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Fatigue Crack Growth Rate in Welded Joints after Stress Relief Heat Treatment†

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Abstract

The effect of stress relief heat treatment on fatigue crack growth rate was studied experimentally. Fatigue tests and residual stress measurements were carried out on three types of specimen; base metal specimen, as-welded specimen and stress relieved specimen. All tests were carried out on center-notched specimen with the identical geometry and size, made from a 80 kg/mm^2 tensile strength steel plate. From experimental results, it was cleared that the fatigue crack growth rate of as-welded specimen was faster than that of base metal specimen. The fatigue crack growth rate of stress relieved specimen, whose tensile residual stress is 5 kg/mm^2, was as same as that of as-welded specimen up to the region of $\triangle K = 70$kg/mm$^{3/2}$. So, the stress relief heat treatment seems to be of little effect on fatigue crack growth rate, if it can't cancel residual stress perfectly.

KEY WORDS: (Fatigue Crack Growth Rate, Residual Stress, Stress Relief Heat Treatment)

1. Introduction

There seems to be a few studies on the effect of welding residual stress on fatigue crack growth rate. But, in the only a few past papers, it is reported that the fatigue crack, which starts from tensile residual stress field, propagates faster than base metal, when the tensile residual stress exists in the vicinity of crack tip. And also, if the tensile residual stress is decreased to nearly equal zero, the fatigue crack growth rate of welded specimen reduces approximately equal to that of base metal. Therefore, stress relief heat treatment on welded members is considered to be effective for fatigue crack growth rate. It is not confirmed, however, the effect of stress relief heat treatment on fatigue crack growth rate minutely.

From this standpoint, this study intends to confirm the effect of stress relief heat treatment on fatigue crack growth rate experimentaly. The experiment was conducted on base metal speicmen and welded specimen of 80 kg/mm^2 tensile strength steel.

The experiment was also made on the welded specimen after stress relief heat treatment.

The fatigue crack growth rate and welding residual stress of all specimens were measured. Data of fatigue crack growth rate were estimated by fracture mechanics method ($\triangle$ K).

2. Material and Test Procedures

The material used was a 80 kg/mm^2 tensile strength steel plate. Its chemical composition and mechanical properties are shown in Table 1.

Fig. 1 shows the center-notched specimen with detail of the notch. The welded specimeen was prepared by submarged-arc-welding as beads-on-plate welds on an edge preparation of 5.5 mm width and 2 mm depth to obtain a unifrom distribution of welding residual stress through the plate thichkness. Welding condition is shown in Table 2. Welding consumables (wire and flux) for 50 kg/mm^2 tensile strength steel were used, but it was considered to

Table 1 Chemical composition and mechanical properties of the plate

Material	Chemical composition (%)									
	C	Si	Mn	P	S	Cu	Cr	Mo	V	B
HT 80	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

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be no trouble for this study's purpose, since the welding was made only to give residual stress.

Fig. 2 shows the hardness distribution in the vicinity of the beads of welded specimen. It can be observed from this figure that the value of hardness drops to that of base metal at the point of 7 mm away from bead center. Therefore the initial center notch length was chosen as 10 mm and the fatigue crack growth rate was estimated from at the point of 2 mm away from the tip of initial notch. The testing proedure is shown in Fig. 3. Three series of the tests were carried out ; first one was made on base metal specimens, second one on as-welded specimens and last one on stress relieved specimens.

The specimens were used for fatigue test and residual stress measurment, respectively. All tested specimens are shown in Table 3.

Table 3 also shows the conditions of stress relief heat treatment. Stress relief heat treatment was carried out by using electric furnace, and temperature was controlled by

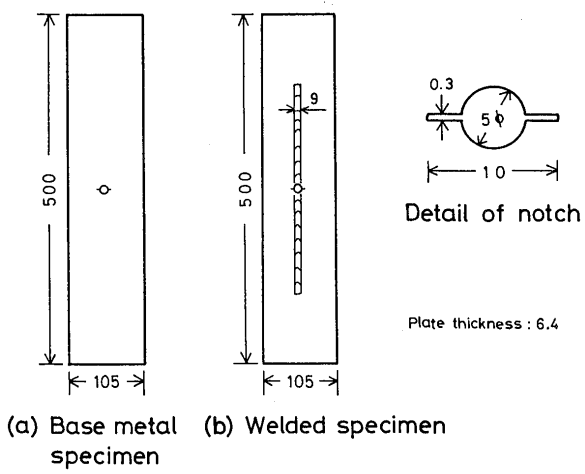


Fig. 1 Test specimens

Table 2. Welding Condition

Current	270(A)
Voltage	30 (V)
Speed	52 (cm/min)
Preheating	No
Position	Flat
Wire	Y-CS 1.6dia.
Flux	NF-16

