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Susceptibility of 316L Austenitic stainless steel and its weldment to stress corrosion cracking

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---***ABSTRACT***---

Slow strain rate test technique was employed to detect the susceptibility to stress corrosion cracking of conventional 3l6L austenitic stainless steel and its weldment. Tensile testing was carried out at room temperature in air and in 3% NaCl solution of pH 1.5 at open circuit potential and under controlled potential. Tensile testing at open circuit and controlled potential resulted in a decrease in tensile properties and time to failure. However, the reduction in tensile properties and % drop in the time to failure, along with the semi brittle features of fracture surface morphology, indicated little evidence for stress corrosion cracking susceptibility. This could be associatedwith the relatively intermediate stacking fault energy values of the tested materials. Stress corrosion cracking susceptibility of 3I6L weldment was competentto that of 3l6L base metal by virtue of delta ferrite in the microstructure of the weld metal. The results were discussed in relation to the effect of chemical composition on the deformation and stress-corrosion behaviour of the investigated materials.

KEYWORDS – *316L, austenitic stainless steel, NaCl, stress corrosion cracking, welding*

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I. INTRODUCTION

Austenitic stainless steels find wide applications as structural materials and components of heat transfer equipment in the chemical, petrochemical, and conventional as well as nuclear power industries as cladding materials in pressure vessels and control rod assemblies. They also constitute integral parts of the components of both the front end and back end of the nuclear fuel cycle [1].The corrosion resistance of these materials have been greatly enhanced through the development of low carbon Mo free 304L alloy and Mo bearing steels; 316L,3l7L and 304L[2].

Although the corrosion resistance of austenitic stainless steels is usually quite outstanding,they are susceptible to both transgranular and intergranular stress corrosion cracking (SCC).Intergranular cracking most often occurs in alloys, which have been sensitized, whereastransgranular cracking is independent of sensitization. The most detrimental agent that hasbeen recognized for cracking austenitic stainless steels is the chloride ion, and chloride attack constitutes the most important drawback to the use of these steels. These alloys are most susceptible to hot concentrated chloride solutions, but failures have been reported in solutionswith chloride contents as low as 5 ppm. [3].

Electron microscope observations have suggested that the metals and alloys most susceptibleto transgranular SCC have low stacking fault energies [4]. Austenitic stainless steel grade 304L(low slacking fault energy 18 J/m2) has greater SCC susceptibility in chloride media thangrade 3l6L (greater stacking fault energy; 78 J/m2) [4]. The most plausible mechanism thatcould describe the process of SCC in austenitic stainless steels is the "slip-dissolution" model [5].The possible effects are either dissolution in the corrosive medium of material in stackingfaults, or of plastically deformed metal in piled-up dislocations, in slip bands at the crack tip. The consequence of this process is the rupture of the passive film and onset of SCC [5]. Thisimplies that resistance of this type of SCC may be increased, by adjusting the alloycomposition to increase the stacking fault energy. The present investigation evaluates theeffect of corrosion electrochemical parameters on the susceptibility to stress corrosioncracking of 3l6L and its weldment, with emphasis on the role of stacking fault energy in determining modes of deformation and stresscorrosion.

II. EXPERIMENTAL

The base metal of the material used in this investigation was the conventional 3l6L stainless steel. The 3l6L steel received a solution heat treatment at 1120 °C and then water quenched. Gas shielded arc welding (GSAW) was applied using a filler material 3l6/SKR electrode for welding 3l6L steel. The chemical composition of the welding electrode (filler material) is given in Table 1. The ferrite number of the welding electrode was about 10 FN.

Table l: Chemical composition of base metaland welding electrode

Element	C	Si	Mn	Cr	Ni	Mo	N
316L	0.02	0.44	1.44	16.67	10.58	2.58	0.06
316L/SKR	0.02	0.8	1.0	I8.0	11.5	2.8	-

Test specimens were in the form of notched tensile round bars with a diameter of 8 mm and alength of 150 mm. The notch angle was 60° and the root radius was 1.75 mm. Tensile tests were carried out at room temperature using Hydropuls standard testing machine (SCHENCKPSB25) at a strain rate of

8xl0-5s-1. The tensile properties of the studied materials wereevaluated in air as a chemically inert atmosphere. Stress corrosion cracking susceptibility (SCC) experiments were first conducted in 3%NaCl solution of 1.5 pH value without applying electrochemical potential, i.e. at open circuit potential. The low pH solution value was selected to simulate that which might be formed inside pits, crevices or even cracks in chloride ion bearing environments. Specimens were then tested in 3% NaCl solution of 1.5pH value under certain applied potential. The value of the applied potential for each test material was selected so as to be more active than its break down potential. A special electrochemical cell was designed for the stress corrosion cracking susceptibility tests. The tensile specimens were insulated with epoxy paint leaving the notch part unmasked to reducethe total current flow during conducting stress- corrosion runs. Fracture surface morphologyof the tested materials in the base metal and weldment conditions was examined usingscanning electron microscope (SEM), Jeol-JSM-400.

