



PITTING CORROSION SUSCEPTIBILITY OF AISI 301 STAINLESS STEEL IN CHLORIDE ENVIRONMENTS

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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. The mechanism of pitting corrosion of the samples involved pit initiation and growth, which is aggravated by chloride ion. This ultimately led to reduction in tensile properties with increased concentration as a function of time.

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

1. 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 - 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: "being insidious, which can result to catastrophic failure of facility 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" [1,7]. Adewuyi [8] observed that corrosion rate of aluminum alloys in tomatoes juice increases with increased concentrations of sodium chloride solution.

Due to its better corrosion resistance than the chromium steels, austenitic steels are widely specified for the more severe corrosive conditions such as those encountered in the processing industries [9, 10]. They are rust-resistant in the atmosphere and find use for domestic 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 NaCl solutions over time is investigated.

2. 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. Reagent grade NaCl (99.9% NaCl after ignition) was used in preparation of the aqueous solutions.

The as-received stainless steel was machined into standard tensile test specimens and optical 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 reagent 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 [11, 12].

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: 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			

Table 2.: Tensile Test Result

TIME (Days)	SAMPLE	CONC (Mol/dm ³)	YS (N/mm ²)	UTS (N/mm ²)	FS (N/mm ²)	% EL	% RA
	X ₀		780	978	890	47.1	60.1
10	A ₁₀	0.1	780	978	890	47.0	60.0
	B ₁₀	0.2	780	977	889	47.1	60.0
	C ₁₀	0.3	779	976	888	46.8	59.2
	D ₁₀	0.5	779	976	887	46.5	58.0
	E ₁₀	0.7	779	976	886	46.7	58.1
	F ₁₀	1.0	778	975	885	46.3	58.0
20	A ₂₀	0.1	779	977	888	46.5	58.3
	B ₂₀	0.2	779	975	886	46.5	57.0
	C ₂₀	0.3	778	975	885	46.0	56.2
	D ₂₀	0.5	778	974	885	45.8	55.6
	E ₂₀	0.7	778	973	884	45.5	55.4
	F ₂₀	1.0	778	971	881	44.0	55.0
30	A ₃₀	0.1	778	976	886	46.2	56.7
	B ₃₀	0.2	778	974	883	45.2	55.8
	C ₃₀	0.3	777	974	882	45.0	55.0
	D ₃₀	0.5	777	973	883	44.6	54.6
	E ₃₀	0.7	777	972	882	44.2	54.3
	F ₃₀	1.0	776	970	880	44.0	54.0
40	A ₄₀	0.1	777	975	884	45.4	55.4
	B ₄₀	0.2	776	973	881	44.0	55.0
	C ₄₀	0.3	776	973	880	44.0	54.8
	D ₄₀	0.5	776	972	878	43.5	52.8
	E ₄₀	0.7	776	971	876	43.1	52.6
	F ₄₀	1.0	775	968	873	43.0	52.0
50	A ₅₀	0.1	777	975	884	45.3	55.3
	B ₅₀	0.2	776	973	879	43.7	53.2

TIME (Days)	SAMPLE	CONC (Mol/dm ³)	YS (N/mm ²)	UTS (N/mm ²)	FS (N/mm ²)	% EL	% RA
	C ₅₀	0.3	776	972	878	43.5	53.0
	D ₅₀	0.5	776	972	874	43.0	52.4
	E ₅₀	0.7	775	970	873	42.8	52.1
	F ₅₀	1.0	775	968	871	42.6	52.0

3. Results and Discussions

Table 2.0 shows the tensile properties of the investigated material in air (X_0) and in the sodium chloride solutions (A₁₀ – F₁₀ to A₅₀ – F₅₀). As can be observed, all the properties 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.

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). 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 described by Uhlig’s [13] Oxygen adsorption theory of passivity which explains that 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 [14, 15]. Chloride ion causes breakdown of passive state leading to the formation of pits.

