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Experimental Investigation of Interactions between Double Oblique Cracks on Crack Growth Behaviours under the Fatigue Loading

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Abstract. In this paper, the interaction of double oblique cracks is researched experimentally and numerally. Fatigue crack growth tests of both the single crack and double crack specimens are conducted to investigate the effect of crack interactions on fatigue crack growth behaviours. Results indicate that the oblique crack has a shielding effect on the crack growth length of the dominant crack. In addition, numerical simulations show that the stress intensity factors at the dominant crack tips in the double crack specimens are smaller than those at the crack tips in the single crack specimens, which explains why the growth length of the dominant crack decreases in the present of the oblique crack.

1. Introduction

Multiple cracks can often be found in pressure equipment, aircrafts, ships, and other engineering components [1-4]. The interactions of multiple cracks exist during the crack propagation process, which can affect the residual strength and fatigue life of damaged components [5-7]. Thus, it is important to research the interactions of multiple cracks.

Previous researches have been found to study the interactions of multiple cracks and their effects on the fatigue crack growth behaviour as well as the stress intensity factor (SIF). Ma et al. [8] found that the values of the SIFs of the two cracks could be affected by the relative crack sizes, as well as the normal and deviation distances. Kishida et al. [9] researched the propagation behaviour among multiple parallel cracks, and the results showed that due to the crack interactions, the maximum value of the SIFs did not always exist in the longest crack. Jiang et al. [10] studied the interactions based on a finite plate containing double unequal cracks under the remote normal stress. It is found that the SIFs at the tips of double cracks decreased because of the crack interactions. Meng et al. [11] obtained the impact coefficients to describe the influence of different relative size and distance of the cracks on the SIF. Jiang et al. [12] researched the fatigue growth behaviour between double parallel edge-cracks in a finite width plate. The results showed that the two offset cracks tended to deviate from the original growth direction and this trend increased as the crack distance decreased and the crack length increased. Jin et al. [13] and Kamaya et al. [14] found that the da/dN-ΔK_I curves of the double cracks had an obvious difference from those of the single crack.

In this study, fatigue experiments have been carried out to study the interactions between double oblique cracks. Crack growth length at the dominant crack tips is measured. Stress intensity factors at crack tips are calculated numerically which explain the different crack growth length under the same load cycles.

2. Experiments

The specimens are manufactured from the rolled plates of S30408 stainless steel, and the dimensions of the specimens are 260 mm × 48 mm × 6 mm. Sizes and positions of the double cracks for different specimens are listed in table 1. In order to find out the interactions between cracks, three kinds of specimens are designed specially, including the single crack specimen (SC), the double oblique crack specimens with *Ra* = 0.9, *l* = 6.1 (OC0.9L6.1), and *Ra* = 1.0, *l* = 6.5(OC1.0L6.5), as depicted in figure 1. The projected length of the oblique crack is $2a_2$, and the symbol *Ra* is the length ratio of the double cracks, a_2/a_1. Symbols A - D represent crack tips of double cracks.

Table 1. Sizes and positions of the cracks in the specimens.

	SC	OC0.9L6.1	OC1.0L6.5
a_1 (mm)	3	3	3
a_2 (mm)	—	2.7	3
l (mm)	—	6.1	6.5
α (°)	—	36.7	36.7

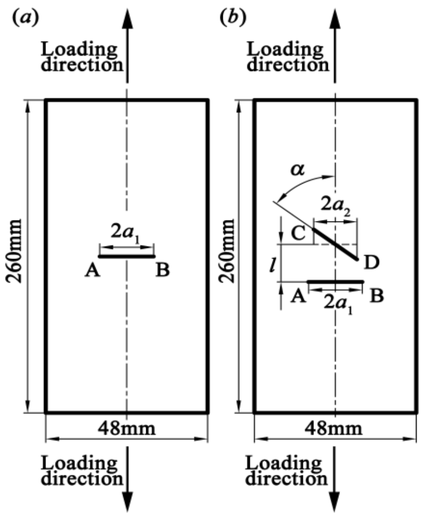

Figure 1. Test specimen geometry: (a) the single crack specimen, (b) the double oblique crack specimen.