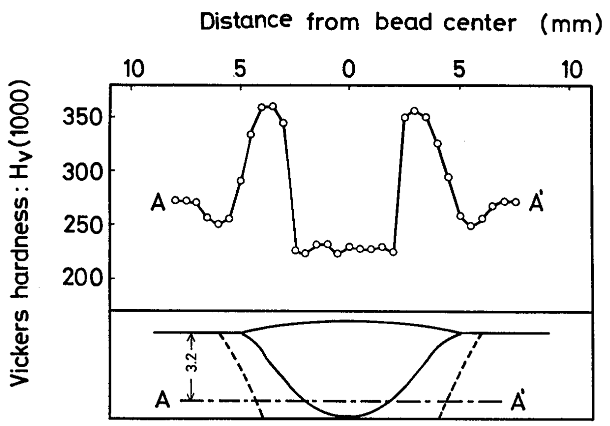


Fig. 2 Vickers hardness distribution in the vicinity of weld beads

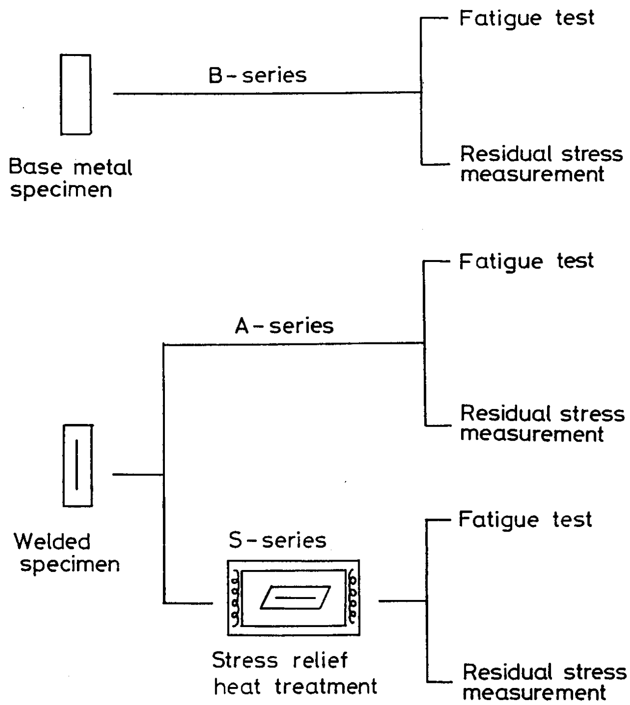


Fig. 3 Testing Procedure

Table 3 Testing conditions

Specimen number	Series	Test purpose	Conditions of SR	
			Temp. (°C)	Time (hour)
B - 1 B - 2	B	F		
A - 1 A - 2	A	F		
A - 3		M		
S - 1	S	F	580	1
S - 2		M		
S - 3		F	580	3
S - 4		M		
S - 5		F	580	12
S - 6		M		
S - 7		F	500	1
S - 8		M		
S - 9		F	630	1
S - 10		M		
S - 11		F	650	1
S - 12		M		

F : Fatigue test
M : Measurement of residual stress

C-A thermo couple. Welding residual stress was measured by eleven small wire strain gages attached along the center line of longitudinal of the speicmen.

Fatigue crack propagation tests were conducted by a electrohydraulic closed loop servo fatigue testing machine under constant amplitude condition R=0 (0 to 9 kg/mm^2).

The testing frequency was 10 Hz. Crack length was measured by using a crack gage, shown in Fig. 4. K-value is caluculated by using Forman's formula

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

where a : Half crack length

w : Specimen width

σ_0 : Uniform tencile stress

3. Test results and Discussion

Fig. 5 shows the residual stess distributions of as welded specimen and base metal specimen. The maximum tensile residual stress of as-welded specimen is nearly equal to zero.

Fig. 6 shows the relationship between fatigue crack growth rate (da/dn) and stress intensity factor range (ΔK) for base metal specimen and as-welded specimen.

This results shows that the fatigue crack growth rate of as-welded specimen is faster than that of base metal specimen. It is caused by the tensile residual stress in the vicinity of crack tip.

The residual stress distributions of stressrelieved specimens are shown in Fig. 7. S-2, S-4, S-6 are the specimens stress relieved at 580°C for 1 hour, 3 hours, and 12 hours, respectively. These results show the increase of holding time length doesn't affect the decrease of residual stress.

On the other hand, S-8, S-2, S-10, S-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.

