Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 37 (1982)

Artikel: Residual stresses in welded members subjected to cyclic loading

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DOI: https://doi.org/10.5169/seals-28931

Residual Stresses in Welded Members Subjected to Cyclic Loading

Contraintes résiduelles dans les éléments soudés soumis à des charges cycliques

Restspannungen bei geschweissten Bauteilen unter Schwingbelastung

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SUMMARY
The effect of residual stress on fatigue crack growth was studied experimentally on base plate and welded specimens of 800 N/mm^2 tensile strength steel. The results indicated that crack growth rate in welded members can be estimated as that of base metal specimens with a stress ratio of 0.5. In addition, the use of stress relief heat treatment has little effect on crack growth rate unless it completely removes the residual stress.

RESUME
L'effet des contraintes résiduelles sur la propagation des fissures dues à la fatigue a été étudié expérimentalement sur des échantillons de plaque de base et soudés en acier dont la résistance à la traction était de 800 N/mm^2. Les résultats indiquent que le taux d'accroissement des fissures dans les éléments soudés peut être estimé égal à celui des échantillons de plaque de base avec un rapport de contrainte de 0,5. L'utilisation d'un traitement thermique a peu d'effet sur le taux d'accroissement des fissures à moins qu'il ne supprime complètement les contraintes résiduelles.

ZUSAMMENFASSUNG
Die Auswirkungen der Restspannung auf die Wachstumsrate von Ermüdungsrissen wurden an Mustern von Grundplatten und geschweissten Teilen aus Stahl mit 800 N/mm^2 Zugfestigkeit experimentell untersucht. Die Experimente zeigten, dass sich die Wachstumsrate von Ermüdungsrissen bei geschweissten Bauteilen mit der Wachstumsrate von Ermüdungsrissen der Grundplattenmuster mit einem Spannungsverhältnis von 0.5 abschätzen lässt. Spannungsfrei Glühen hat keinen Einfluss auf die Wachstumsrate von Ermüdungsrissen, wenn dadurch die Restspannung nicht vollständig abgebaut wird.

1. INTRODUCTION

It is very important to know the fatigue crack growth rate in the plate with residual stress to estimate the fatigue life, when we disign a welded steel structure under cycle loading, since the most of fatigue cracks initiate from welding beads or their vicinity, and propagate in the welding residual stress field. But, there seems few, if any, systematic studies on the effect of welding residual stress on fatigue crack growth rate . In the past studies, it is reported that fatigue life of welded members was shorter than that of non-welded members. For instance, in reference [1],the fatigue life of half-scale model of box chord members with high tensile strength steel, was much shorter than that of small specimen. This shortness in fatigue life is considered as caused by the effect of welding residulal stress, or welding residual stress makes fatigue life short.

If the fatigue crack growth rate of welded members is faster than that of base metal by the existence of welding residual stress, it might be said that welding residual stress should be decreased.

From these standpoint, the effect of welding residual stress on fatigue crack growth rate was studied on $80kg/mm^2$ tensile strength steel.

The experiment was carried out by using three types of specimen; base metal, as-welded and stress relieved. Fatigue crack growth rate and welding residual stress were measured. Crack opening and closure was also observed.

2. EXPERIMENT

2.1 Material and specimen

The material used was $80kg/mm^2$ tensile strength steel plate of 6.4mm in thickness. Its' chemical composition and mechanical properties are shown in Table 1. The center-notched specimens, shown in Fig. 1, were used. Fig. 1 also shows the detail of notch. Three types of specimen were used ; base metal specimen,as-welded specimen and stress relieved specimen.

The welded specimen was prepared by submarged-arc-welding as beads-on-plate welds on an edge preparation of 5.5mm width and 2mm depth to obtain a uniform distribution of welding residual stress through the plate thickness. Welding consumables (wire and flux) for $50kg/mm^2$ tensile strength steel were used, but it was considered to be no trouble for this study's purpose, since the welding was made only to give residual stress. From the observation of the hardness distribution in the vicinity of the beads of welded specimen,the value of hardness drops to that of base metal at the point of 7mm away from the center of the beads. Therefore the initial center notch length was chosen as 10mm and the