2.1. Fatigue Test Setup

The fatigue crack growth tests are conducted by a fatigue testing machine (INSTRON 8800). A uni – axial cyclic load with frequency of 45Hz, maximum value of 40kN, and load ratio of 0.1 is employed. The crack growth length for different specimens is monitored and recorded by a digital microscope system during the fatigue tests.

2.2. Fatigue Tests Result

2.2.1. Crack Growth Paths. From figure 2, it can be found that the crack propagates perpendicularly to the direction of the load. For OC0.9L6.1 and OC1.0L6.5 specimens, only the crack perpendicular to the loading direction, or the dominant crack, propagates continuously, while the oblique crack is in the dormant state due to the interaction of the dominant crack.

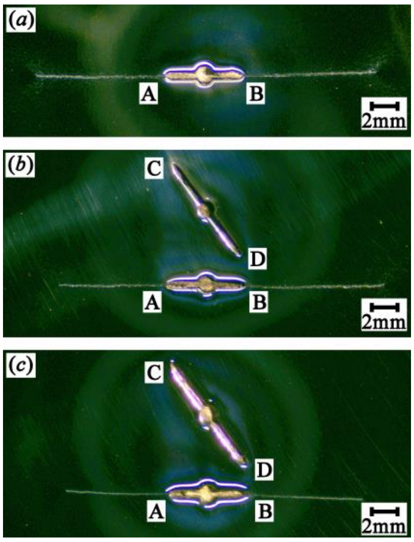

Figure 2. Crack growth paths for different specimens: (a) SC, (b) OC0.9L6.1, (c) OC1.0L6.5.

2.2.2. Crack Growth Length. For the purpose of investigating the interactions on the dominant crack directly, the load cycle number is set to be zero when the sum of the crack growth length, a_x, at two tips of the dominant crack is 7mm. The relationship between crack growth length, a_x, and the load cycle number, N, for the specimens is plotted in figure 3. At a given cycle number, the crack growth length at the double crack specimens is shorter than that at the single crack specimen, and the crack growth length decreases in order of OC0.9L6.1, OC1.0L6.5. In addition, as shown in figure 3, at the same cycles, the crack growth length at crack tip A of the double oblique crack specimens is shorter than that at crack tip B, because of different interactions of the oblique crack to the crack tips of the dominant crack.

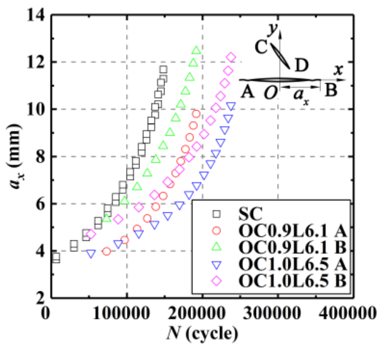

Figure 3. Changes of the crack growth length with the increasing load cycle number.

3. Numerical Simulations

3.1. Finite Element Model

From the experiments, it can be found that the interactions of double cracks do exist, and the crack growth length of different specimens can be influenced by crack interactions. Thus, based on the geometry of the specimens, finite element models with double cracks under the uniform remote tension stress σ of 125MPa are established. The 8-node plane element is adopted to generate meshes of the finite element model. To improve the calculation accuracy of finite element simulation, meshes are refined around the crack tips, as indicated in figure 4. Specially, singular elements are created at the crack tips to obtain the SIFs.

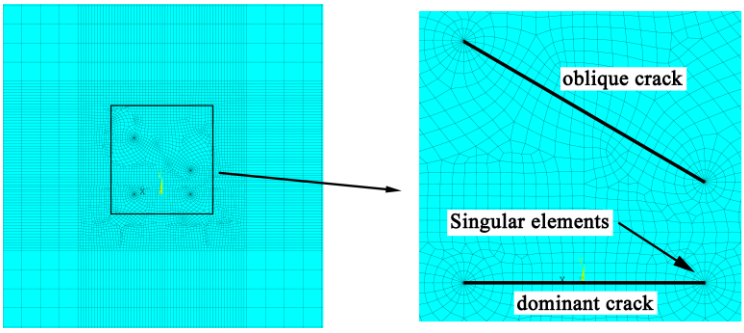

Figure 4. Mesh model of the plate with double cracks.

