S-N Curve Estimation of AISI 304 in Air and Corrosive Environment Using Finite Element Method

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Abstract

Endurance limit that can be predicted from the S-N curve has become an interesting issue for reliability and quality assessment of stainless steel especially in corrosion environment. However, the study of corrosion mechanism related to S-N curve is not well established. This paper discusses application of finite element method for S-N curve estimation of AISI 304 in air and corrosive environment. Finite element simulation was carried out using ANSYS Release 13. An experimental set up using fatigue rotary bending machine based on ASTM E466 standard is used to validate the simulation result. In the air environment, endurance limit obtained from finite element analysis is similar to references. In the corrosive environment, even though the endurance limit obtained by finite element analysis is lower than that obtained by experimental set up, the trend line of S-N curves for both works and analyses are the same. Therefore, finite element simulation result can be used to estimate S-N curve as good as the experimental set up.

Keywords: finite element method, fatigue life, AISI 304, and corrosive environment.

Introduction

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses. Fatigue is one of the most common failure mechanism in metal, estimated to be approximately 90% of the source of all metallic failures (Callister, 2007). Furthermore, fatigue can occur suddenly without preliminary signs and result in catastrophic failures. Various methods have been developed to address this issue. The most common method is to use stress versus cycles plot, or S-N curve. This curve plot fatigue strength with respect to time-to-failure. In general, the purpose of S-N curve estimation is to avoid failure problems in relation to safety, economy, durability and liability.

Austenitic stainless steels are the most commonly used metallic materials in application requiring corrosion resistance because of their high strength and ductility (Mc.Guire, 2008). However, austenitic stainless steels has some of relative weakness, such as austenitic stainless steels are less resistant to cyclic oxidation than are ferritic grades and they can experience stress corrosion cracking (SCC) if used in an environment to which they have insufficient corrosion resistance. The risks of these limitations can be avoidable by taking proper precautions such as to know the endurance limit of the material before.

Li et al (2006) has done simulation for cyclic stress/strain evolutions and redistributions, and evaluation of fatigue parameters suitable for estimating fatigue lives under multi-axial loadings. The local cyclic elastic–plastic stress–strain responses were analyzed using the incremental plasticity procedures of ABAQUS finite element code for both smooth and notched specimens made of three materials: a medium carbon steel in the normalized condition, an alloy steel quenched and tempered and a stainless steel, respectively. For experimental verifications, a series of tests of biaxial low cycle fatigue composed of tension/compression with static and cyclic torsion were carried out on a biaxial servohydraulic testing machine. Comparisons between numerical simulations and experimental observations show that the FEM simulations allow better understanding on the evolutions of the local cyclic stress–strain. But, this paper not considering the effect of corrosion fatigue.

In this paper, application of finite element method for S-N curve estimation of AISI 304 in different media, i.e air and corrosive environment, is discussed. Specimen models are based on ASTM E-466. This study is expected to give information on the fatigue life of AISI 304 in evaluating the application of the air and corrosive environment. So, that further studies on the optimization of the design components can be done for this type of material.

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The Material and Experimental Method

Material

The chemical composition of the AISI 304 is given in Table 1. Figure 1 show geometry of specimen is used in this experimental set up. Before fatigue test, the cross-section was mechanically polished using progressively finer grades of abrasive paper followed by buff-finishing to make sure no scratch on surface of specimen.

Table 1 Chemical composition (wt.%)

C	Cr	Fe	Mn	S	Ni	P	Si	N
0.08	20.00	74.0	2.0	0.03	12.00	0.045	0.75	0.10

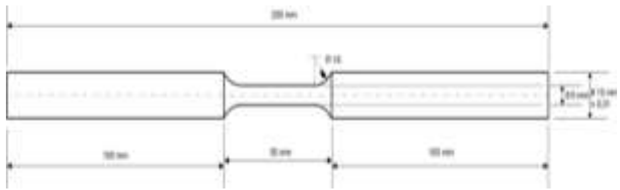

Figure 1. Specimen configuration.

Experimental Methods

Fatigue tests were performed using four points rotary bending fatigue test machines operating at frequency of 50Hz shown in Figure 2. Fatigue tests were performed with five different loading conditions;12 kg, 10 Kg, 8 Kg, 7 Kg, and 6 Kg. The corrosive environment is simulated using 3.5% NaCl solution.

Figure 2. Rotating Bending Machine.

Simulation Method

A standard specimen has been analyzed by finite element method, subjected to a condition similar to experimental test. Since the test conditions were the same, it is possible to compare the results and evaluate whether the finite element method could be suitable to predict fatigue life of AISI 304.

