The Effect of High Peak Stresses on Damage Accumulation by Low Peaks

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INTRODUCTION

Even very low amplitudes of stress, much lower than the endurance limit, give enough damage and cause fatigue failure, especially when such low peaks are preceded by intermittently applied high peaks larger than the endurance limit. The damage seems to be given through the plastic strain induced by the higher peaks, which otherwise is not observed at the lower stress levels. S-N curves decided by constant stress amplitude tests should be modified to take the damage effect of low peaks into account, when applied to predict fatigue lives in the varying stress amplitude tests (Ref.1).

No evidence has ever been reported, however, about the influence of such factors as the magnitude of the higher stress and the cyclic ratio of high to low peaks. The effect of high and low peaks on crack initiation and propagation is not also made clear.

In this study flexural and rotating bending tests are performed on a carbon steel and an aluminum bronze to investigate the effect of such factors.

TESTING PROCEDURE

Notched and unnotched specimens of 0.25%C carbon steel and an aluminum bronze, designated as S25C and AMB102F respectively, are investigated. S25C is tested under rotating bending, while AMB102F tested under rotating and out-of-plane bending as well. The diameter of the rotating bending specimen is 10 mm. The cross section of a plane bending specimen is 4 mm thick and 10 mm wide. The elastic stress concentration factor K_t of the notched rotating and flexural bending specimens is 4. Not only final fracture life but crack initiation life is determined for notched specimens. Crack length is measured at the both ends of cross-cut diameters for the round bar specimen with the aid of x400 microscope, whereas crack initiation life is determined by the red-dye penetrating method for the plate specimens.

Two-step interval tests as well as constant amplitude test are carried out, the testing procedure of which is illustrated in Fig.1. The higher stress amplitude σ_1 is chosen higher than the endurance limit σ_w determined by the constant amplitude test, while the lower amplitude σ_2 is determined smaller than σ_w. The effect of magnitude of and cyclic ratio n_1/n_2 is investigated.

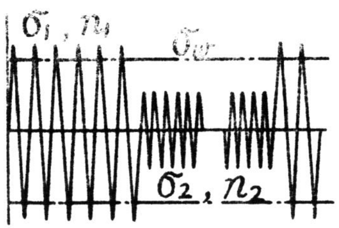

Fig.1. Two-step interval test

TESTS RESULTS

In Figs. 2 and 3 are given the constant and varying amplitude test results on AMB102F and S25C unnotched specimens respectively. The four-step interval test result (Ref.1) is also plotted in Fig.3. Varying amplitude test results are arranged with the assumed life N_i at the lowest stress level, which is calculated under assumption of $N_i = n_i/\{1-\Sigma(n/N)_j\}$ (n_j, N_j: the number of cycles attained by the time of failure and the original life at the j-th stress level). Newly reduced S-N curves for the variable amplitude loading lie far below the original ones for both of the materials. The fatigue life is fairly affected by the value of the cyclic ratio n_1/n_2 as seen from Fig.3. An optimum

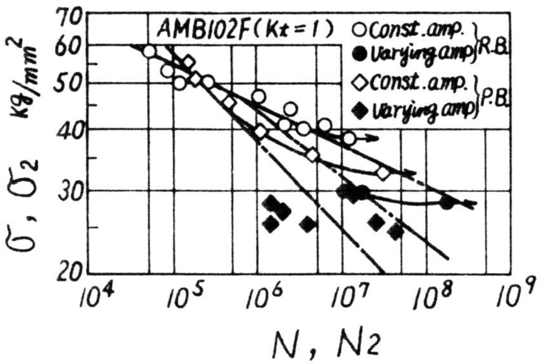

Fig.2 Test result (AMB102F, Kt=1)

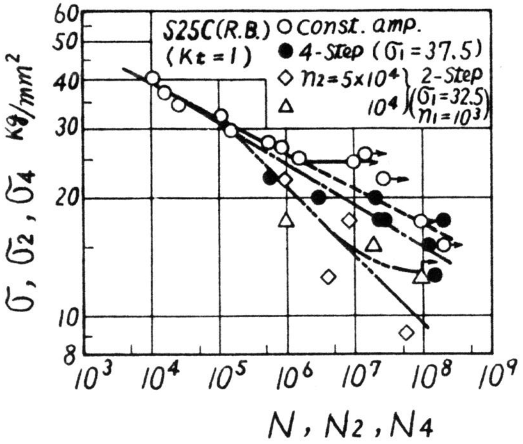

Fig.3 Test result (S25C, Kt=1)

value seems to exist, which makes the fatigue lives shortest.