Table 4 shows the vicker's hardness of as-welded specimen and stress relieved specimen.

The hardness of the specimen, stress-relieved at

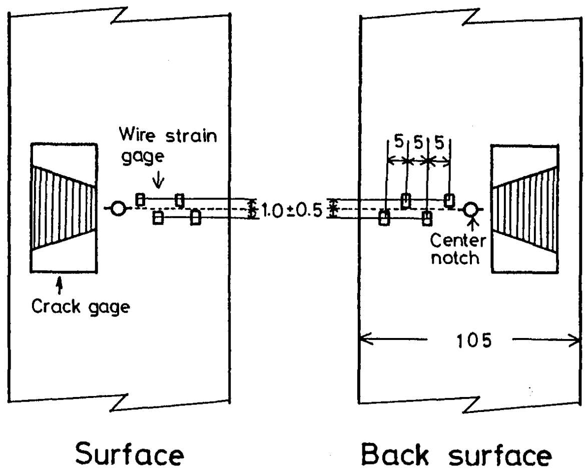


Fig. 4 Location of guages

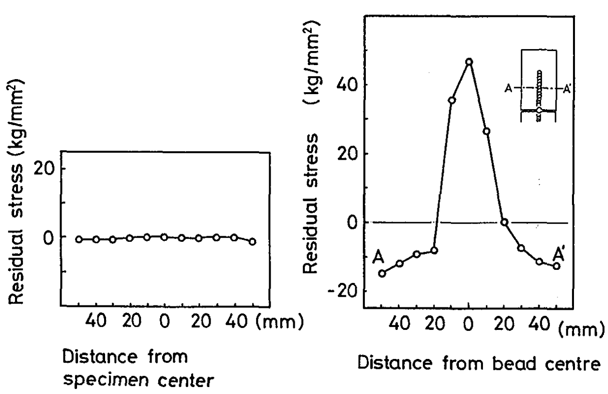
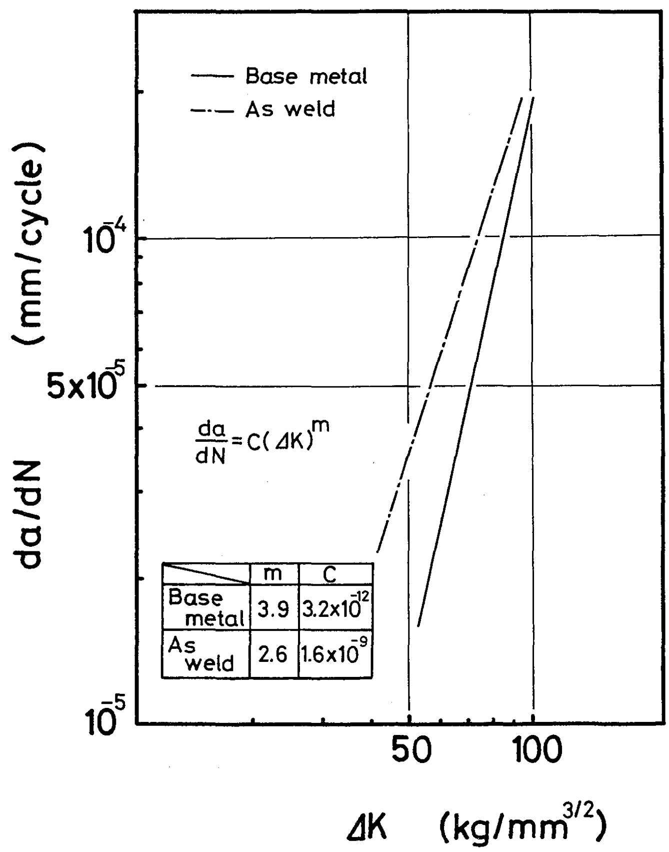


