) flammable fluids and aggressive chemicals. Pitting corrosion has been described as: "under certain conditions, particularly involving high concentrations of chlorides (such as sodium chloride in sea water), and moderately high temperatures and exacerbated by low pH (i.e. acidic conditions), very localized corrosion can occur leading to perforation of pipes and fittings etc. This is not related to published corrosion data

as it is extremely localized and severe corrosion which can penetrate right through the cross section of the component[7].

Due to its better corrosion resistance than the straight chromium steels, austenitic steels are widely specified for the more severe corrosive conditions such as those encountered in the processing industries. They are rust-resistant in the atmosphere and find use for architectural purposes in the kitchen, food manufacturing and dispensing and for application where contamination (rust) is undesirable. Though it has high resistance to general corrosion it may suffer from localized corrosion. Hence, in this work, the pitting corrosion susceptibility of AISI 301 stainless steel in various NaCl environments over time is investigated.

### Experimental Procedure

The AISI 301 stainless steel used for this investigation as obtained from Petroleum Training Institute (P.T.I.), Effurun, Delta State, Nigeria. The Chemical composition of the steel is presented in Table 1.0. Reagent grade NaCl (99.9% NaCl after ignition) was used in preparation of the environments.

The as-received stainless steel was machined into standard tensile test specimens and microscopic examination samples. Six different molar concentrations of the NaCl (0.1M, 0.2M, 0.3M, 0.5M, 0.7M and 1.0M were prepared from the regent grade NaCl and deionized water in equilibrium with the atmosphere. The specimens were exposed to these solutions by complete immersion. The specimens were prepared using well established procedures contained elsewhere [8, 9].

Tensile strength of the specimens in the various concentrations mentioned above was determined at intervals of 240 hours (10 days) for a period of 1200 hours (50days). The specimens were tested to fracture at room temperature using universal tensile testing machine. Microscopic examination was carried out with an Olympus optical metallurgical microscope fitted with photographic devices. Number of pits on each view was noted and recorded.

**Table 1.0: Chemical Composition of the investigated AISI 301 steel**

| Element | C | Si | Mn | P | S | Cr | Mo |
|---|---|---|---|---|---|---|---|
| Content (Wt %) | 0.047 | 0.288 | 1.28 | 0.0056 | 0.0084 | 18.59 | 1.27 |
| Element | Ni | Al | Co | Cu | Nb | Ti | V |
| Content (Wt %) | 6.56 | <0.0010 | 0.246 | 0.204 | 0.042 | 0.016 | 0.106 |
| Element | W | Pb | Sn | Fe | | | |
| Content (Wt %) | 0.058 | <0.0050 | 0.034 | 71.25 | | | |

## Results and Discussion

Table 2.0 shows the tensile properties of the investigated material in air ($X_o$) and in the chloride environments ($A_{10} - F_{10}$ to $A_{50} - F_{50}$). As can be observed, all the properties

