FATIGUE LIFE PREDICTION CONSIDERING RESIDUAL STRESS RELAXATION

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Summary: It is necessary to take residual stress relaxation into account to predict fatigue lifetime more correctly. We developed a fatigue life prediction model based on a nominal stress approach considering residual stress relaxation. Finite element analysis of residual stress relaxation was carried out on an X-grooved butt weld specimen. The estimated fatigue lifetime was compared to experimental results.

INTRODUCTION

A lot of study on welding residual stress has been conducted in experimental and numerical areas but the effect of residual stresses on fatigue life has not been clearly explained until yet. Some results show the effect of welding residual stresses on fatigue life is significant. On the other hand, other results show specimens with tensile residual stresses have even longer fatigue life. These unclear conclusions seem to be mainly concerned with residual stress relaxation during fatigue tests and the metallurgical difference between weld metals and parent materials. In this study, we studied the effect of welding residual stress relaxation on the fatigue behavior of a material, JIS SM 490 A, with yielding strength of about 350 MPa and tensile strength of about 520 MPa. Fatigue tests of X-grooved butt weld plates under tensile loading and unloading at loading ratio, $R = 0.1$, were carried out to failure. The dimension of the specimens is 200×25×10 mm. The S-N curves are shown in Fig. 1 and 2. We can observe in the long life ($N > 2\times10^5$) the fatigue strength of AAY is higher than that of AAN, but in the short life, vice verse. These phenomena seem to be related mainly to residual stresses and structural changes due to post weld heat treatment. In the following section, a model considering residual stress relaxation and structural changes will be described.

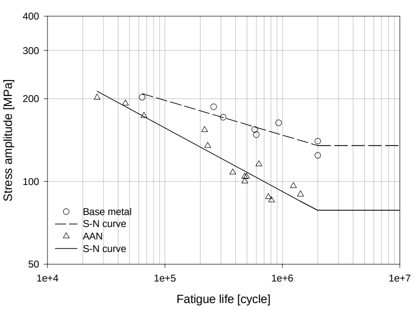

Fig. 1 S-N curves for base material and as-welded (AAN) specimens

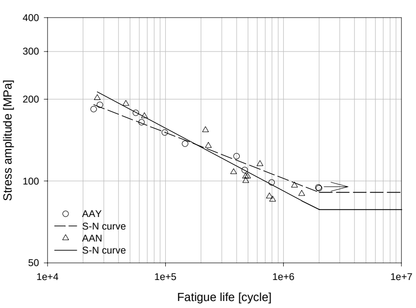

Fig. 2 S-N curves for annealed (AAY) and as-welded (AAN) specimens

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The effects of residual stresses and structural changes due to post weld heat treatment on fatigue behavior are presented schematically in Fig. 3. We consider a tensile loading-unloading constant amplitude fatigue test. The line A-E is the S-N curve for the base material. The line A-F is for a notched specimen without residual stresses. When the effect due to structural changes is added to the line A-F, the S-N curve A-F will move to a curve C-G, which may go upward or downward. When the effect due to residual stresses is added to the line A-F, the S-N curve would be a curve B-D-H. At point D the sum of applied stress and initial residual stress in the $S_{\max}$ direction, $(S_{\max} + \sigma_{r_{ini}})$, is equal to the yield strength of the material, S_y. Notch root and nominal stresses are represented by σ and S respectively. When $(S_{\max}+\sigma_{r_{ini}})$ is greater than S_y, the initial residual stress is relaxed to σ_r. σ_r is assumed to be a function of applied load and loading cycles.

$$\sigma_r = \sigma_{r_{ini}} \left[1 - k_1 \ln\left(\frac{S_{\max}+\sigma_{r_{ini}}}{S_y}\right) \right] e^{-k_2(N-1)} \quad \text{if} \quad (S_{\max}+\sigma_{r_{ini}}) \geq S_y \tag{1}$$

where k_1 and k_2 are constants. According to experimental results, the amount of relaxation through the first cycle is dominant. We consider only the first cycle.

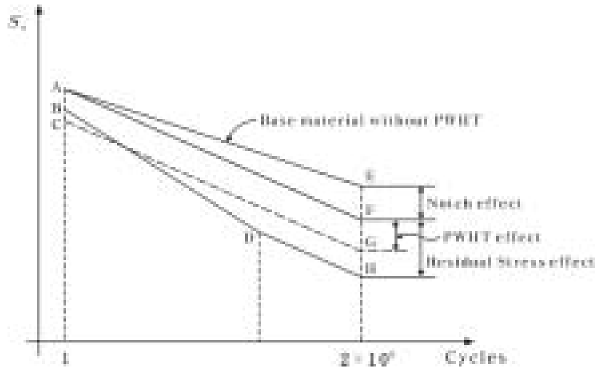

Fig. 3 Schematic diagram of S-N curves

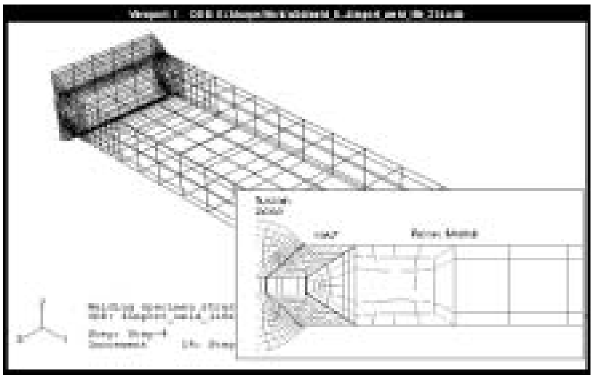

Fig. 4 3-D FE model for butt welded specimen

Fig. 4 shows the meshed geometry for an X-grooved butt weld specimen. A half of the specimen is considered. The initial residual stresses were obtained by thermal and elastoplastic analyses. Then, the relaxation of the initial residual stress was obtained by finite element analysis.

The S-N curve for the base metal is expressed by Basquin's equation:

$$S_a = AN^m \tag{2}$$

To predict the fatigue lifetime for a welded joint with residual stresses, the stress concentration factor by the applied load is obtained by finite element analysis and the fatigue notch factor, K_f, is calculated by Neuber's method. The fatigue strength for the notched part at 2 million cycles is given by S_f / K_f. The fatigue strength for the notched and smooth parts at one cycle is assumed to be the same. The S-N curve for the notched part, line A-F in Fig. 3, is written :

$$S_a = A_1 N^{m_1} \tag{3}$$

The residual stress after one cycle of loading, σ_r, is calculated by finite element analysis and Equ. 1. The residual stress σ_r is added to the mean stress term of the modified Goodman diagram :

$$\frac{S_a}{S_f} + \frac{(S_{mean}+\sigma_r)}{S_u} = 1 \tag{4}$$

Inserting S_a obtained from Equ. 4 to Equ. 3, we can predict the fatigue lifetime of the welded member. The predicted lifetime is in good agreement with the experimental.

Acknowledgement

This work was supported by the National Research Laboratory (NRL) program of the Korea Ministry of Science and Technology. We are grateful for the support.