Fig. 5 Residual stress distributions of base metal and as welded specimens



	m	C
Base metal	3.9	3.2×10^{-12}
As weld	2.6	1.6×10^{-9}

Fig. 6 Fatigue crack growth rates in base metal and as welded specimens

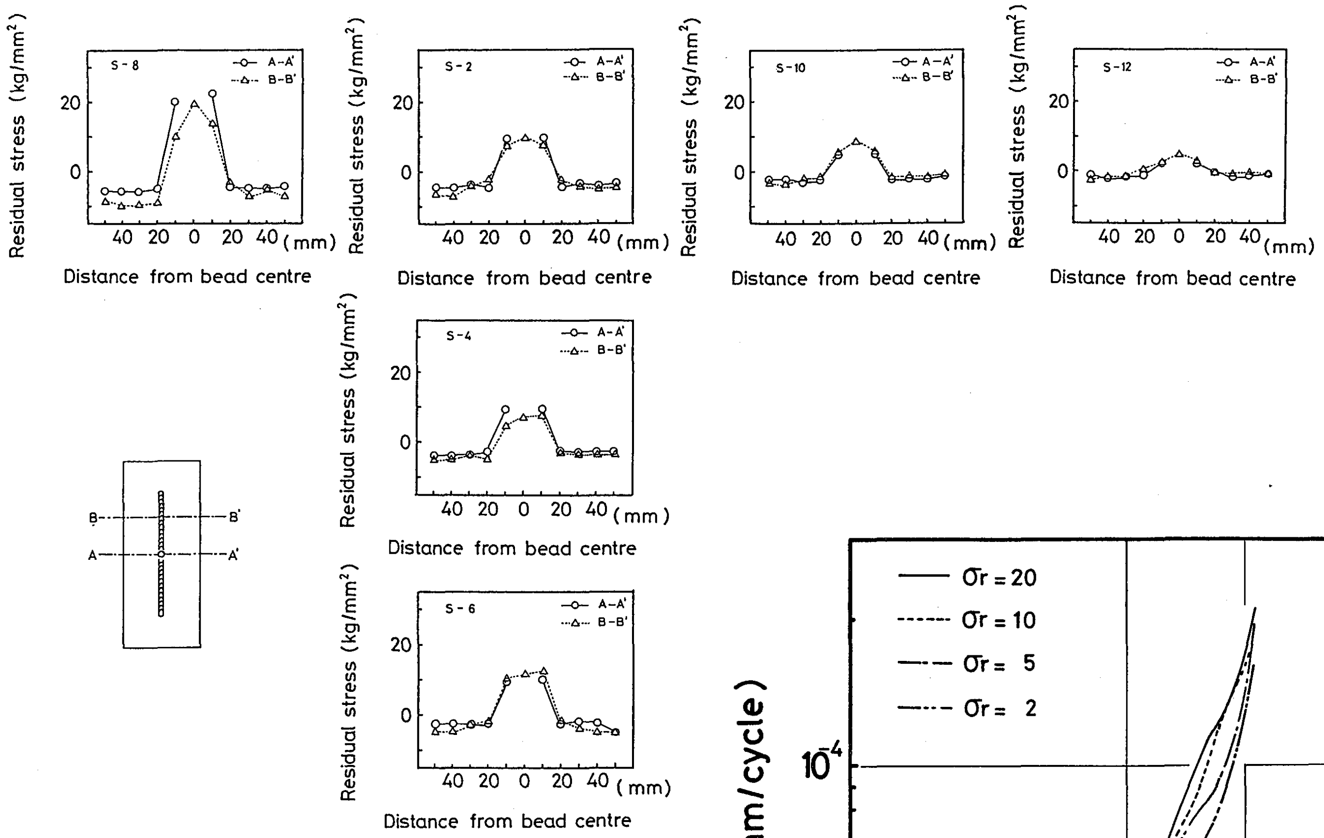


Fig. 7 Residual stress distributions of stress relieved specimens

Table 4. Vickers hardnesses of specimens

	As welded specimen	SR specimen			
		S-1	S-7	S-9	S-11
Hv (1000)	272	278	279	272	252

650°C, is a little lower than the others. So, heat treatment higher than 650°C is aboided. It is appeared from Fig. 7 that the different 6 types of the stress relieved conditions yield 4 types of residual stress distributions.

In short, maximum tensile residual stresses are nearly equal to 20 kg/mm^2, 10 kg/mm^2, 5 kg/mm^2, and 2 kg/mm^2.

Fig. 8 shows the results of the fatigue crack growth rate in these specimens. The data of stress relieved specimens in small $\triangle$K region fall within a narrow band no matter what value the initial tensile residual stress may be.

Especially, three lines, which except the data of initial tensile residual stress is 2 kg/mm^2, are almost same, up to the range of $\triangle$ K=70 kg/mm$^{3/2}$.

