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# Fatigue and fracture mechanical behavior for Chinese A508-3 steel at room temperature

# Fatigue and fracture mechanical behavior for Chinese A508-3 steel at room temperature

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**Abstract.** Material, A508-3 steel, has been used in nuclear reactor vessels. In the present study, fatigue and fracture mechanical behavior of Chinese A5083 steel at room temperature are studied by mechanical material testing machine (MTS). Test data of material's mechanical behavior including uniaxial tension, low cycle fatigue (LCF), threshold value of stress intensity factor (SIF) range, fatigue crack growth (FCG), and fracture toughness is generated and given for further study. It is worth noting that the model in predicting FCG of material from LCF parameters is verified and discussed.

## 1. Introduction

The basic material experimental data is important design input parameters for the structural integrity assessment of engineering components. Reactor pressure vessel (RPV) is an important part of the reactor coolant for the second and third generation nuclear power plants (NPPs). A set of operation, emergency, and accident transients could exist that allow cold water to come into contact with the inner surface of the vessel wall, producing high thermal stress. The low alloy ferritic steel, A508-3 steel, have been used to make RPVs. Because the A508-3 steel has good weld ability and radiation resistance than other low carbon ferritic steel. The A508-3 steel, firstly, is developed from A533-B steel in American for pressure vessel with the higher safety standards of nuclear. The A533-B steel's mechanical properties were widely studied [1-4] and the steel has been used extensively in heavy section pressure vessels for nuclear applications. During the operating lifetime of these vessels, neutron bombardment is sufficient to affect substantial changes in the metallurgical and mechanical properties of the vessel structural materials. Neutron irradiation increase strength properties and decrease ductility.

For the Chinese A508-3 steel, at room temperature, the uniaxial tension, low cycle fatigue (LCF), threshold value of stress intensity factor (SIF), fatigue crack growth (FCG), and fracture toughness is studied, analyzed, and discussed in the present study.

## 2. Mechanical behavior of ChineseA508-3 steel

In this section, test data comes from the hydraulic mechanical testing machines (MTS).

### 2.1. Uniaxial tension properties

Figure 1 givens the uniaxial tension engineer stress and strain curves. Before necking stage, the true stress and strain can be calculated by using Bridgman's correction factor [5].

Based on the arc funnel specimen (Radius=10 mm), the full-range stress and strain curve (figure 2) is obtained by finite aided testing method [6].

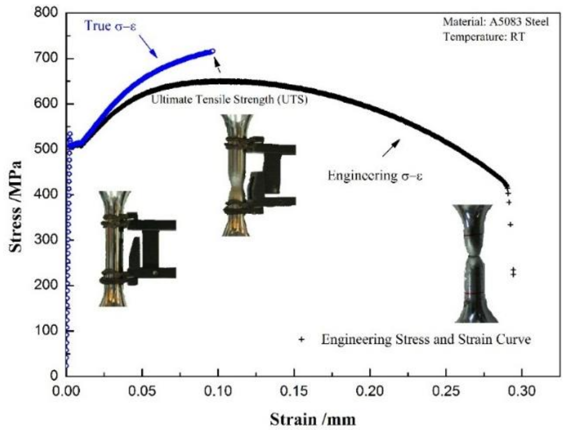


**Figure 1.** Test specimen of equal diameter round bar, Diameter=8 mm.

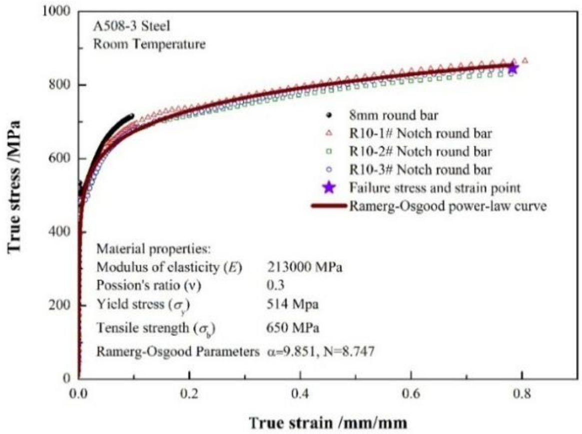


**Figure 2.** Test specimen of equal diameter round bar (Diameter=8 mm) and arc funnel specimen (Radius=10 mm).

*2.2. Low cycle fatigue (LCF) behavior*

There exist many methods available to analyze the crack nucleation and failure life. For complex structures and environments, especially, finite element analyses combined with the local strain theory are often used in design phase analysis [7]. Previous studies including Basquin, Manson, and Coffin have obtain the relationship between strain range and cyclic failure life for testing materials. In addition, the average stress $\sigma_m$ parameter is considered in Manson-Coffin equation which is a classic relation in order to describe the low cycle fatigue behavior of materials under different load environments. Figure 3 shows the typically low cycle fatigue curve of A508-3 steel.