**Table 2.0: Tensile Test Result**

| TIME (Days) | SAMPLE | CONC (Mol/dm$^3$) | YS (N/mm$^2$) | UTS (N/mm$^2$) | FS (N/mm$^2$) | % EL | % RA | $e_{env}/e_{air}$ |
|---|---|---|---|---|---|---|---|---|
| | $X_0$ | | 780 | 978 | 890 | 47.1 | 60.1 | 1.000 |
| | | | | | | | | |
| 10 | $A_{10}$ | 0.1 | 780 | 978 | 890 | 47.0 | 60.0 | 0.998 |
| | $B_{10}$ | 0.2 | 780 | 977 | 889 | 47.1 | 60.0 | 1.000 |
| | $C_{10}$ | 0.3 | 779 | 976 | 888 | 46.8 | 59.2 | 0.994 |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $D_{10}$ | 0.5 | 779 | 976 | 887 | 46.5 | 58.0 | 0.987 |
| | $E_{10}$ | 0.7 | 779 | 976 | 886 | 46.7 | 58.1 | 0.991 |
| | $F_{10}$ | 1.0 | 778 | 975 | 885 | 46.3 | 58.0 | 0.983 |
| | | | | | | | | |
| 20 | $A_{20}$ | 0.1 | 779 | 977 | 888 | 46.5 | 58.3 | 0.987 |
| | $B_{20}$ | 0.2 | 779 | 975 | 886 | 46.5 | 57.0 | 0.987 |
| | $C_{20}$ | 0.3 | 778 | 975 | 885 | 46.0 | 56.2 | 0.977 |
| | $D_{20}$ | 0.5 | 778 | 974 | 885 | 45.8 | 55.6 | 0.972 |
| | $E_{20}$ | 0.7 | 778 | 973 | 884 | 45.5 | 55.4 | 0.966 |
| | $F_{20}$ | 1.0 | 778 | 971 | 881 | 44.0 | 55.0 | 0.934 |
| | | | | | | | | |
| 30 | $A_{30}$ | 0.1 | 778 | 976 | 886 | 46.2 | 56.7 | 0.981 |
| | $B_{30}$ | 0.2 | 778 | 974 | 883 | 45.2 | 55.8 | 0.960 |
| | $C_{30}$ | 0.3 | 777 | 974 | 882 | 45.0 | 55.0 | 0.955 |
| | $D_{30}$ | 0.5 | 777 | 973 | 883 | 44.6 | 54.6 | 0.947 |
| | $E_{30}$ | 0.7 | 777 | 972 | 882 | 44.2 | 54.3 | 0.938 |
| | $F_{30}$ | 1.0 | 776 | 970 | 880 | 44.0 | 54.0 | 0.934 |
| | | | | | | | | |
| 40 | $A_{40}$ | 0.1 | 777 | 975 | 884 | 45.4 | 55.4 | 0.964 |
| | $B_{40}$ | 0.2 | 776 | 973 | 881 | 44.0 | 55.0 | 0.934 |
| | $C_{40}$ | 0.3 | 776 | 973 | 880 | 44.0 | 54.8 | 0.934 |
| | $D_{40}$ | 0.5 | 776 | 972 | 878 | 43.5 | 52.8 | 0.923 |
| | $E_{40}$ | 0.7 | 776 | 971 | 876 | 43.1 | 52.6 | 0.915 |
| | $F_{40}$ | 1.0 | 775 | 968 | 873 | 43.0 | 52.0 | 0.913 |
| | | | | | | | | |
| 50 | $A_{50}$ | 0.1 | 777 | 975 | 884 | 45.3 | 55.3 | 0.962 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| B_50 | 0.2 | 776 | 973 | 879 | 43.7 | 53.2 | 0.928 |
| C_50 | 0.3 | 776 | 972 | 878 | 43.5 | 53.0 | 0.923 |
| D_50 | 0.5 | 776 | 972 | 874 | 43.0 | 52.4 | 0.913 |
| E_50 | 0.7 | 775 | 970 | 873 | 42.8 | 52.1 | 0.909 |
| F_50 | 1.0 | 775 | 968 | 871 | 42.6 | 52.0 | 0.904 |

