On the Decrease of Residual Stress Due to Cyclic Stress

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INTRODUCTION

The author has reported that residual stress decrease during fatigue process could be separated into twostages. For the first stress cycle a large decrease of the residual stress is cuaused by static yielding, then in the following stress cycles the residual stress decrease is gradual. The author applied the rate process theory on the second stage of residual stress, and showed that the experimental results could be described by a equation as follows

$$i=C(\sigma/\sigma_Y)^{\alpha}\exp(-Q/RT)$$

EXPERIMENTAL PROCEDURE

The plane bending specimens of 0.17% C carbon steel (JIS SS41) were machined, surface were ground and vacuum annealed at 650°C for 45 minutes. They were shot peened by a centrifugal type machine using 1.0mm cut wire shots and the surface roughness was smoothed by emery papers and final electrolytic polishing. The fatigue tests were conducted by Schenck type machine under completely reversed stress cycles.

The surface residual stress was measured by Cr K X-ray with V filter at 30KV, 5mA, time constant 8sec., and divergence angle 0.35° for the both slits. The relaxation of residual stress was measured at intervals during the fatigue test removing the specimen from the testing machine.

The static test at constant tensile stress in higher temperature was carried out using a creep testing machine. The specimens were identical with the ones for fatigue test. The furnace was set at the temperature then the specimen installed and kept at the temperature for 30minutes before the constant stress was applied by dead weights. After 15 minutes loading the specimen was taken out of the furnace then cooled at room temperature for about 15 hours prior to the measurement of residual stress. The condition of X-ray dif- fraction method was the same as the fatigue test. The tem- perature were 150, 200, and 230°C, and the constant loads were 20, 22 and 25 kg/mm^2.

EXPERIMENTAL RESULTS

Fatigue tests.

The decrease of surface residual stress during fatigue process was checked at five stress amplitudes, namely 21.3, 23, 25, 27 and 29 kg/mm^2. An example of the results were shown in Figure 1. The decrease was very sharp in the first stress cycle because of the static yielding. Then in the following cycles the relaxation was gradual and linearly proportional to the logarithm of number of stress cycles.

Static load tests.

The results are shown in Table I. The values in Tab- le I were average of at least two measurements. It was found out that the value of initial residual stress did not affect the rate of residual stress relaxation by static load from the preliminary investigation.

DISCUSSION

In this experiment i was taken as the rate of residual stress relaxation and ln i were plotted against 1/RT, the two lines were almost parallel and did not converge at 1/RT = 0. Therfore the following equation was chosen for this experiment.

$$i = C(\sigma/\sigma_Y)^{\alpha}\exp(-Q/RT) \quad \text{----------(1)}$$

where

i : rate of reaction

σ : applied stress

σ_Y: standard stress

C,α : constants

From equation (1) the relation of ln i and 1/RT is repre- sented by parallel stright lines and the slope of them in- dicate the activation energy which is a constant in this case. The segment of ln i axis is equal to $\ln C + \alpha\ln(\sigma/\sigma_Y)$.

The constant α can be determined from the ln i vs. $\ln(\sigma/\sigma_Y)$ plotting, i.e. the slope of isothermal line gives the value of α, as in Figure 2. From the experimental results of static loading test α, C and Q could be determined. i was calculated from the $\Delta\sigma_R$(decrrase of residual stress in 15 minutes) by

$$i = \Delta\sigma_R/\sigma_Y \times 1/900 \quad (1/\text{sec.}) \quad \text{-----(2)}$$

i : rate of residual stress relaxation

σ_Y: yielding point in compression of shot peened surface = 42.4 kg/mm^2

From the natural logarithms of rate of residual stress re- laxation at 200°C, constant α was calculated to be 13.2,for fatigue it was 4.2. By therelation of ln i vs. 1/RT the value of Q calculated to be 16.2kcal/mol for 20 kg/mm^2 and 18.4 kcal/mol for 22 kg/mm^2. In calculation of ln C, mean of these values 17.3 kcal/mol was used and C was obtained as 4.83 10 1/sec.. The values of Q and C are in the same order as Bennett & Sinclair and Sasaki.

It had been expected that from the activation energy of static load test the experimental results of fatigue test wasexplained. However calculation showed far small values of rate of residual stress relaxation for fatigue test. The reason for this was thought to be the difference of activation energy, since the nature of applied stress were quite dif- ferent. Therefore using constant α of static test and α of fatigue test the activation energy under fatigue load was calculated and the value obtained was 15.5 kcal/mol which was about 10% less than static test.

The experiments of residual stress relaxation under static or cyclic bending stress at elevated temperature are underway.