Table 1 Chemical composition and mechanical properties the plate

Steel	Chemical composition (%)									
	C	Si	Mn	P	S	Cu	Cr	Mo	V	B
HT80	0.12	0.26	0.88	0.017	0.005	0.23	0.89	0.31	0.04	0.0007

Y.S. (kg/mm^2)	T.S. (kg/mm^2)	El. (%)
80	85	22

Y.S.:Yield stress
T.S.:Tensile strength
El. :Elongation

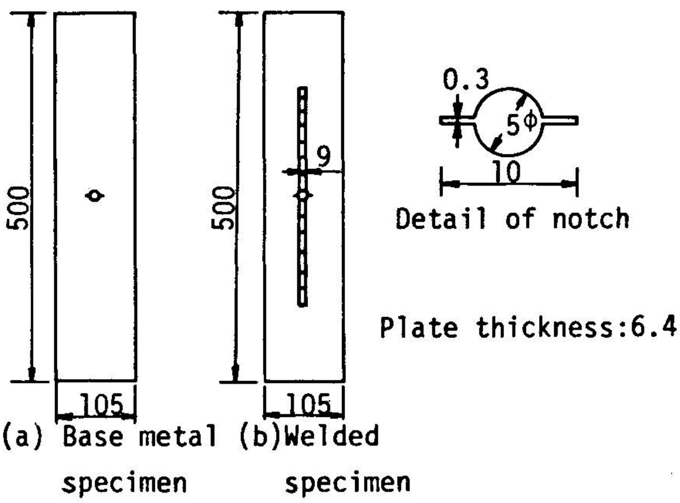


Fig.1 Geometry and size of specimen

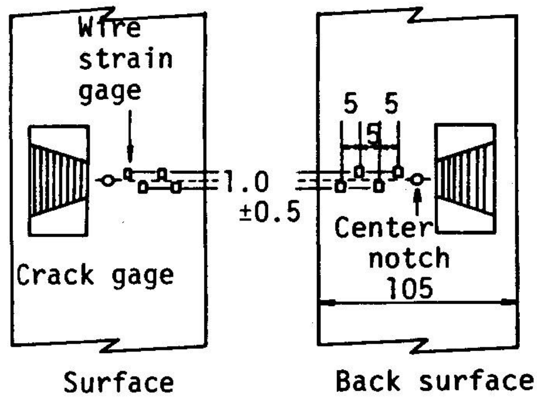


Fig.2 Gage location

fatigue crack growth rate was estimated from at the point of 2mm away from the tip of initial notch.

2.2 Testing procedure

This investigation was devided into two series of tests. First series were conducted under variable stress ratio and constant residual stress, another series were under constant stress ratio and variable residual stress.

All tests were conducted by using an electrohydraulic closed loop servo fatigue testing machine. The testing freguency was 10Hz.It was dropped, however , to 0.1Hz or 1.0Hz when observing a crack opening and closure. Crack length was measured by using a crack gage and the observation of crack opening and closure was made by attaching small wire strain gages at the points quite close to the expected fatigue crack extension line. (Fig. 2)

In this investigation, the crack opening or closure was determined from a deflection point in a hysteresis curve between a load cell output (Y-axis) and an output of a wire strain gage near the crack tip (X-axis), as is illustrated in Fig. 3. Stress relief heat treatment was carried out by using electric furnace, and temperature was controlled by C-A thermo couple.

Welding residual stress was measured by eleven small wire strain gages attached along the center line of longitudinal of the specimen.

K-value is caluculated by using Forman's formula.