3.2. Stress Intensity Factors

According to the size of the double cracks listed in table1, the Mode I SIF, K_I, of the dominant crack in the OC0.9L6.1 and OC1.0L6.5 specimens is calculated. In addition, a single crack of length $2a_1$ subjected to the same stress is introduced as a reference, and the SIF at the tip of single crack is represented by K_I^0. For the OC0.9L6.1 specimen, the ratios of K_I to K_I^0 at crack tips A and B are 0.847 and 0.911, respectively, and for the OC1.0L6.5 specimen, the ratios of K_I to K_I^0 at crack tips A and B are 0.824 and 0.870, respectively. The values of K_I/K_I^0 at the dominant crack imply that these cracks experiences a shielding effect due to the oblique crack. It can be inferred from figure 3 that the shielding effect of the crack can affect the crack growth length. For the same load cycle number, the crack growth length decreases as the shielding effect increases. Moreover, crack tip A of the double oblique crack specimens propagates longer than crack tip B, because of the different shielding effect of the oblique crack to the two tips of the dominant crack.

The SIFs at the crack tips along the crack growth paths are also obtained by the finite element method. Both the Mode I SIF range, ΔK_I, and the Mode II SIF range, ΔK_{II}, are calculated during the crack growth process, corresponding to the fatigue load range.

Figure 5 shows the relationship of ΔK_I and ΔK_{II} at the crack tips A or B and the load cycle number, *N*, in different specimens. Obviously, for all the specimens, ΔK_I increases with the increasing *N*. However, ΔK_{II}, fluctuates around the value of 0, meaning that the dominant cracks in different specimens propagate in Mode I. The Mode I SIF range, ΔK_I, at the dominant crack in the double oblique cracks decreases significantly at the same load cycle number, compared with that in the single crack, and ΔK_I of the dominant crack decreases as the shielding effect increases. Moreover, ΔK_I at crack tip A shows smaller values than that at crack tip B when the load cycle number is relatively small, because of the different shielding effect of the oblique crack to the two crack tips of the dominant crack. With the number of cycles increasing, the difference of ΔK_I at crack tips A and B decreases, because the shielding effect to the dominant crack gradually vanishes.

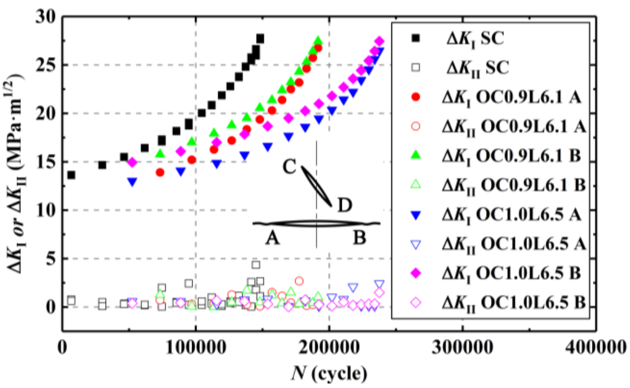

Figure 5. Relationship between ΔK_I and ΔK_{II} at tips A or B and the load cycle number.

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4. Conclusions

In this study, interactions between double through-thickness oblique cracks are investigated experimentally and numerally. Conclusions are obtained as follows:

(1) The experiment results show that the interaction between the oblique crack and the dominant crack affects the growth length of the dominant crack, but not the growth direction of the crack.

(2) Because of the different shielding effects by the oblique crack, the two crack tips of the dominant crack propagate at different rates.

(3) Numerical simulations show that the SIFs at the dominant crack tips in the double crack specimens are smaller than those at the crack tips in the single crack specimens, which explains why the growth length of the dominant crack decreases in the present of the oblique crack.

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