measured decreased with increased time and concentration.  Figures 1 – 2 present the ductility parameter [i.e. elongation parameter ($e_{env}/e_{air}$)] versus concentration and time respectively.  Again the parameter decreased with increased concentration and time.
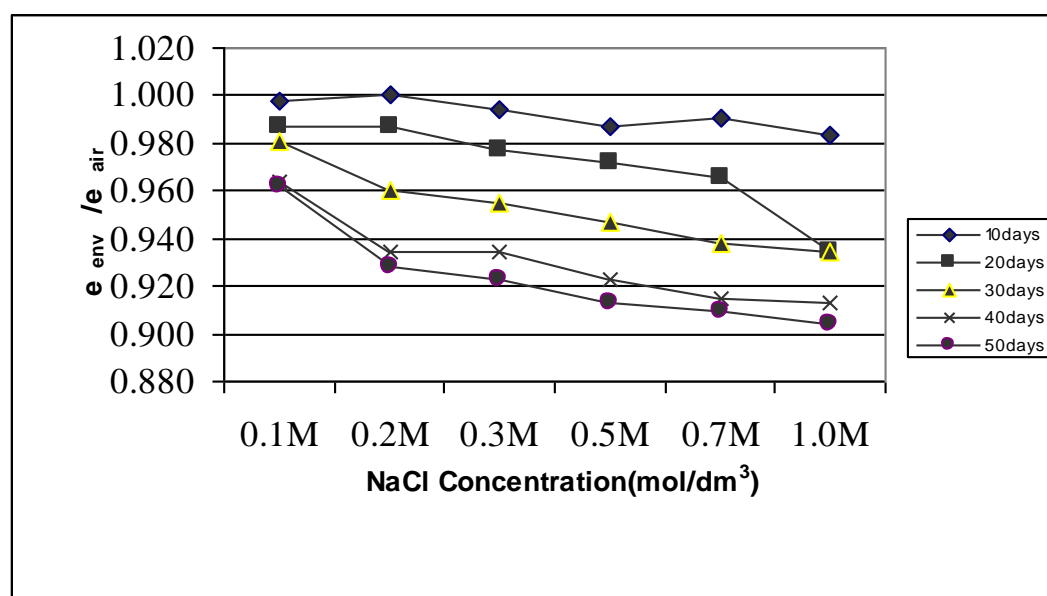


Fig. 1: Elongation Parameter Vs Concentration
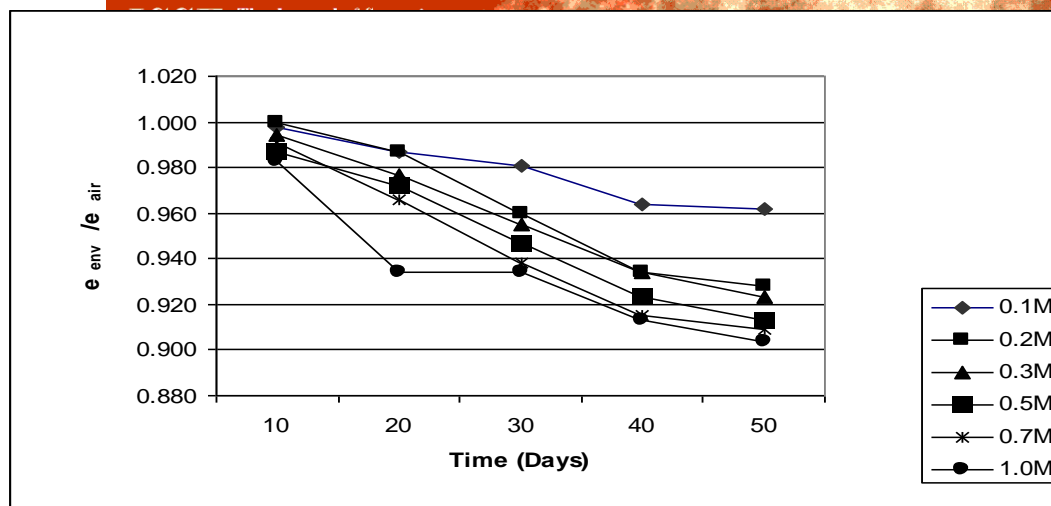
**Fig. 2: Elongation Parameter Vs Time**