III. RESULTS

3.1. Tensile Properties

Tensile properties of the investigated materials after testing in air, in3% NaCl solution (opencircuit potential) and in 3%NaCl solution under applied potential are summarized in Table 2.Fig. 1 shows typical stress-strain curves of tested materials after tensile testing in air atroom temperature. The main observation is that the 316L weldment acquires less elongation than that of the base material.

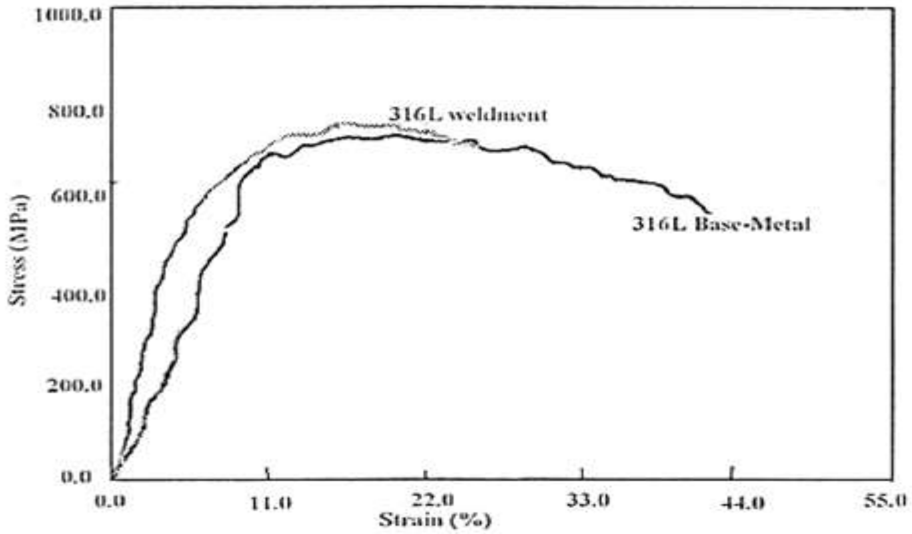

Figure l: Stress-strain curves of 316L base metal and its weldment

Table 2 shows that for all test conditions the yield and tensile strength values for the weld material are higher than those for the base metal. On the otherhand, the values of the strainparameters (%reduction in area and % total elongation) are higher in the case of the base metal.

As can be seen, tensile testing at open circuit and controlled potential resulted in a decreasein tensile properties and time to failure, the decrease being more pronounced in the yield strength and the total elongation values. Itis worthy to note that, theleast tensile properties and time to failure values are in the case of testing at the applied potential.

Table 2: Tensile properties of the testedmaterials

Material	Test condition	σ_y (MPa)	σ_U (MPa)	RA (%)	E_T (%)	Time to Failure (h)
3I6L B.M	Air	540	750	75	43	1.8
	Solution	510	720	76	40	1.6
	Cont. Pot. (-l00mV)	460	700	72	40	1.5
3I6L W.M	Air	620	780	55	l9	1.1
	Solution	580	720	57	18	1.0
	Cont. Pot. (l00mV)	560	700	53	16	0.9

σ_y yield strength, σ_u tensile strength, RA :reduction in area, E_T: total elongation

An important index, which can be used to compare the SCC susceptibility of the tested materials at different testing conditions, is the lime to failure (Tf). The value of this index is governed by all parameters that take part in determining the test duration. These are stress(yield, tensile), strain (%reduction in area and % elongation) and strain hardening (rate andcapacity) as well as the test environmental conditions (open and controlled potential). SCC susceptibility%, as presented in Table 3, was evaluated using the following relation.

SCC Susceptibility, % = (T_f air – T_f environment) / T_f air

The following results indicate that stress corrosion cracking susceptibility of 3I6L weldment was competent to that of 3l6L base metal.