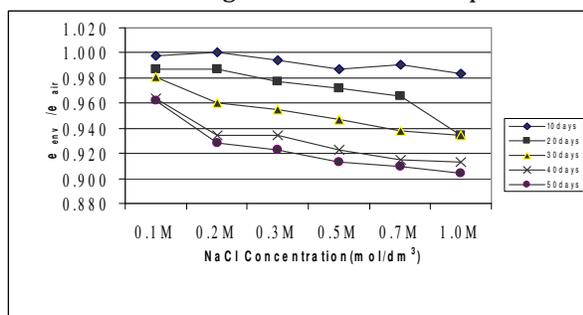


Fig. 1: Elongation Parameter Vs Concentration

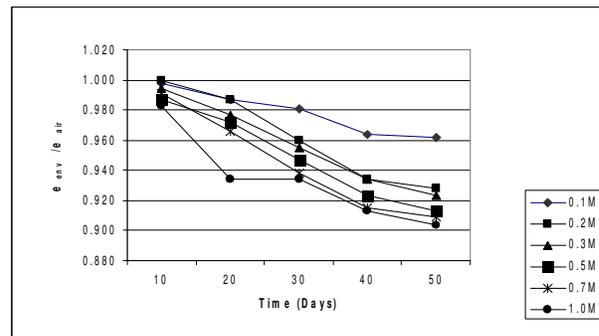


Fig. 2: Elongation Parameter Vs Time

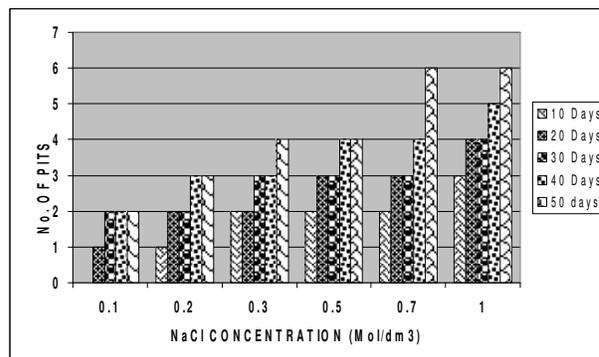


Fig. 3: No. of Pits Vs Concentration

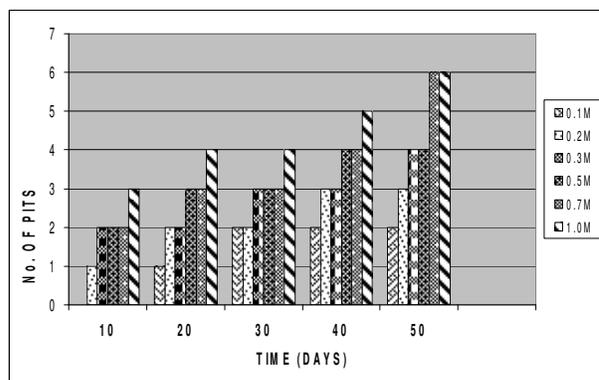
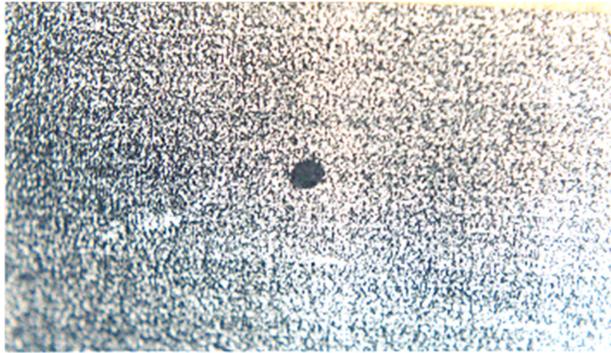
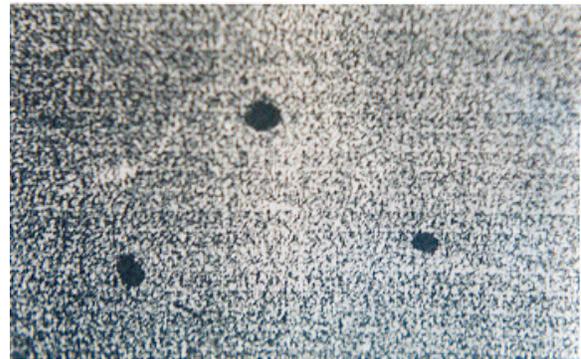


Fig. 4: No. of Pits Vs Time (days)



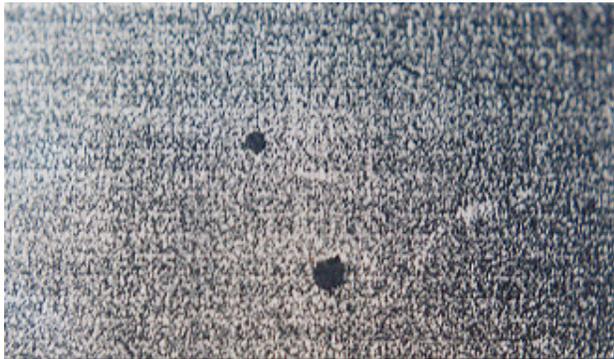
X400

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



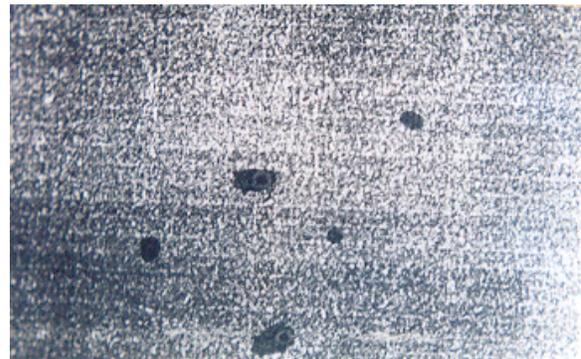
X400

Plate 4: Optical Micrograph of D_{30} (i.e. the sample in 0.5M NaCl solution at the 30th day)



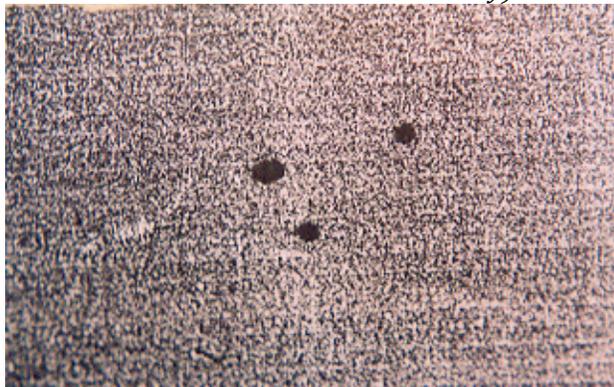
X400

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



X400

Plate 5: Optical Micrograph of E_{50} (i.e. the sample in 0.7M NaCl solution at the 50th day)



X400

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



X400

Plate 6: Optical Micrograph of F_{50} (i.e. the sample in 1.0M NaCl solution at the 50th day)

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 performed under inert conditions (air or oil). A ratio (e_{env}/e_{inert}) is evaluated and if the ratio is near 1.0, there is no susceptibility to SCC [6, 16]. Though, figure 1 – 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 resulted in the deterioration of the properties of the 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.

4. 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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