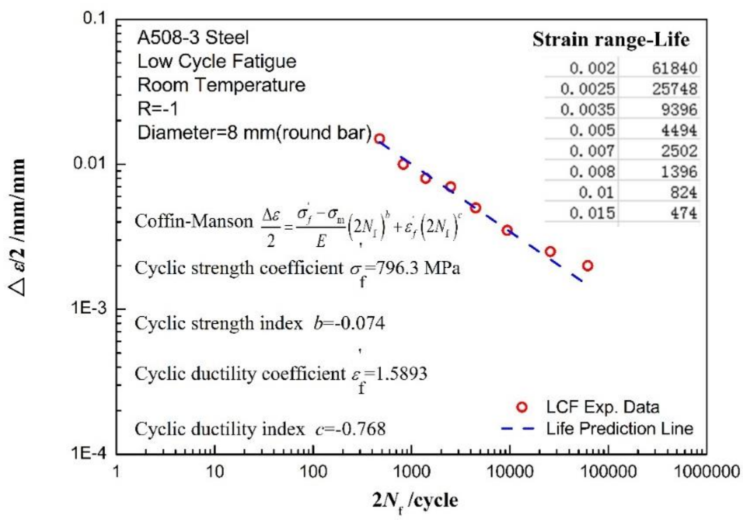


**Figure 3.** Low cycle fatigue properties of A508-3 steel.

*2.3. Threshold value of SIF*

Considering the simplicity and accuracy of elastic unloading compliance theory, the amount of crack propagation is detected and calculated using elastic unloading compliance method by computer codes. Based on the definition of threshold value of stress intensity factor for metal materials, test data is obtained and analyzed when no crack propagation is found in $10^7$ cyclic life. For a material, commonly, the linear relation between the load stress ratio and the threshold value of SIF does not exist. However, a conservative calculation result would be obtained based on assuming the establishment of a linear dependency for servicing engineering analysis [8]. Figure 4 givens only the threshold value of stress intensity factor (SIF) range under load stress ratio $R$=0.1.

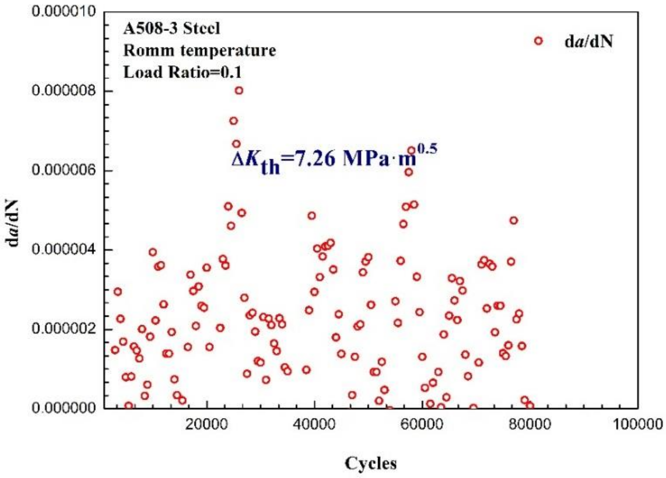


**Figure 4.** Threshold value of stress intensity factor (SIF) range of A508-3 steel.

Combination the threshold value of SIF and the low cycle fatigue (LCF) properties, material's fatigue crack growth (FCG) of second stage is estimated by kinds of prediction model of mode tension type failure cyclic life.

### 2.4. Fatigue crack growth (FCG)

Considering previous research results, fatigue crack growth would be studied from the following two scales, macroscopic and microscopic. Reference [9] has also studied the driving force, stress intensity factor $K$, near crack tip based on the stress criterion. The load stress ratio can affect the result of FCG rate of material. But, in the present study, the load stress ration is not considered and investigated.

Figure 5 shows only the fatigue crack growth (FCG) rate under second stage corresponding to the load stress ratio $R$=0.1.