REFERENCES

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Table I

Decrease of residual stress by static loading $\Delta\sigma_R$(kg/mm²)

	100°C	150°C	200°C	230°C	250°C
20 kg/mm²	0	0	7.51	21.16	24.20
22 kg/mm²	0	3.27	26.23	31.6	-

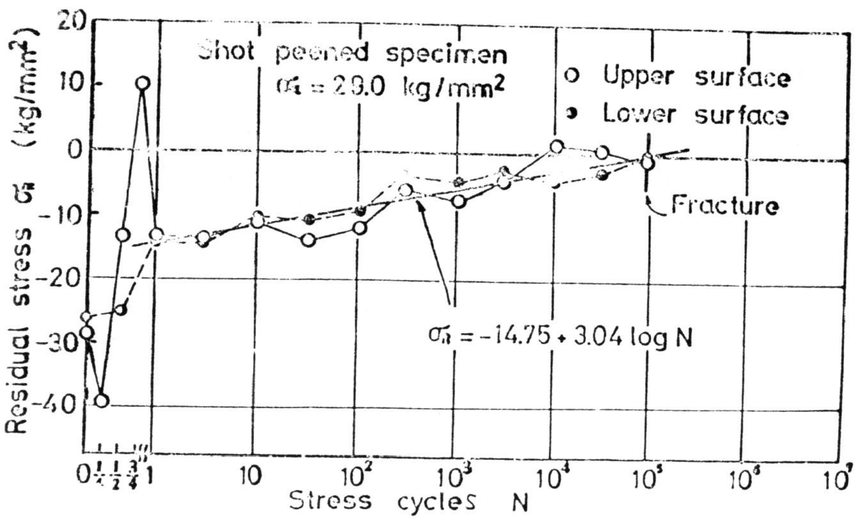


Figure 1 Residual stress relaxation at 29 kg/mm²

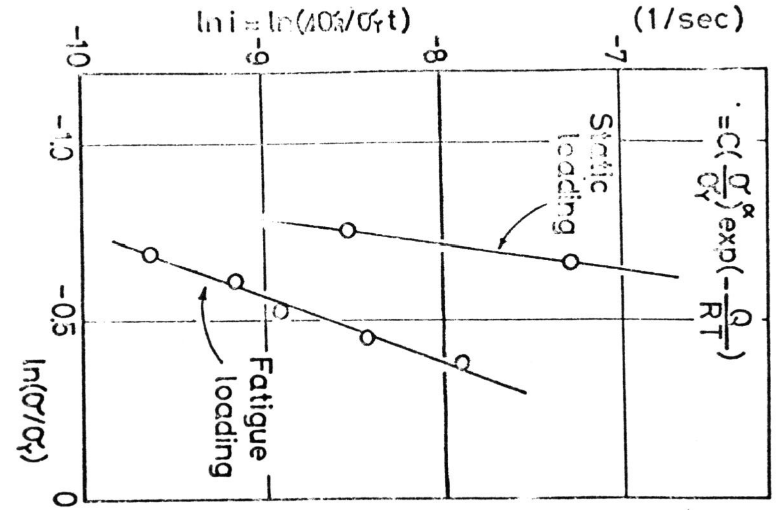
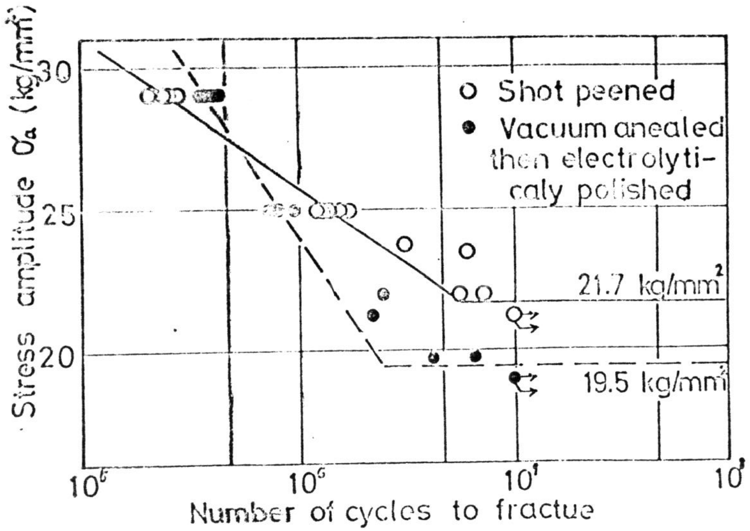


Fig. 2 Residual stress relaxation ratio i vs.σ/σ_Y



S-N curve