Fatigue failure analysis of 304 austenitic stainless steel using cohesive zone model

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Abstract

Fatigue crack growth in CT sample with pre-crack is modeled by cohesive zone model. Load-controlled fatigue tests are performed on the specimen using the MTS Machine. In the result, the relations between fatigue crack growth rate and stress intensity factor amplitude is attained. And the can also obtain the curve of crack length and number of cycle. By simulating the T-S curve in commercial simulation software Abaqus, the relations between traction and separation of cohesive zone element can be available.

Keywords

Fatigue crack growth, cohesive zone model, R-effect.

1. Introduction

As for fatigue failure of structures, there are many feasibility analysis method. One of the classical methods is the S-N curve. However, it is limited to full-life prediction and structures without crack. Another common design method is Paris law [1], which is aimed at structures with crack. They all have some drawback. Firstly, these two approaches are empirical formulas. Though they can be used to describe fatigue behavior of material, the parameters in the two sets of formulas is dependent special experimental conditions, that is, the parameters used in different experimental conditions are also different. To some extent, these theories have the limitations. The second is that Paris formula describing the relations between fatigue crack growth(FCG) rate and stress intensity factor amplitude(ΔK) is based on the theory of linear-elastic fracture mechanics. And the process zone of the crack tip contains plastic deformation, which can not be negligible especially for larger plastic deformation. Hence, Paris has no ability to predict the propagation of fatigue cracks accurately. Third, fatigue crack growth can be divided into three stages, including crack initiation, stable propagation, and crack fracture. And the third stage can not be described by Paris law, in that the rate of crack propagation of this period is larger than the other two(da/dN＞1.0e-3), which belongs to plastic stage, and Paris based on linear elastic fracture mechanics and limited to small scale yield are not suitable for the situation. Except the above mentioned, there are still many researchers questioning validity of J-integral based on the theory of deformation. Also, node release technique is used for fatigue crack growth. The biggest shortcoming of it is that it is only available for cracked model. And there are defects caused by mechanical parameters of fracture, because fracture mechanics parameters is dependent on special geometry.

The approach in this paper is based on cohesive zone model to assess fatigue crack growth of 304 austenitic stainless steel under cyclic loading. This method has a lot of advantages, which is widely recognized and used. First of all, CZM can be regarded as a material law, and the parameters in CZM is independent of geometry, and they is only determined by material. There are no problems in principle with transferring the fracture parameters from small specimens to large components as in the classical macroscopic fracture mechanics approach.

2. Material and testing

Using MTS machine controlled by hydraulic control system, uniaxial load-controlled fatigue tests with sinusoidal wave with different stress ratio and a frequency of 1 Hz were performed on the CT specimen. The dimentions of CT specimen are shown Fig.1. And experimental equipments are listed in Table 1.