In Fig.4, the total number of cycles to failure is plotted against the r.m.s. value of the plastic strain range at the mid-life for the varying amplitude test. The r.m.s. value of the plastic strain range throughout the specimen life is used in case of the constant amplitude test. Test results for the constant and variable amplitude conditions coincide well with each other. Plastic strain range seems to play an important role in determining the fatigue life. The relation between applied stress and plastic strain range observed is shown in Fig.5. Plastic strain range at each stress level in varying amplitude tests is much larger than that in constant amplitude tests. The relationship appears to be affected by the value of cyclic ratio n_1/n_2 and magnitude of σ_1. These are the reasons for lower strength and dependence of the fatigue life on cyclic ratio n_1/n_2 in the varying amplitude loading.

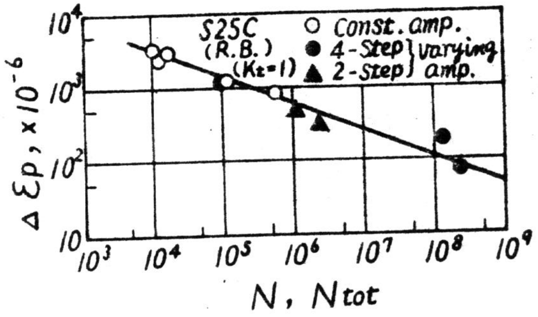

Fig.4 Plastic strain range versus total number of cycles to failure

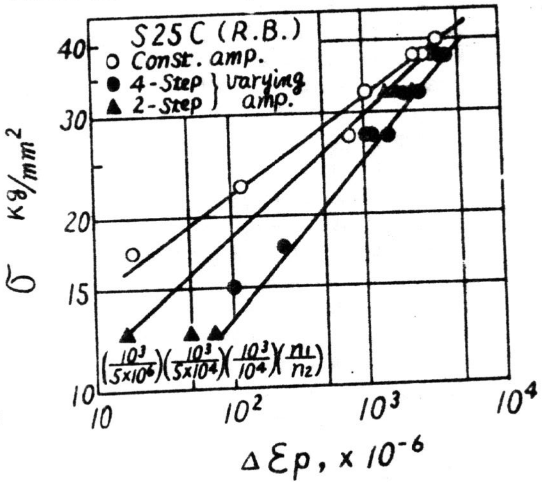

Fig.5 Relation between applied stress and plastic strain range

Fig.6 shown the test result on notched specimens of S25C. When n_1/n_2 is very small, a crack initiates along the broken line which is the extension of S-N line for crack initiation, whereas the final fracture does not occur along the corresponding line for final fracture but at the fairly longer life. The crack propagation process is shown in Fig.7. The total number of cycles of only the higher stress is taken on the abscissa in the figure.

A crack initiates much earlier in the variable amplitude test. Crack propagation rate, however, seems rather low. The retardation of crack propagation under the varying amplitude condition seems to be caused by the compressive residual stress induced at the crack tip after stress change to σ_2. Residual stress is induced because the plastic zone size at the crack tip at the higher stress is rather large as expected from the result of Fig.5. Plastic strain range reversed at the notch root controll the crack initiation life. Once a crack has started, however, compressive residual stress induced at the crack tip controlls the crack propagation rate at the lower stress level.

Higher magnitude of the higher peak and higher value of n_1/n_2 cause shorter lives to crack initiation. This is due to the dependence of the plastic strain range on σ_1 and n_1/n_2.

