I - 232 PREDICTION OF FATIGUE CRACK PROPAGATION LIFE UNDER OVERLOAD CONDITIONS

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1. Introduction It is well known that the overload can reduce crack growth rate significantly at the lower stress range level following the overloads. The fatigue crack growth rate and the crack closure tests under single overload conditions at Nagoya University re-examined the retardation effect due to overload in structural steel JIS SM520B. The results are reported elsewhere[1),2)]. A large plastic zone is formed ahead of the crack tip and the residual plastic deformation around crack tip due to loading and unloading procedure causes crack closure in the wake of an advancing crack. To open the crack fully, the contact stresses between crack surfaces due to crack closure should be overcome and then crack can advance. The stress level above which crack is fully open is defined as an opening stress σ_{op}. Crack opening stress or effective stress intensity factor range ΔK_{eff} is an important concept in understanding the fatigue crack growth behavior under random load conditions with the consideration of the load interaction effect, because different load sequence may cause different residual plastic deformations on the crack surfaces, therefore different contact stresses. In the present study, an analytical model of predicting fatigue crack propagation life is developed based on the crack closure concept. The analytical results of opening stress, fatigue crack growth rate and crack propagation life are compared with the test results. The test specimens are center prenotched plates. The maximum stress σ_{max} and the minimum stress σ_{min} are equal to 64 MPa and 14 MPa, respectively.

2. Analytical Model and Assumptions The opening stress can be calculated from contact stress which depend on the residual plastic deformation due to the loading and unloading sequence. Only the effective stress intensity factor ΔK_{eff} ($=\Delta K_{max} - \Delta K_{op}$) has a contribution to the crack growth. Crack growth rate is $da/dN = C(\Delta K_{eff})^m$. The constants C and m are obtained from the test results under constant amplitude (CA) loading condition by considering effective stress range. Several assumptions are made in the present model. (a) At crack tip the plastic zone size and shape are equivalent to Dugdale's plastic zone. (b) Elastic-perfectly plastic behavior of material is assumed. (c) The constraint factor α is introduced to account for the constraint effect on the plastic deformation in the direction of the plate thickness.

3. Comparisons between Analytical and Test Results First, crack opening displacement (COD) as well as the residual stress ahead of the crack tip and the contact stress in the crack wake under CA are calculated. They are shown in **Fig.1**. The shaded region shows the plastic deformation ahead of the crack tip and the residual plastic deformation in crack wake. It is noted that the lower unloading level causes the wider crack closure, and therefore, the more contact stress. This result agrees well with the FEM analysis by Newman[3)].

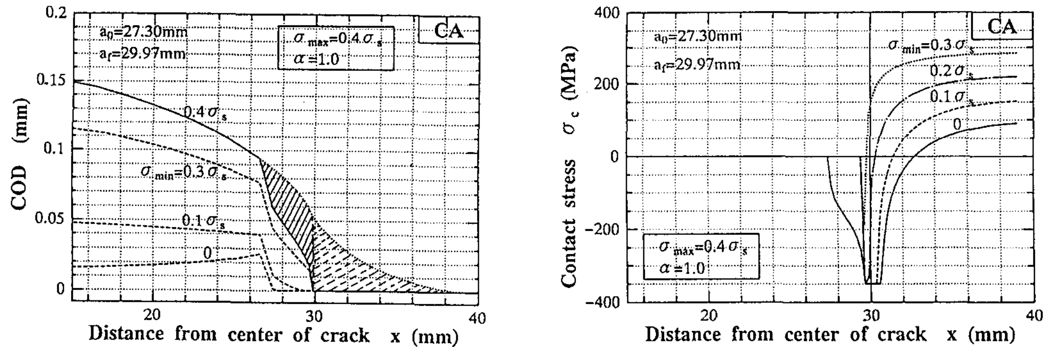

Fig.1 COD, residual stress and contact stress upon unloading

Next, the opening stresses and the crack growth rates are calculated under overload condition and compared with the test results, as shown by the dash-dotted lines in **Fig.2**. Before overload, *i.e.* corresponding to the CA loading condition, the opening stress is constant. After overload, the opening stress firstly goes down due to crack tip blunting under overload, and then gradually goes up to the peak value, finally recovers to that of CA. As the crack grows, the crack growth rates change in accordance with the opening stress. After overload application, the crack growth rate increases firstly, and then decreases to the minimum value and finally recovers to that of CA. The analytical results show the same tendency as the test results.

Moreover, the relation between crack length and crack propagation life are also obtained under CA and periodical overload conditions. They are compared with the test results, as shown in **Fig.3**. The analytical results predict overall tendency of the test results, although the present model estimation of the fatigue crack growth retardation effect due to overload is more than the test results.

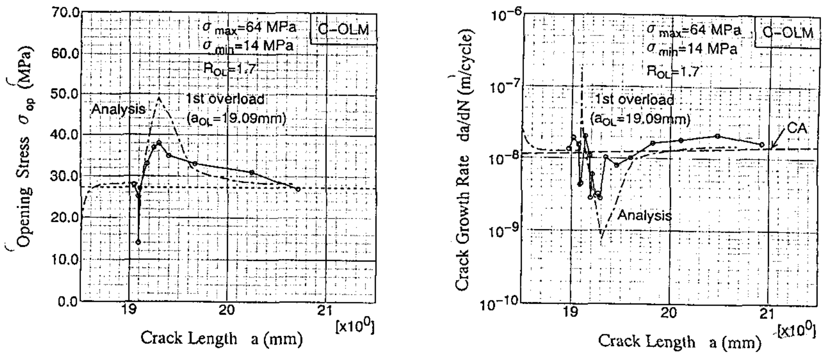

Fig.2 Opening stress and crack growth rate under overload condition

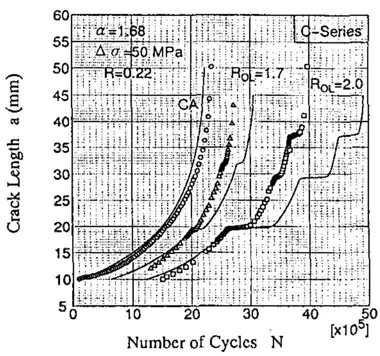

Fig.3 Relation between crack length and crack propagation life

4. Summary From above analyses and comparison with the test results under CA and overload conditions, the present analytical model based on the crack closure concept can predict fatigue propagation life well with the consideration of load sequence effect. For the further study, the fatigue life evaluation for other load conditions, such as random variable amplitude load condition, should be conducted.

References

1) Cheng, Okuhara, Yamada and Kondo : Fatigue Crack Growth Rate Measurement of Structural Steel under Overload Conditions, to be published in Proc. of JSCE, April, 1994

2) Cheng, Yamada and Okuhara : Fatigue Crack Closure Test under Overload Condition, Chubu Branch of JSCE, No.I-36, March, 1994.

3) Newman : A Finite-Element Analysis of Fatigue Crack Closure, Mechanics of Crack Growth, ASTM STP 590, pp.281-301, 1976