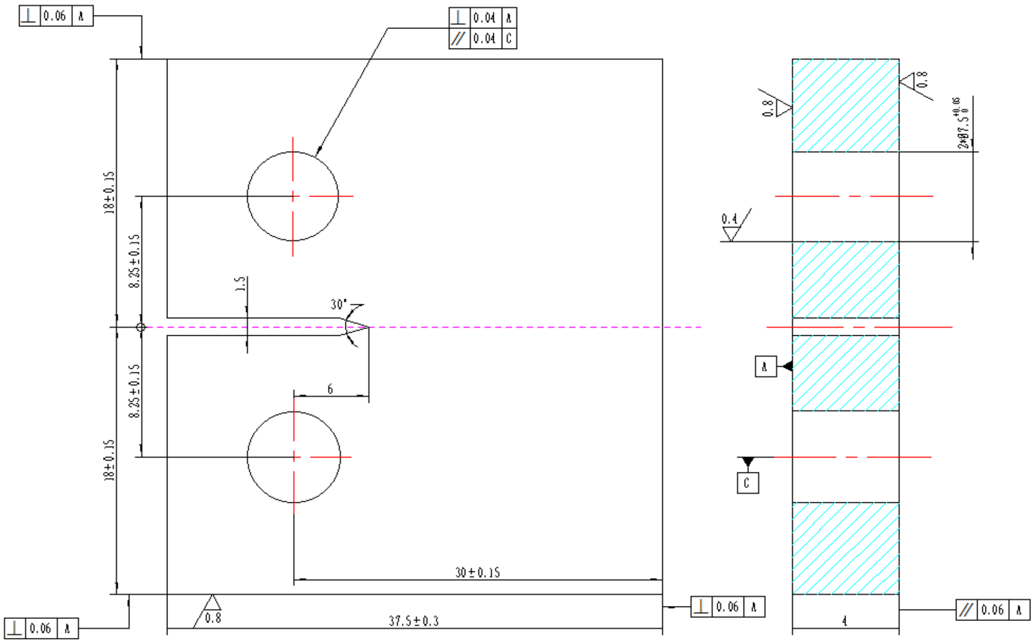

Fig.1. The schematic drawing of CT specimen

Table 1. Experimental equipments

Numbering	Equipment name	Quantity	Material
1	CT specimen	6	304 austenitic stainless steel
2	MTS fatigue tensile tester	1	
3	pin	2	GCr15
4	washer	4	Copper or iron
5	The constant current source	1	
6	Wire	4	Copper
7	Fixture	2	40Cr

3. Cohesive zone model formula

Cohesive zone model is a model describing the relations between Traction and Separation of cohesive element in process zone. It contains expressions of traction separation constitutive relation and damage evolution for elastoplastic damage problems. Cyclic loading consists of two parts: loading and unloading [2]. In order to describe the repeated damage effect on fatigue crack growth, a damage variable D is introduced, which will change present traction[3-5].The

$$Tn=Tn,0*(1-D) \tag{1}$$

Where Tn, T (n,0) are the present traction and initial traction respectively. The damage variable D will increase with the increase of the cycle number N, which follows the law of continuous damage evolution:

when the cumulative deformation value exceeds the threshold value, the fatigue damage begins to accumulate.

damage increment is related to deformation increment.

there is a endurance limit, when the stress level is lower than the endurance limit, the material can endure continuous circulation without causing damage to the material.

$$\dot{D} = \frac{\dot{\delta_n}}{\delta_\Sigma} * \left[\frac{T_n}{\sigma_{max}} - \frac{\sigma_F}{\sigma_{max,0}}\right] * H\left(\frac{\bar{\Delta}n}{\delta_0}\right) \tag{2}$$

Where two fatigue parameters are introduced, cohesive endurance limit and accumulative cohesion length. The accumulative crack opening displacement describes when fatigue damage occurs using Heaviside law.

$$\bar{\Delta}n = \int_0^t \left|\dot{\delta n}\right| dt \tag{3}$$

$$\sigma_{max} = \sigma_{max,0} * (1 - D) \tag{4}$$

Where σmax, σmax, 0 are present stress and initial stress, respectively, and the is related to present damage value, which reflects current intensity of cohesive element.

4. Conclusion

Seven points incremental polynomial technique is used to obtain the relations between fatigue crack growth rate (da/dN) and stress intensity factor amplitude(ΔK). Application of direct current method(DC) for crack length measurement in normal temperature is available. The experience results are illustrated in Fig.2.

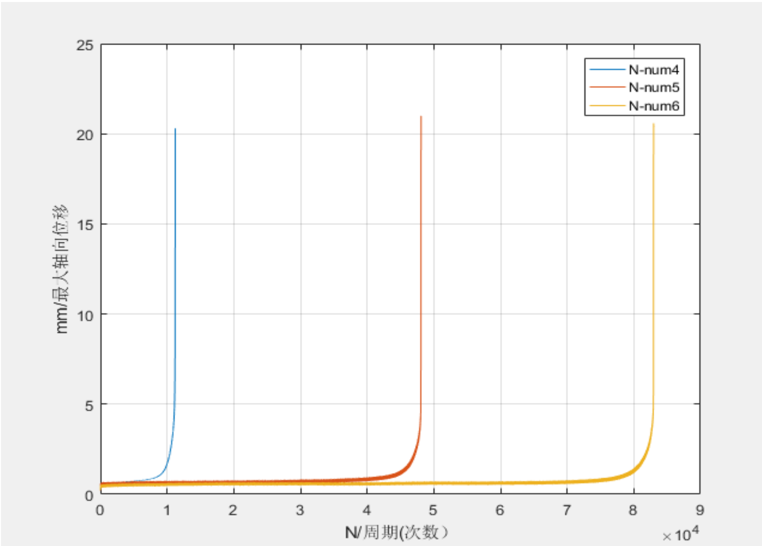

Fig.2 The effect of R on relations between crack length and number of cycle

Fig.2. demonstrates that when the minimum load is fixed, the greater the stress ratio is, the greater the fatigue life is. And difference resulting from R is negligeble.

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