ANSYS Release 13 was employed in this work which is running under windows 7 ultimate. In ANSYS Fatigue module, the available type of fatigue analysis is Stress Life and Strain Life. Stress Life is based on empirical S-N curves and take into account a variety of factors. Strain Life is based upon the Strain Life Relation Equation where the Strain Life Parameters are values for a particular material that best fit the equation to measured results. The Strain Life Relation requires a total of six parameters to define the strain-life material properties; four strain-life parameter properties and the two cyclic stress-strain parameters. And the six parameters required for a Strain Life analysis are Fatigue Strength Coefficient, Fatigue Strength Exponent, Fatigue Ductility Coefficient, Fatigue Ductility Exponent, Cyclic Strength Coefficient, and Cyclic Strain Hardening Exponent. The Strain Life Relation equation is shown as:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_f}{E}\left(2N_f\right)^b + \varepsilon_f\left(2N_f\right)^c \quad (1)$$

Where:

$\Delta\varepsilon$ = Total Strain Amplitude
$\Delta\sigma$ = Stress Amplitude
E = Modulus of Elasticity
N_f = Number of Cycles to Failure

The two cyclic stress-strain parameters are part of the equation shown as:

$$\Delta\varepsilon = \frac{\Delta\sigma}{E} + 2\left(\frac{\Delta\sigma}{K}\right)^{1/n} \quad (2)$$

Where:

$\Delta\varepsilon$ = Strain Amplitude
$\Delta\sigma$ = 2 x the Stress Amplitude
E = Modulus of Elasticity
K = Cyclic Strength Coefficient
n = Cyclic Strain Hardening Exponent

Solid Modeling

In Simulation monotonic and cyclic properties for AISI 304 are given in Table 2 that obtained from Colin (2010). Load from experiment is converted to moment in simulation.

Linear elastic model with the static structural analysis is chosen for the analysis. Two moments are applied on two sides of the specimen with different direction, and cylindrical support, which is chosen to hold a specimen in tangential direction, is set to free as shown in Figs. 3.

Table 2. Monotonic and cyclic properties for AISI 304

monotonic properties	SS304
Modulus of elasticity	196
Yield strength (0.2% offset), S_y (MPa)	208

Ultimate tensile strength, S_a (MPa)	585
Percent reduction in area, %RA	84
Strength coefficient, K (MPa)	680
Strain hardening strength, n	0.214
True fracture strength, σ_f (MPa)	2051
True fracture ductility, ε_f (MPa)	186
Cyclic properties	SS304
Cyclic modulus of elasticity, E' (GPa)	196
Fatigue strength coefficient, bilinear fit, $\sigma'_{f1}/\sigma'_{f2}$(MPa)	330/1890
Fatigue strength exponent, bilinear fit, b_1/b_2	-0.0373/-0.0204
Fatigue ductility coefficient, ε'_f	0.1325
Fatigue ductility exponent, c	-0.3738
Cyclic strength coefficient, bilinear fit, K'_1/K'_2 (MPa)	434/4742
Cyclic strain hardening exponent, bbilinear fit, n'_1/n'_2	0.1106/0.5121
Cyclic yield strength, S'_y (MPa)	220

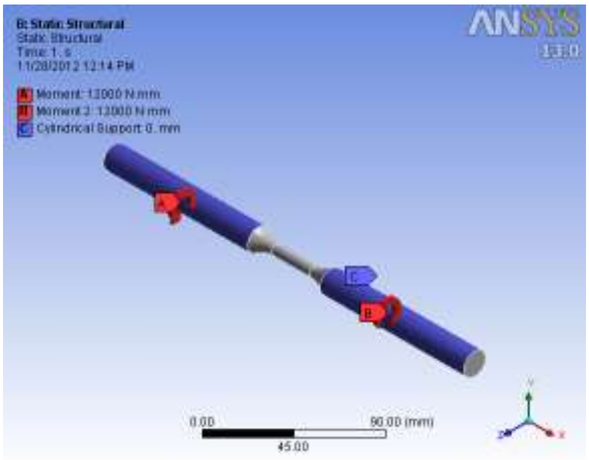

Figure 3. Geometry and boundary condition.

For corrosive environment, boundary condition is approach by using analytic formula to get the stress life parameter that used for engineering data in ANSYS. The result shown in Table 3.

$$\log N = \log \bar{a} - m \log \Delta\sigma \ldots\ldots\ldots\ldots\ldots\ (3)$$

N = predicted number of cycles to failure for stress range $\Delta\sigma$
$\log \bar{a}$ = intercept of log N-axis by S-N curve
M = negative inverse slope of S-N curve
$\Delta\sigma$ = Stress Range

Table 3. Alternating Stress Mean Stress

Cycles	Alternating Stress (MPa)
10	3243.40
20	2574.29
50	1896.75
100	1505.45
200	1194.88
2000	554.61
10000	324.34
20000	257.43
100000	150.55
200000	119.49
1000000	69.88

Result and Discussion

Fatigue life analyses of five different loading conditions was performed by using ANSYS Release 13. The fatigue life contours of specimen shown in Figs. 4.