Figures 3 and 4 showed that the number of pits on the specimen increased with increased concentration and time.  Plates 1 – 6 revealed the pits covered by the corrosion products (dark spots).
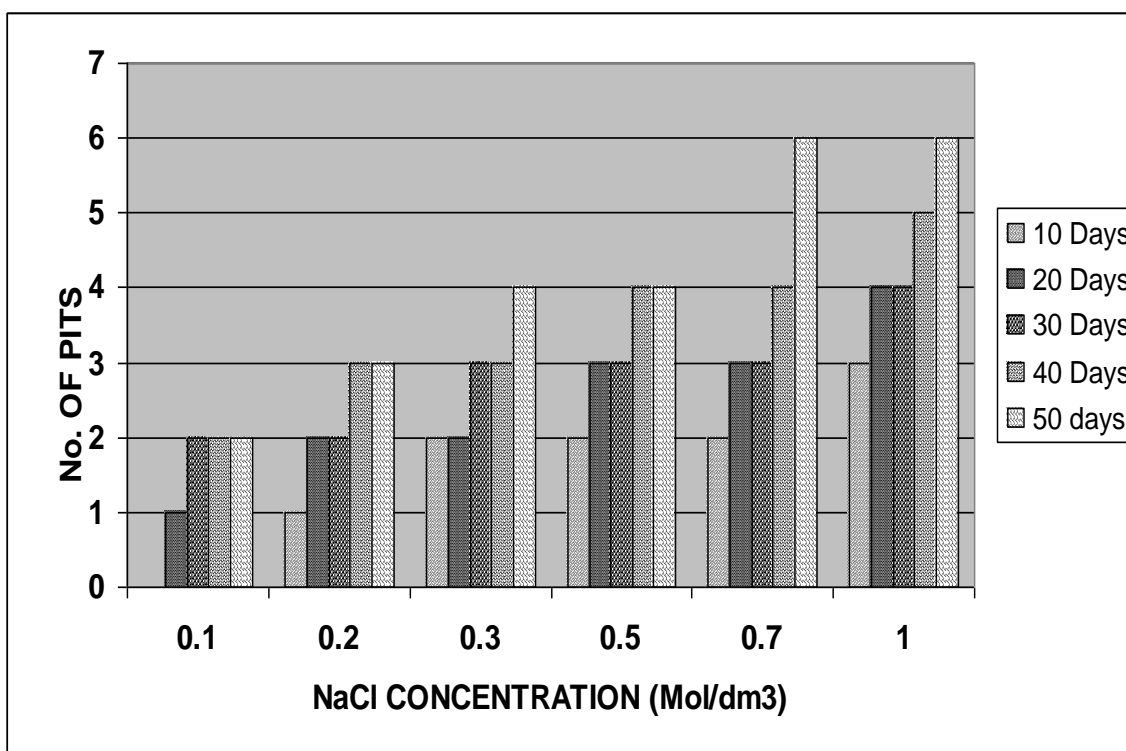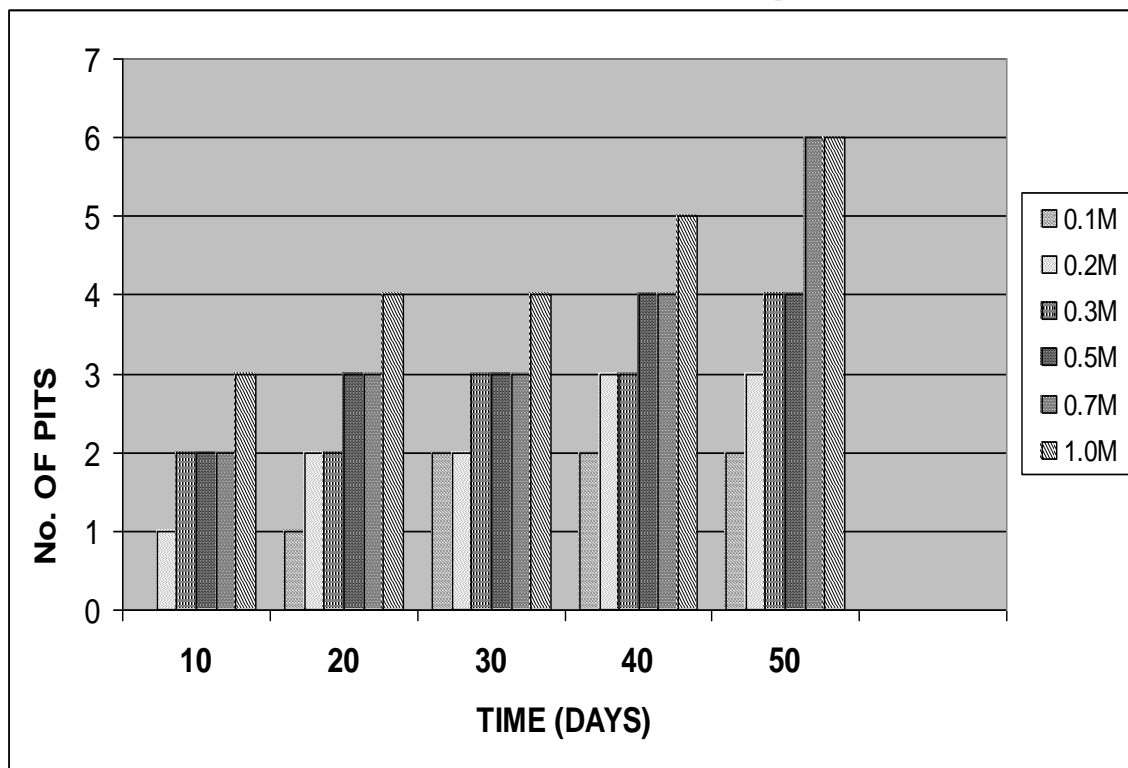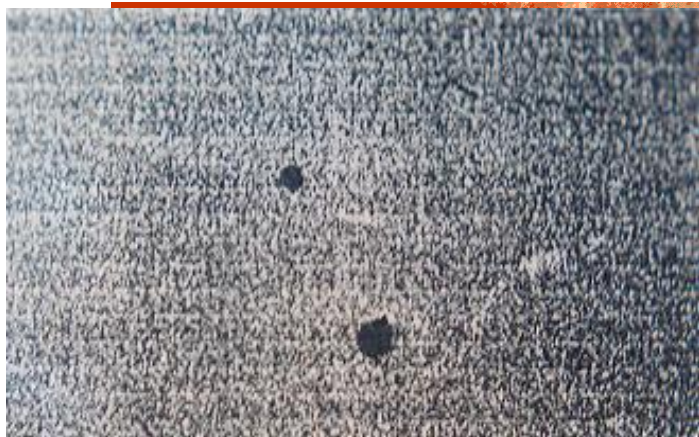