Table 3: SCC susceptibility % of tested materials

Material	Test condition	Susceptibility %
3I6L B.M	Solution	11
	Cont. Pot. (100 mV)	17
3I6L W.M	Solution	9
	Cont. Pot. (100 mV)	17

3.2. Fractography

Examination of the fracture surface of tested specimens, at low magnifications, demonstratedtwo distinct fracture zones; the inner one which covered most of the fracture surface and the outer one, at the rim of the fracture surface. The inner zone, at all test conditions, was characterized by fibrous morphology which was identified at higher magnifications ascoalesced microvoids (dimples), a feature characteristic of ductile fracture. The dimple sizewas finer inthe case of weldment specimens. This agrees with tensile test results since the alloy weldment condition exhibited greater yieldand tensile strength levels over alloy base metal condition. The outer zone of the fracturesurface displayed fine microvoids along with brittle fracture features that differed in morphology according to test condition.

The testing tensile specimens were round and notched in the middle. The stress concentration generated at the root of the notch would lead to a localization of the tensile stress as well asthe electrochemical reaction of the solution. It is then expected that cracks would nucleate atthe lo1ch root and propagate inward. Attention was given to the fracture features at the outerzone of the specimens since it represents the site where synergistic effect of stress and electrochemical interaction takes place. The following figures present fractographs for the outer zone of investigated materials after testing in 3% NaCl solution (open circuit potential)and after testing under controlled potential.

Fig. 2 shows that the fracture surface morphology of 3l6L base metal. (Fig.2a) and 3l6L weldment (Fig.2b), tested in 3%NaCl solution, is characterized by fine dimples developed by micro-void coalescence. However, the dimple size is much finer in the case of 3l6L weldment. It can also be seen that the dimpled structure of the 3l6L base metal envelopes small faceted regions. These faceted regions indicate onset of transgranular decohesion, that might have arisen from the chemical interaction of the solution with the 3l6L base metal under the applied tensile stress. Theabsence of these regions in the case of 3l6L weldment reflects higher resistance to chemicalinteraction with the solution during tensile loading. The susceptibility of the 3l6L weldment,under this test condition, is a little bit lower than that of the 316L base metal (9 % vs. 11%).

The application of controlled potential to tensile testing in the 3% NaCl solution resulted inadditional fracture surf-ace features that indicate outbreak of brittleness. This is manifested aslarger decohesion facets alongside fine dimples in the case of 3l6L base metal (Fig.3a) whichcaused the susceptibility,to increase Io 17 %. On the contrary, the fracture surface of 316Lweldment (Fig.3b) is still free from similarfacets but exhibited a kind of distortion of the dimpledstructure.

The fracture surface features described above show that, as testing condition change fromopen circuit to controlled potential (nobler potential), the morphology becomes more faceted.This indicates that less plastic deformation is experienced and semi brittle fracture took place.This observation shows that, even highly ductile materials as austenitic stainless steels mayexhibit fracture with little deformation (outer rim), although neighboring regions of thematerial reveals anabsenceof embrittlement (inner zone). Stress corrosion cracking usuallyfollows branched paths and feathery, transgranular rupture is produced. Nevertheless, other forms of brittle fracture can be present (cleavage and quasi cleavage). The absence of any of these brittle features in the fracture surface of the studied alloys gives evidence to a little susceptibility of stress corrosion cracking.

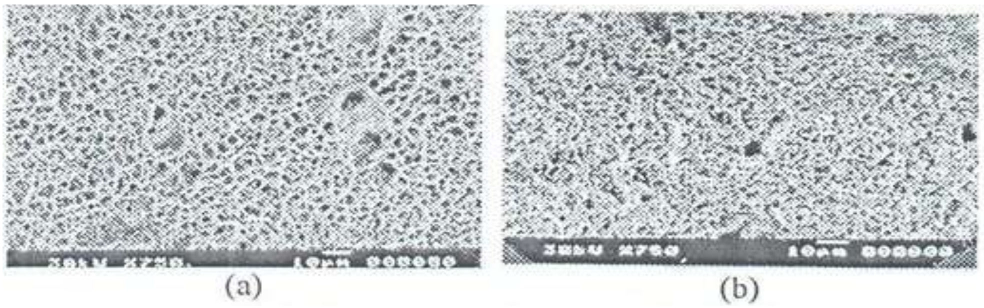
(a) (b)