$$K= \sigma_0\sqrt{\pi a \cdot \sec(\pi a/W)}$$

where a:Half crack length W:Specimen width σ_0:Uniform tensile stress

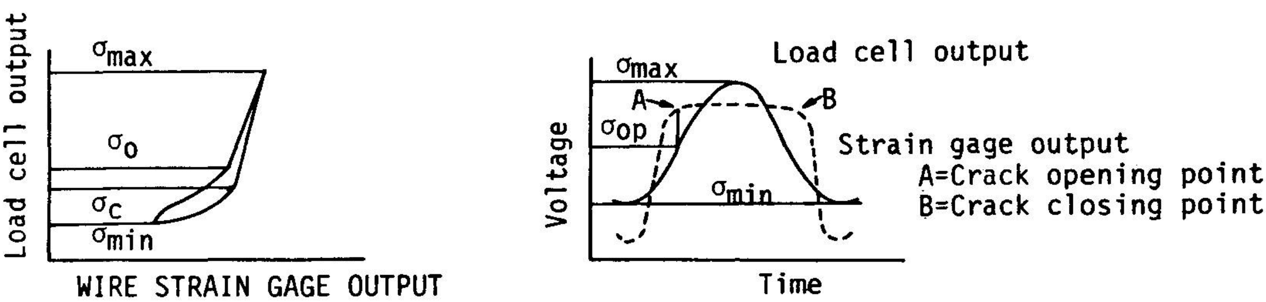


Fig.3 Observation of crack opening and closure

3. TEST RESULTS AND DISCUSSION

3.1 Variable stress ratio test series

Fig.4 shows the distributions of welding residual stress for base metal specimen and as-welded specimen.

Stress ratio was changed from R=0.5 (HB1) to R=-1.0 (HB5) for base metal specimen and from R=0.5 (HW1) to $R=-\infty$ (HW8) for as-welded specimen. Fig.5 shows the relationship between fatigue crack growth rate da/dN-ΔK .Secant formula was used in evaluating ΔK. It can be seen that da/dN decrease with the decrease of stress ratio R, for base metal specimen. While,the data of welded specimens in small ΔK region or more precisely in small crack length region fall within a narrow band no matter what value the stress ratio may be, which is quite different from the case of base metal specimens.

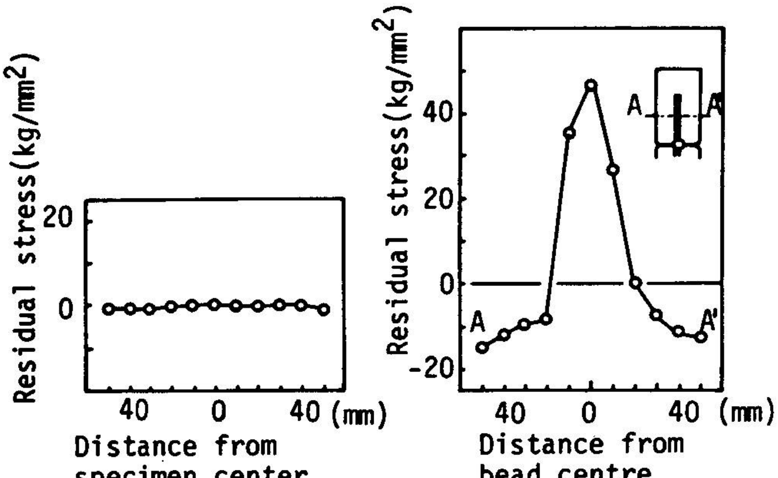
The data of HW8, which was obtained under repeated compression loading ($R=-\infty$),show that da/dN quite rapidly after exceeding approximately ΔK= 60Kg/mm$^{3/2}$. Unlike other cases, the right hand side data and the left hand side data of HW8 are quite different so each result is shown in the figure as HW8-A and HW8-B.But in either case of A or B, a crack is found to propagate even under repeated compression loading, where a crack is considered never to propagate if the welding residual stress is not present and the remarkable effect of welding residual stress can be observed. The da/dN of as-welded results of Fig.5, usingΔKeff which is evaluated by Eq,(2) based on experimentally obtained U value.[2]

$$\Delta K_{eff} = U \times \Delta K \qquad (2)$$

Where $U = \dfrac{\sigma_{max} - \sigma_{close}}{\sigma_{max} - \sigma_{min}}$

It is generally observed by comparing Fig.5 with Fig.6 that experimental results which scatter quite widely on da/dN- K plots fall within a narrow band if they are replotted using Keff.

Thus, it is easily understood that the behavior of crack opening and closure plays quite an important role in evaluating the effect of stress ratio R in base metal specimens and in evaluating the effect of welding residual stress in welded specimens. In as-welded specimen except HW8 ($R=-\infty$) and base plate specimen with stress ratio R=0.5 (HB1), crack did not close or U=1.The fatigue crack growth rate of as-welded specimens can be estimated as that of base metal specimen with the stress ratio of 0.5.