**Fig. 3: No. of Pits Vs Concentration.**

**Fig. 4: No. of Pits Vs Time.**

## MICROPHOTOGRAPH OF SOME SAMPLES



**x400**

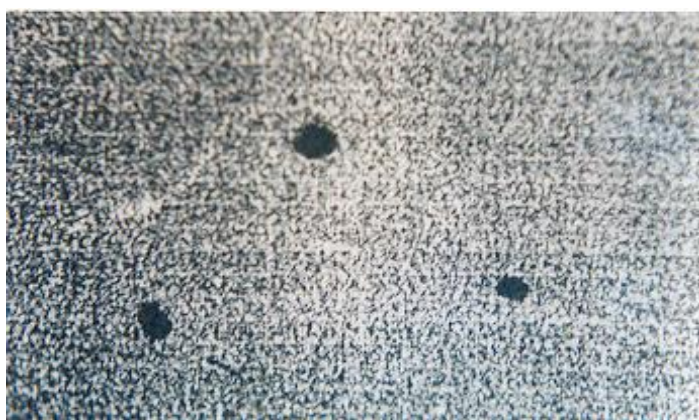**Plate 1: Optical Micrograph of A$_{20}$ (i.e the Sample in 0.1M NaCl solution at the 20$^{th}$ day)**