Figure 2: 316 Base metal (a) and 316 weldment (b) tested in 3%NaCl solution

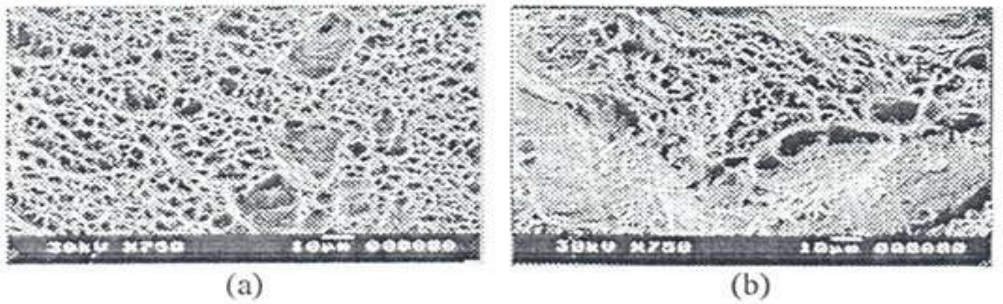
(a) (b)

Figure 3: 316 Base metal (a) and 316 weldment (b) tested under controlled potential

IV. DISCUSSION

The results showed that the investigated materials had developed little signs of stresscorrosion cracking susceptibility after testing in 3% NaCl solution at open circuit and atcontrolled potential. Despite the observed reduction in tensile test parameters (strength,ductility, and time to failure), the amount of this reduction is not sufficient to describe occurrence of stress corrosion cracking. In addition, fractographic morphology did not reveal features of brittle fracture as no transgranular cleavage or quasicleavage were identified. The difference in the response of the studied materials to the applied test conditions, despite their overall reduced susceptibility to stress corrosion cracking will be discussed.

Susceptibility to stress-corrosion cracking depends on simultaneous existence of certaincritical conditions. These conditions include electrochemical parameters as concentration of corrosive medium, pH, electro chemical potential and temperature. Alloy composition plays a key role in SCC susceptibility as it determines passive film stability, and magnitude of the stacking fault energywhich are crucial to the process of SCC of austenitic stainless steels.

The most feasible mechanism that could account for SCC of austenitic stainless steels is the"slip dissolution" model [5]. The main factor which controls this mechanism is the stackingfault energy value. In alloys with low stacking fault energy, deformation takes the form of planner slip. This type of slip has been associated with transgranular SCC, and in high-chloride environments, evidence was presented that preferential corrosion occurred along the high dislocation-density plane created by planar slip [5].

The reduced susceptibility of the studied materials (Table 3) could be attributed mainly to alloy composition. The type and content of alloying elements (Mo, Ni, and Cr) present in thebase metal and weld material under investigation would imply moderate magnitude of stacking fault energy and satisfactory level of passive film stability [6]. There upon, it could been visage that, under the combined action of mechanical stress and corrosive environment, the rate of repassivation of the protective oxide film would be greater than the rate of film rupture at the crack tip. Thus, a limited amount of SCC susceptibility, for the studied materials is yielded. Other factors that could have contributed to the limitation of SCC susceptibility comprise test temperature, strain rate and notch bluntness [7].

As mentioned earlier, the 3l6L weld material contained about l0% deltaferrite. The presenceof ferrite in austenitic stainless steels is known to reduce its corrosion resistance through selective interaction with the chloride medium. SCC susceptibility of the 316 base metal was close to that of the 316 weldment at open and controlled potential (Table 3). This indicates that the ferrite phase had played a role in raising the resistance against SCC. It was shown that the existence of delta ferrite in austenitic stainless steels generally improves resistance to chloride ion SCC. The beneficial effect of delta ferrite is generally attributed toits interference with the propagation of cracks across the austenite matrix. In this instance, theaustenite grains crack transgranulary

but continuation of the transgranular crack path through the ferrite grains is blocked, resulting in intermittent transgranular and intergranular cracksegments in a zigzag pattern [8]. Nevertheless, considerable quantities of ferrite must bepresent, such as those found in duplex stainless steels, in order to obtain significantly improved resistance to SCC.

V. CONCLUSIONS

3l6L austenitic stainless steels and its weldment were tensile tested in air, and in 3% NaCl solution at open circuit and at controlled potential, at slow strain rate. The following conclusions were drawn:

1. Testing in 3% NaCl solution at open circuit and at controlled potential leads to a reduction in tensile strength and ductility as well as time to failure for all tested materials.
2. The investigated base metal and its weldment have limited stress corrosion cracking susceptibility, indicated by the minor reduction, in tensile properties and time to failure in addition to the semi brittle features of fracture surface morphology.
3. 3l6L weldment has stress corrosion cracking susceptibility comparable to that of 3l6L base metal.
4. The apparent resistance of the studied materials to stress cracking could be associated with the effect of alloying elements content on the stacking fault energy and oxide film stability.

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