Fig.8 is the result on notched specimens of AMB102F. There is no difference found between crack initiation and propagation processes. This is explained as follows. The plastic strain range even at the higher stress level is thought to be very small and it vanishes immediately after the stress change to the lower one as

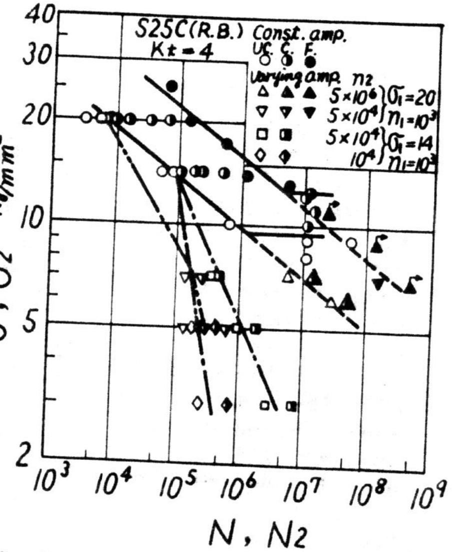

Fig.6 Test result (S25C, Kt=4)

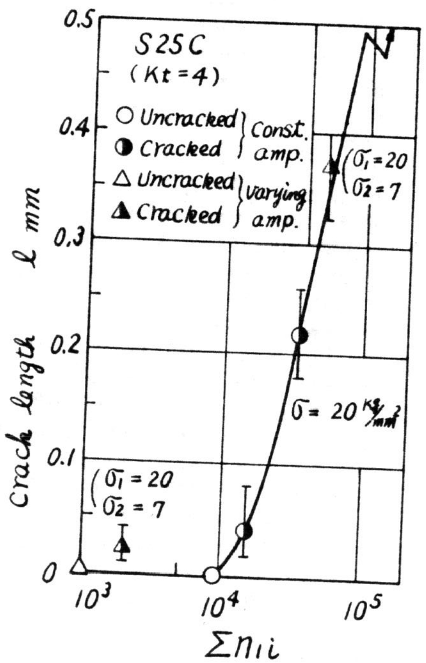

Fig.7 Crack propagation (S25C, Kt=4)

is expected from the result about the unnotched specimen, and so the plastic zone size at the crack tip seems too small or localized to cause enough residual stress which seems to bring about retardation of crack propagation.

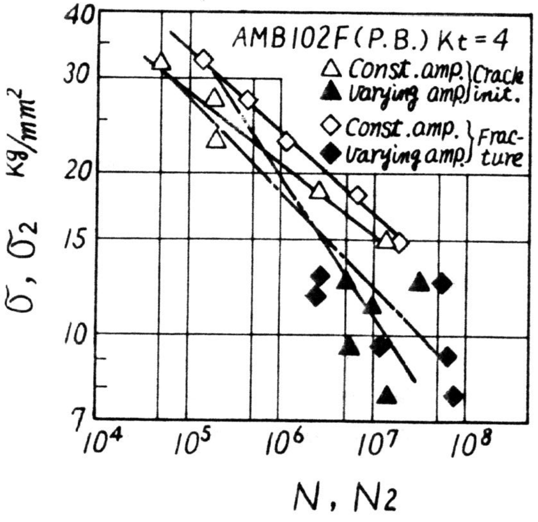

Fig.8 Test result (AMB102F, Kt=4)

CONCLUSIONS

Even very small peaks lower than the original endurance limit come to give enough damage when preceded by high peaks, and a newly reduced S-N curve which lie far below the original one is needed to fit the varying amplitude test result. Higher plastic strain range at every stress level in the varying amplitude test is the cause of the phenomenon. The magnitude of the higher stress amplitude and the value of the cyclic ratio of the higher amplitude to the lower one affect the fatigue life of a specimen. This is also explained through plastic strain occurred.

Crack initiation life is much shorter in the varying amplitude test, though the crack propagation is rather retarded in some materials such as S25C. The residual stress induced at the crack tip after stress drop is thought to be the cause of retardation. In materials like AMB102F remarkable retardation would not occur. This seems due to the small plastic zone at the crack tip.

REFERENCE

1) H. Nakamura, T. Kamata, T. Horikawa, To be published in the Proceedings of ICM (1971, Kyoto), Vol. II.

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