Fig. 9 shows the results of all data. This figure shows that the da/dN in stress relieved speicmen, except the specimen of initial tensile residual stress is 2 kg/mm^2, are just as same as the da/dN in as-welded specimen up to the region of $\triangle$ K=70 kg/mm$^{3/2}$. It is very important that the

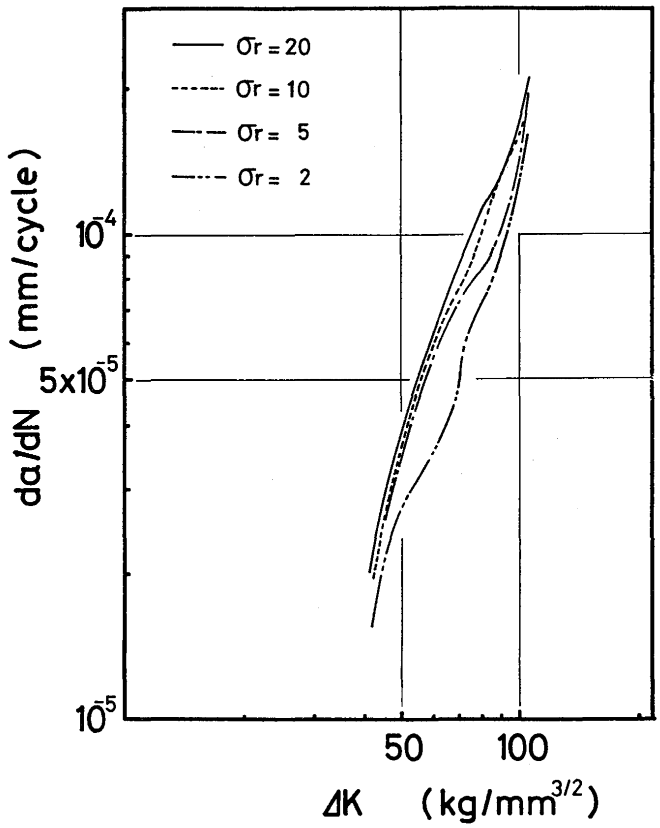


Fig. 8 Fatigue crack growth rates in stress relieved specimens

da/dN in stress relieved specimen, whose initial tensile residual stress is 5 kg/mm^2, is as same as that in as welded specimen, whose initial tensile residual stress is 40 kg/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 almost same. This resulit 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 stresss may be less than these specimens, since the length of fatigue crack is very short, as compared with the ligament length. So, the fatigue crack growth rate in stress reliev-ed members may be same to that in as-welded members up to finial unstable fracture in prototype members. From this standpoint, stress relieve heat treatment on prototype members may be of little effect form viewpoint of fatigue crack growth rate.

4. Conclusion

From these experimental results, we came to the conclusions as follows.

1) The fatigue crack growth rate in as-welded specimens is faster than that in base metal, for example, as-welded specimen is twice faster than base metal at the point of $\Delta K=50\ kg/mm^{3/2}$.
2) 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 decrease of residual stress.
3) The fatigue crack growth rate in stress relieved specimen, whose residual stress is $5\ kg/mm^2$, is same to that in as-welded specimen, whose initial tensile residual stress is $40\ kg/mm^2$, up to the region of $\Delta K=70\ kg/mm^{3/2}$, Stress relief heat treatment is of little effect on fatigue crack growth rate.
4) 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.

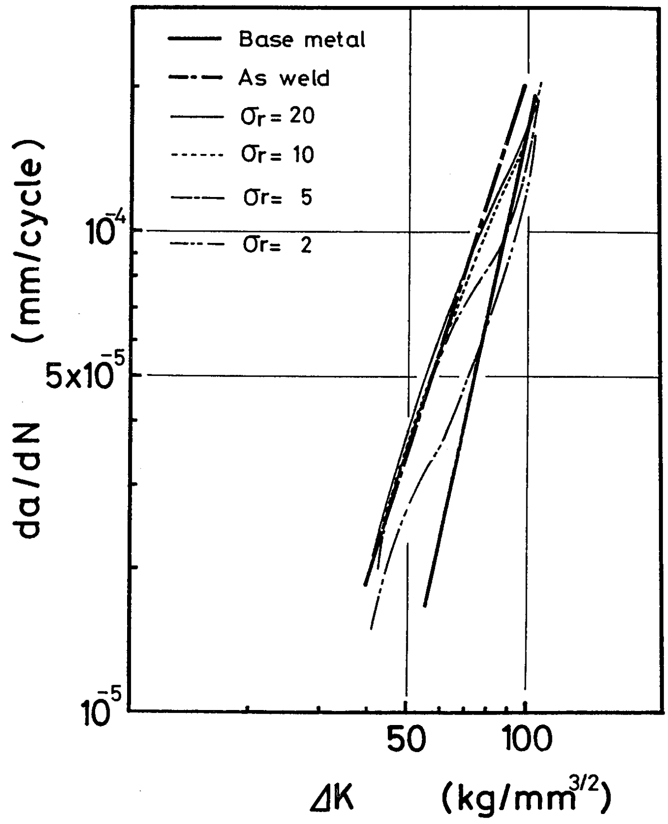


Fig. 9 Fatigue crack growth rates in all specimens