(a)Base metal specimen (b)As-welded specimen

Fig.4 Residual stress distributions

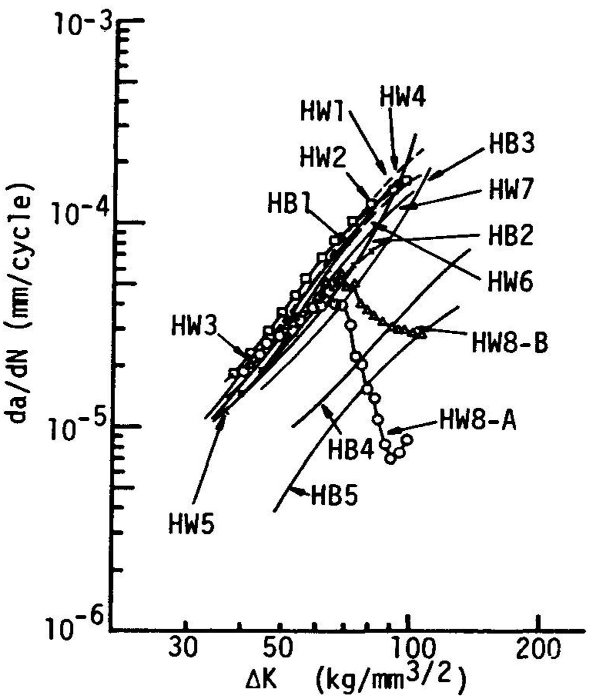


Fig.5 da/dN-ΔK relations

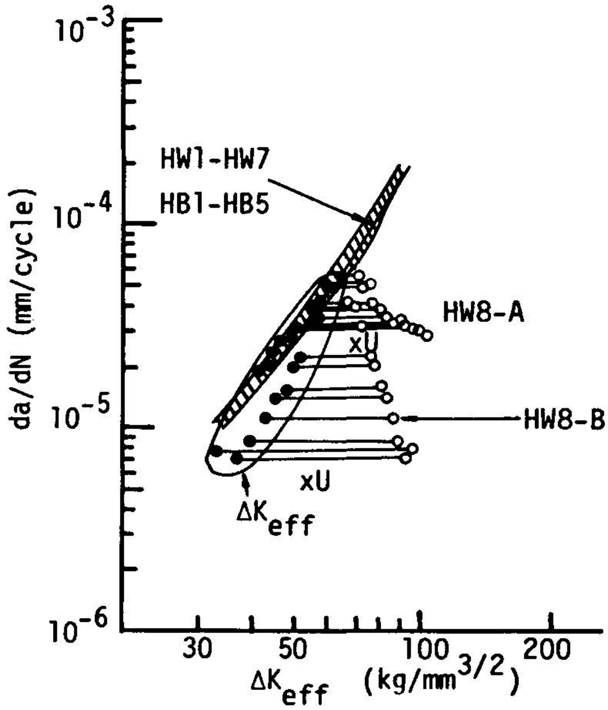


Fig.6 da/dN-ΔK_{eff} relations

3.2 Variable residual stress test series

Fig.7 shows the residual stress distributions of stress relieved specimens.HS-2, HS-4,and HS-6 are the specimens stress relieved at 580° C for 1 hour, 3 hours, and 12hours, respectively. These results show the increase of holding time length doesn't affect the decrease of residual stress. The other hand, HS-8,HS-2,HS-10 and HS-12 are the specimens stress relieved for 1 hour at 500°C, 580°C,630°C and 650°C respectively. These results show the more increase of holding temperature, the more decrease of welding residual stress. The hardness of the specimen stress-relieved at 650°C is a little lower than the others. The different 6 types of the stress relieved conditions yield 4 types of residual stress distributions, in short, maximum tensile stress is nearly equal to 20kg/mm^2, 10kg/mm^2 ,5kg/mm^2 and 2kg/mm^2. Fig.8 shows the results of the fatigue crack growth rate in these specimens. The data of stress relieved specimens in small ΔK region fall within a narrow band no matter what value the initial tensile residual stress may be. Especially, three lines, which except the date of initial tensile residual stress is 2kg/mm^2,are almost same , up to the range of ΔK=70kg/mm$^{3/2}$. This figure also shows that the da/dN in stress relieved specimen,except the specimen of initial tensile residual stress is 2kg/mm^2,are just as same as the da/dN in as-welded specimen up to the region of ΔK=70kg/mm^2