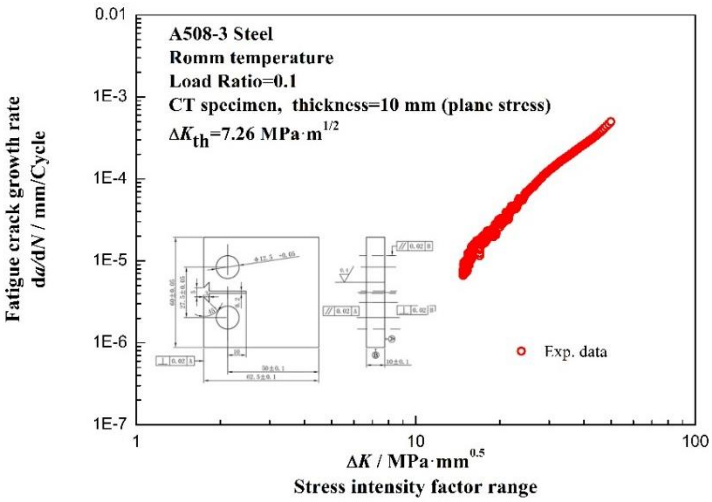


**Figure 5.** Fatigue crack growth rate of A508-3 steel.

The conception that there is the highly strained zone near the crack tip is like a small low cycle fatigue (LCF) test specimen is assumed by many studies. In Pandey's model, for example, the process zone is viewed as the highly strained zone in the front of crack tip. Considering the energy of process zone equals to the energy of whole plastic zone [10]. Using the essential relationship between low cycle fatigue (LCF) and fatigue crack growth (FCG) rate, various prediction models are applied for analyzing behavior of Chinese A508-3 steel. Many prediction results including SHI-CAI model [11], Glinka model [12], and Ellyin-Li model [13] are showed in figure 6.

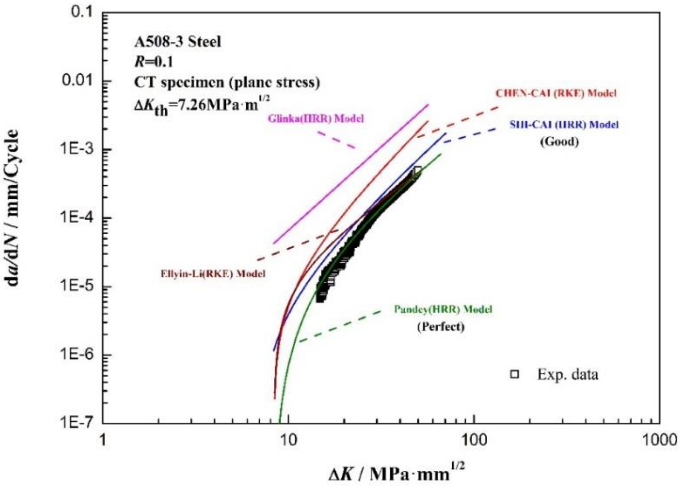


**Figure 6.** Prediction results based on estimating models of A508-3 steel.

## 2.5. *Fracture toughness*

The three primary factors which affect the fracture toughness of structural steels are temperature, loading rate, and constraint. Generally, the fracture toughness of structural steels increases with increasing temperature and decreases with increasing loading rate.

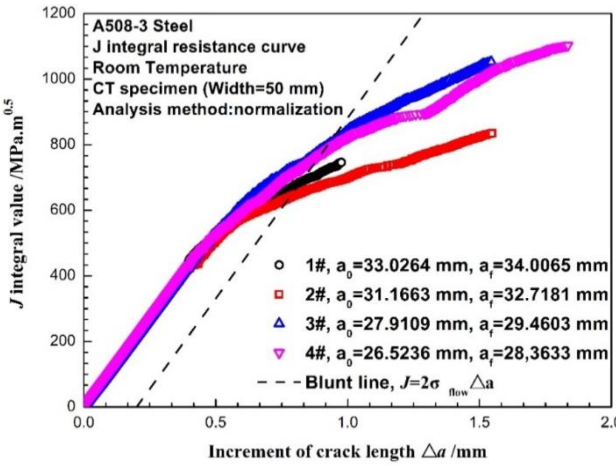


**Figure 7.** *J* integral resistance curve of A508-3 steel.

For real fracture, the crack failure degree, test specimen thickness, and experimental loading environment have influence on the constraint in front of the crack tip [14]. Figure 7 obtains the result of *J* integral resistance curve with different initial crack length $a_0$. Results show the different *J* integral resistance curves for compact tensile specimens with 50mm thickness. A so-called constraint effect would be introduced into explaining above phenomenon. The constraint have defined in measuring of the resistance to plastic flow. Basically, a low *J* integral value corresponds to a high level of constraint near the crack tip. The reason is that the plastic deformation and associated energy dissipation are restricted by constraint. Therefore, the resistance to fracture is low. The stress triaxiality can often been used to described the level of constraint in the front of the crack tip. In other words, a high value of stress triaxiality is equivalent to a high level of constraint [15].

## 3. Conclusion

For Chinese A508-3 steel, the mechanical properties at room temperature are given, which include uniaxial tension, low cycle fatigue (LCF), threshold value of stress intensity factor (SIF), fatigue crack growth (FCG), and fracture toughness. These basic behaviors is analyzed and discussed, in the present study, in order to service the nuclear power plant safety.

The mechanical properties in different temperature environments will be studied and discussed in the future.

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