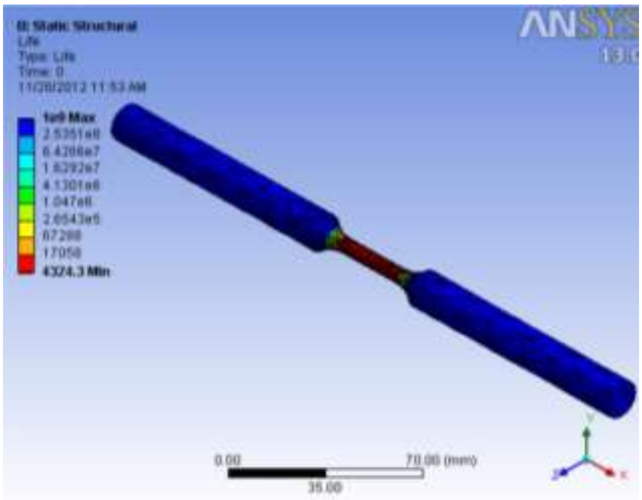

Figure 4. The fatigue life of AISI 304 in cycles for 12Kg load.

The S-N curve from fatigue analysis in air condition for AISI 304 is shown in Figure 5. It can be seen from the curve that the fatigue limit for AISI 304 was at 323.34 MPa. This result is close to result from INCO data published by NiDI (Keytometal). This data shows endurance limits from reverse bending fatigue tests as can be seen in Table 4.
S-N curve in Figs. 6 shows comparison of results obtained from simulation and experiment in corrosive environment. Even though the curve obtained by finite element analysis is lower than that obtained by experimental set up, the trend line of S-N curves for both experiment and finite element analysis are similar.

Table 4. Endurance limit data for common AISI stainless steels

AISI Type	Endurance Limit, MPa
301	240
303	240
304	240
310	215

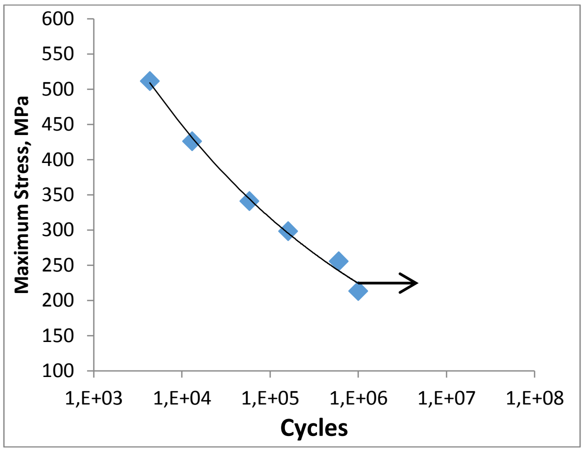

Figure 5. S-N curve simulation in air environment.

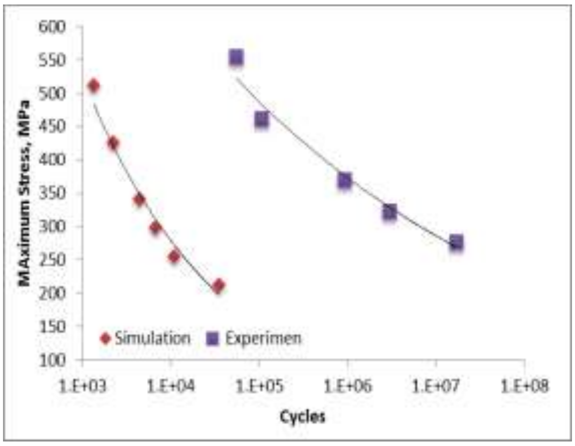

Figure 6. The comparison of S-N Curve simulation and experiment in corrosive environment.

Conclusion

From the result of this study, it can be seen that finite element simulation produce a good agreement compare to experimental result. Finite element method simulation is able to provide insight and prediction of fatigue life comparable to experimental works. In the corrosive environment, even though the endurance limit obtained by finite element analysis is lower than that obtained by experimental work, probably by the presence of micro crack, the trend line of S-N curves for both works and analyses are similar. Therefore, finite element simulation result can be used to estimate S-N curve as good as the experimental work.

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