It is very important that the da/dN in stress relieved specimen, whose initial tensile residual stress is 5kg/mm^2,is as same as that in as-welded specimen, whose initial tensile residual stress is 40kg/mm^2. In spite of the initial tensile residual stress is decreased to 1/8,the fatigue crack growth rate in those two specimens are same. This result is seemed that stress relief heat treatment may be of little effect on fatigue crack growth rate, if it is not cancel the residual stress perfectly. The stress relieved specimens change their growth rate, as the residual stress is released according to their fatigue crack growth. In prototype members, the release of residual stress may

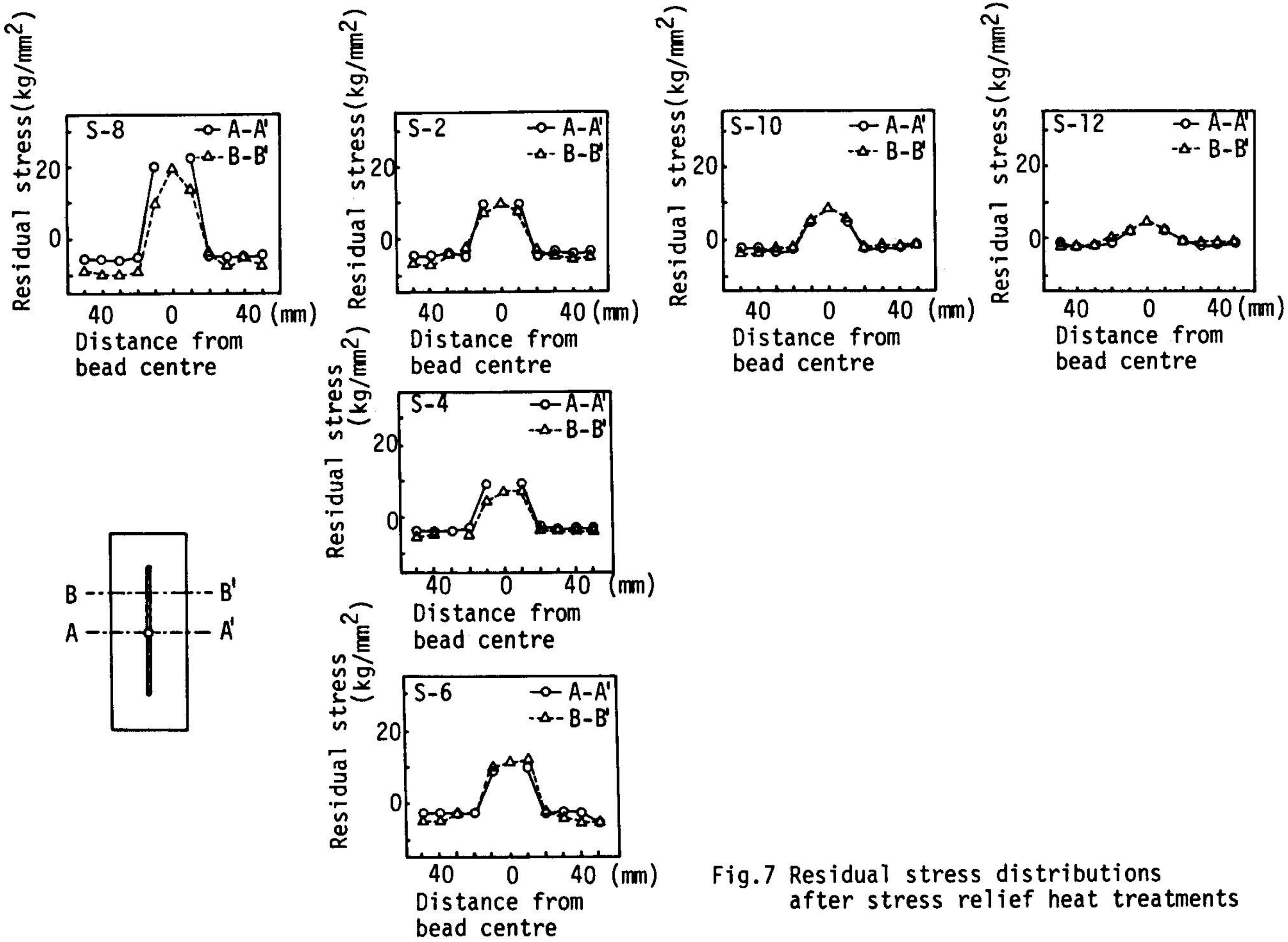


Fig.7 Residual stress distributions after stress relief heat treatments

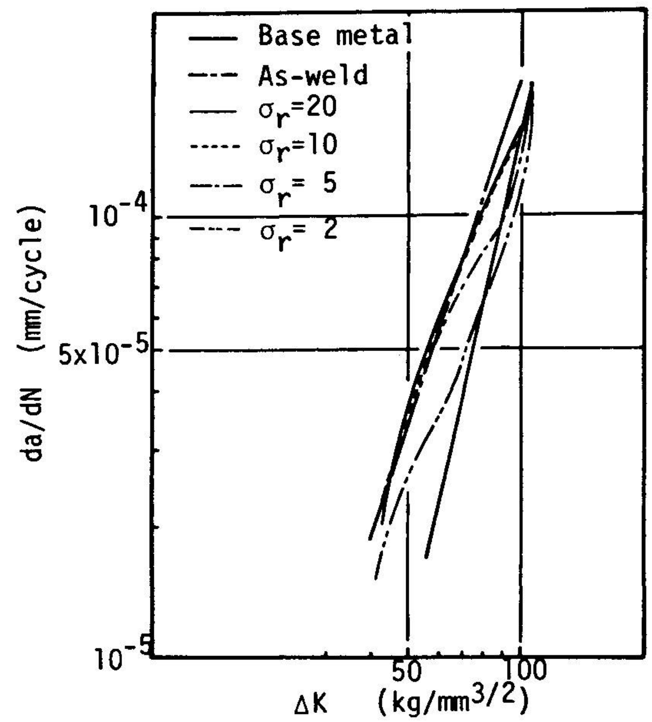


Fig.8 da/dN-ΔK relations after stress relief heat treatment

be less than this type of splecimens, since the length of fatigue crack is very short, as compared with the ligament length. So, the fatigue crack growth rate in stress relieved members may be same to that in as welded members up to finial unstable fracture in prototype members. From these considerations stress relief heat treatment on prototype members may be of little effect from viewpoint of fatigue crack growth rate.

4. CONCLUSIONS

The major conclusions obtained are as follows;