**x400**

**Plate 2: Optical Micrograph of B$_{20}$ (i.e. the sample in 0.2M NaCl solution at the 20$^{th}$ day)**



**x400**

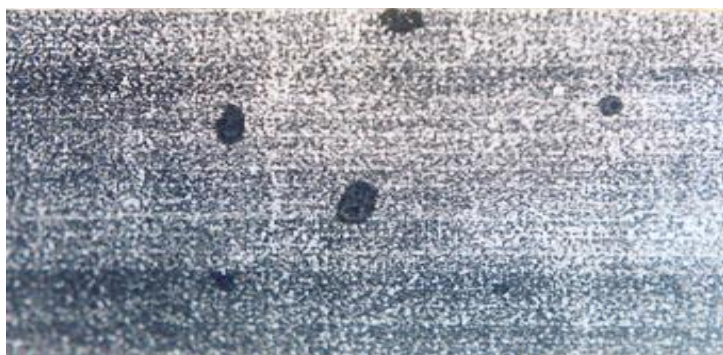**Plate 3: Optical Micrograph of C$_{40}$ (i.e. the sample in 0.3M NaCl solution at the 40$^{th}$ day)**



**x400**

**Plate 4 Optical Micrograph of D$_{30}$ (i.e. the sample in 0.5M NaCl solution at the 30$^{th}$ day)**

x400

**Plate 5 Optical Micrograph of E$_{50}$ (i.e. the sample in 0.7M NaCl solution at the 50$^{th}$ day)**



x400

**Plate 6 Optical Micrograph of F$_{50}$ (i.e. the sample in 1.0M NaCl solution at the 50$^{th}$ day)**

All the results showed that increasing chloride concentration has adverse effect on the properties of the material. The loss of these properties could be attributed to the initiation and growth of pits as could be verified from figures 3 and 4. This can better be explained by Uhlig's [10] Oxygen adsorption theory of passivity; chloride ion adsorbed on the metal surface is in competition with dissolved oxygen. This adsorption increases the exchange current and critical current density for anodic dissolution, leading to breakdown of passivity. The dissolution of the passive film is controlled by increasing hydrogen ion (H$^{+}$) concentration and the presence of chloride ion (Cl$^{-}$) has stronger capability to cause breakdown of the film [11,12]. Chloride ion causes breakdown of passive state leading to the formation of pits.

Figures 1 – 2 showed decline in ductility parameters. The most useful parameter to evaluate SCC susceptibility is the elongation parameter, which compares a test performed under corrosive condition with a test

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performed under inert conditions (air or oil). A ration ($e_{env}/e_{inert}$) is evaluated and if the ratio is near 1.0, there is no susceptibility to SCC [6, 13]. Though, figure 15, 2 portray deviation from mechanical failure, the deterioration of the ductility parameter cannot be attributed to SCC as the elongation parameter only decreased from 1.0 to 0.904 within the investigated concentration and time. But this could rather be attributed mainly due to the nucleation and growth of pits as evident in figures 3 and 4 and in plates 1 – 6. It takes longer time for pit to initiate in lower concentrations as can be seen in figures 3 – 4 having no pit for sample in 0.1M within the first 240 hours (10 days). Growth of the pits after initiation cause greater harm to the investigated material.

Inclusions act as stress raisers for pit initiation. This could be verified from plates 5 – 6, which revealed that some of the pits were formed around inclusions as shown by the white ring – like structures enclosed in the pits.


## Conclusion

From the foregoing, it is therefore concluded that the investigated material (AISI 301) is susceptible to pitting corrosion in chloride environments. The susceptibility increases with increased chloride concentration as the time of exposure increases. It was equally observed that the initiation and growth of pits resulted to increased loss of tensile properties of the steel within the investigated time and concentrations.

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