Fatigue Crack Closure Test under Overloading Condition

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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 test under single overload conditions at Nagoya University re-examines the retardation effect due to overload in structural steel JIS SM520B. The results are reported elsewhere[1]. A large plastic zone at crack tip and residual plastic deformation formed near crack tip due to overloading and unloading procedure causes crack closure in the wake of an advancing crack tip. To open the crack fully, the 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 is an important concept in understanding fatigue crack growth behavior under random load conditions with considering the load interaction effect. Some experimental work and analytical models have been conducted with some aluminum and few steels. In the present study, crack closure test is carried out on SM520B steel centrally prenotched specimens (**Fig.1**). Crack opening stress σ_{op} is determined graphically before and after overload.

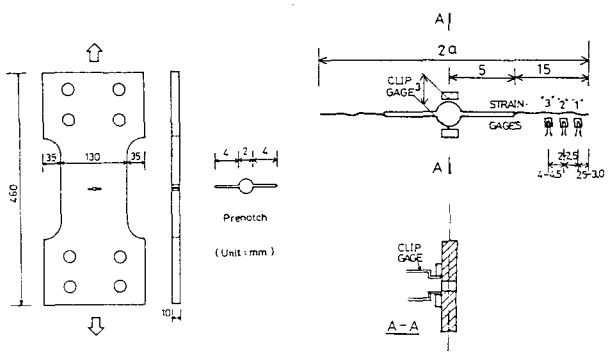

Fig.1 Test Specimen and Gage Arrangement

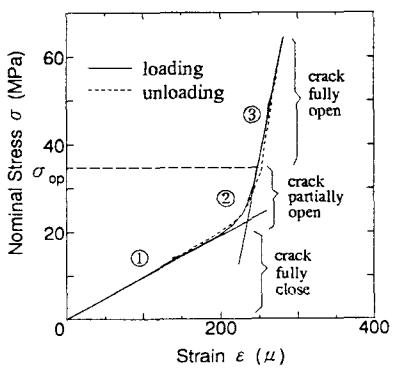

Fig.2 Typical σ-ε Curve

2. Experiment

The fatigue crack closure test is carried out during the fatigue crack growth rate test. The maximum stress σ_{max} and the minimum stress σ_{min} are equal to 64 MPa and 14 MPa, respectively. Fatigue test is interrupted before overload to attach three strain gages at different locations near crack tip and to mount a clip gage beside the center of prenotch, as shown in **Fig.1**. The readings of strain gages and clip gage at different load levels in one cycle before and after overload are recorded.

3. Results of Observation

The typical relation of nominal stress and strain in the wake of crack tip in one cycle is shown in **Fig.2**. It can be divided three parts: (1) first linear part; (2) nonlinear part where crack is to start open and then to open fully; and (3) linear part after crack fully opens. At the transient point of (2) and (3), the corresponding stress is regarded as crack opening stress σ_{op}. In different positions away from crack tip, the degree of this behavior due to crack closure may be different. **Fig.3** shows the σ-ε relation of the three gages at three different locations before overload application. Since crack closure is not uniform along the crack wake, the location away from crack tip, such as strain gage 3, starts to open earlier than the location closer to crack tip, such as strain gage 1. For stain gage 1 the longer

nonlinear part (2) is observed, which implies longer opening procedure. Upon unloading, the σ-ε curve almost coincides with that of loading procedure, since at lower stress level the material always behaves elastically except very close to crack tip. The opening stress σ_{op} at which the crack closure is overcome and crack fully opens, can be determined graphically by the tangent line of segment (3) of the gage 3 which is the closest to the crack tip. The crack opening stress is defined as about 31 MPa. The opening stress range (σ_{op}-σ_{min}) is approximately one third of stress range (σ_{max}-σ_{min}) of CA loading. Fig.4 shows the relation between the applied load P and crack opening displacement (COD) at the center of the crack. The same behavior as σ-ε curve may be observed except the convex or concave of curve. Theoretically, COD=$\frac{4\sigma}{E}\sqrt{a^2-x^2}$ at x=0 after crack fully opens.

Moreover, in the cycle just after the overload application, the relations of σ-ε, P - COD and crack opening stress are unchanged. In order to investigate the crack closure behavior and opening stress variation during the retardation effect period after overload, the further test is undergoing now.

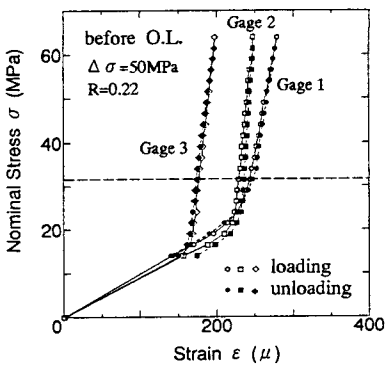

Fig.3 σ-ε curve before overload

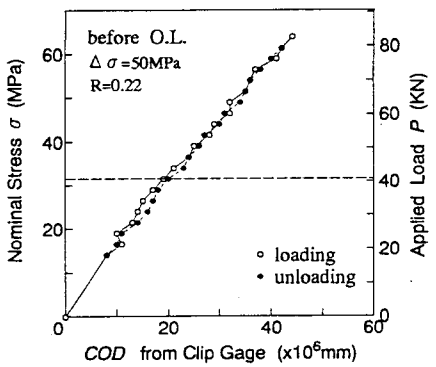

Fig.4 P-COD curve before overload

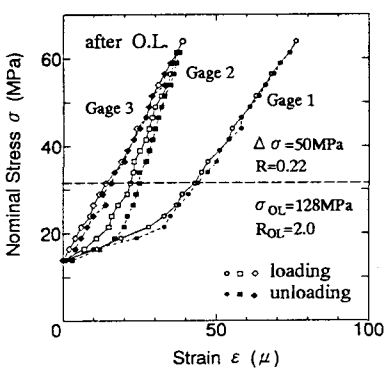

Fig.5 σ-ε curve after overload

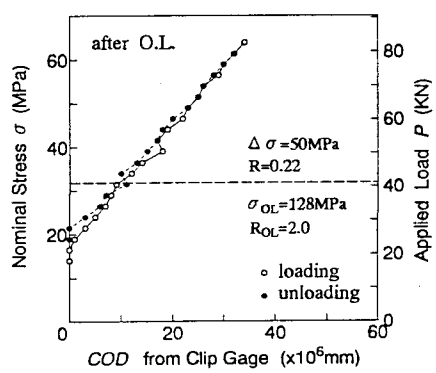

Fig.6 P-COD curve after overload

4. Summary

From above experiment, fatigue crack closure is observed before and after overload application in the wake of crack tip at the low mean stress level of CA loading. Crack closure phenomenon exists in the structural steel. The corresponding opening stress range is about one third of stress range of CA loading before overload.

Reference

1) Cheng, Okuhara, Yamada and Kondo : Fatigue Crack Growth Rate Measurement of Structural Steel under Overload Conditions, Submitted to Proc. of JSCE, August, 1993