(1)Although the lines of da/dN-ΔK differ for different stress ratios in the case of base metal specimens, the data of da/dN-ΔK for small crack length fall within a narrow band in the case of welded specimens, even though their stress ratios are different. In this study, da/dN of as-welded specimens is as same as that of base metal specimen with the stress ratio of 0.5.

(2)In the presence of welding residual stress, fatigue cracks are found to propagate even under fully repeated compression loading.

(3)All data of welded specimens and base metal specimens which scatter quite extensively on da/dN- ΔK plots fall within a narrow band if they are replotted by ΔKeff.

(4)In the specimens stress relieved at 580°C, the lengthen of holding time is not much effective on release of residual stress. The other hand, in the specimens, stress relieved at 500°C to 650°C, the more increase of heat treatment temperature yields the more decreare of residual stress.

(5)The fatigue crack growth rate in stres relieved specimen , whose residual stress is 5Kg/mm^2 , is same to that in as-welded specimen, whose initial tensile residual stress 40Kg/mm^2, up to the region of ΔK= 70Kg/mm$^{3/2}$. Stress relief heat treatment is of little effect on fatigue crack growth rate.

(6)If residual stress can't be canceled perfectly, it seems that stress relief heat treatment on prototype members is of little effect on fatigue crack growth rate.

REFERENCE

1. Jiro Tajima, et al.:Fatigue Strength of Large Size Weldments of High Tensile Strength Steels, Proceedings of International Conference on Welding Research in the 1980's
2. Elber,W.: Significance of Fatigue Crack Propagation, ASTM STP 486