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An Experimental Study of Redistribution of Welding Residual Stress with Fatigue Crack Extension†

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Abstract

In spite of the recent considerable progress in fracture mechanics theories and applications, there seems to be no, at least to the authors' knowledge, systematic study of the effect of welding residual stress upon fatigue crack propagation. This paper constitutes a part of our systmatic research work program to make clear the effect of welding residual stress upon fatigue crack propagation based on fracture mechanics. There is a point which is always at issue when it comes to discussing the effect of welding residual stress on fatigue crack propagation. i.e., as the welding residual stress often decreases with the repetition of loading cycles in an unnotched specimen, it is duly expected that in a notched specimen not only the phenomenon of the redistribution of welding residual stress with fatigue crack extension occurs but also the phenomenon of the decrease of welding residual stress with the repetition of loading cycles might possibly occur at the same time and this would make the problem quite difficult. Therefore, in this paper, the phenomenon of the redistribution of welding residual stress with fatigue crack extension is studied experimentally in an attempt to clarify this point.

1. Introduction

It is quite important not only from the standpoint of academic interest but also from the standpoint of industrial applications to make clear the effect of welding residual stress upon fatigue strength. In fact, as far as fatigue life is concerned, a great number of research work have been carried out to study the effect of welding residual stress. But in spite of the recent considerable progress in fracture mechanics theories and applications, there seems to be no, at least to the authors' knowledge, systematic study of the effect of welding residual stress on fatigue crack propagation.

This paper constitutes a part of our systematic research work program to make clear the effect of welding residual stress upon fatigue crack propagation based on fracture mechanics. There is a point which is always at issue when it comes to discussing the effect of welding residual stress on fatigue crack propagation. i.e., as the welding residual stress often decreases with the repetition of loading cycles in an unnotched specimen, it is duly expected that in a notched specimen not only the phenomenon of the redistribution of welding residual stress with fatigue crack extension occurs but also the phenomenon of the decrease of welding residual stress with the repetition of loading cycles might possibly occur at the same time and this would make the problem quite difficult. Therefore, in this paper, the phenomenon of the redistribution of welding residual stress with fatigue crack extension is studied experimentally in an attempt to clarify this point.

2. Experimental Procedure

The material used in this experiment is JIS SS41 mild steel. The geometry and the size of the specimen is shown in **Fig. 1**. At the center of the specimen a notch is introduced as a model for transverse crack as shown in **Fig. 2**. The length of the notch is chosen equal to the bead width, i.e., approximately 18 mm, in an attempt to exclude as much as possible the effect of microstructural changes in the material caused by heat input and to study the effect of welding residual stress on fatigue crack propagation first solely from the standpoint of mechanics. The notch was introduced by sawing and no finishing process was applied to the tip of the notch. Therefore, the notch was not extended to the base metal part and its length was kept equal to the bead width in order to obtain stable fatigue crack propagation in base metal part by letting the initial process of fatigue crack

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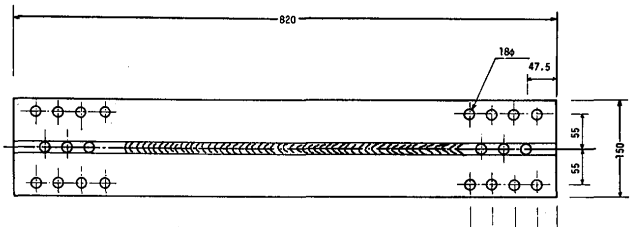

Fig. 1 Submerged arc welded test specimen

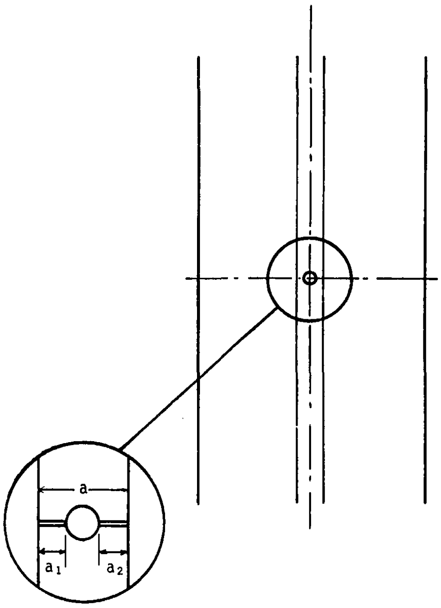

Fig. 2 Central notch of SAW test specimen

propagation being in HAZ. The specimens were butt-welded using submerged arc welding with the edge preparation of 60°V, and the root spacing of 0 mm and the butt face of 3 mm. One side single layer welding was carried out using flux backing method with the push-up air pressure of 1 kg/cm^2, and comparatively good uranami was obtained. **Table 1** shows the welding condition.

Table 1 Welding condition

Current	800 A
Voltage	36 V
Speed	60 cm/min
Wire	U. S. 36 4.8 dia.
Flux	MF 38 12 x 65

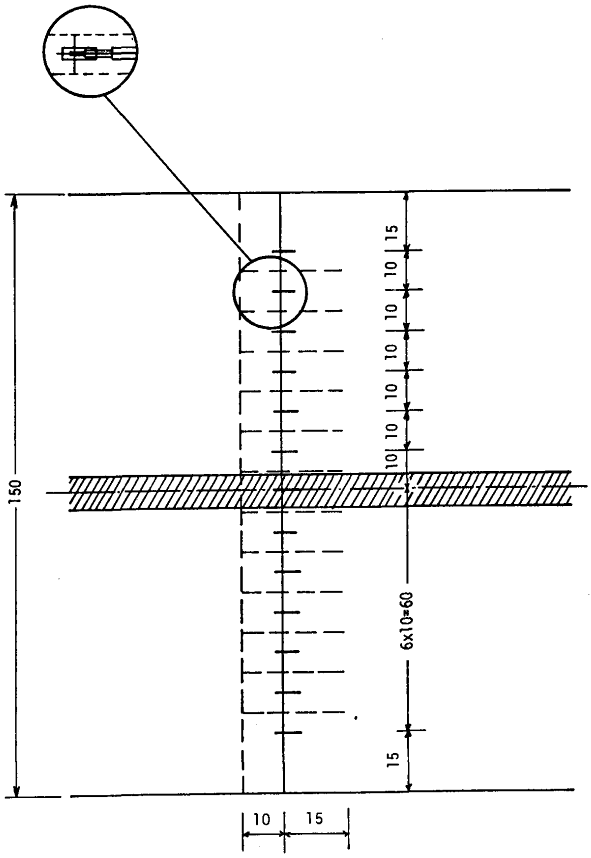

Fig. 3 Location of gages for residual stress measurement

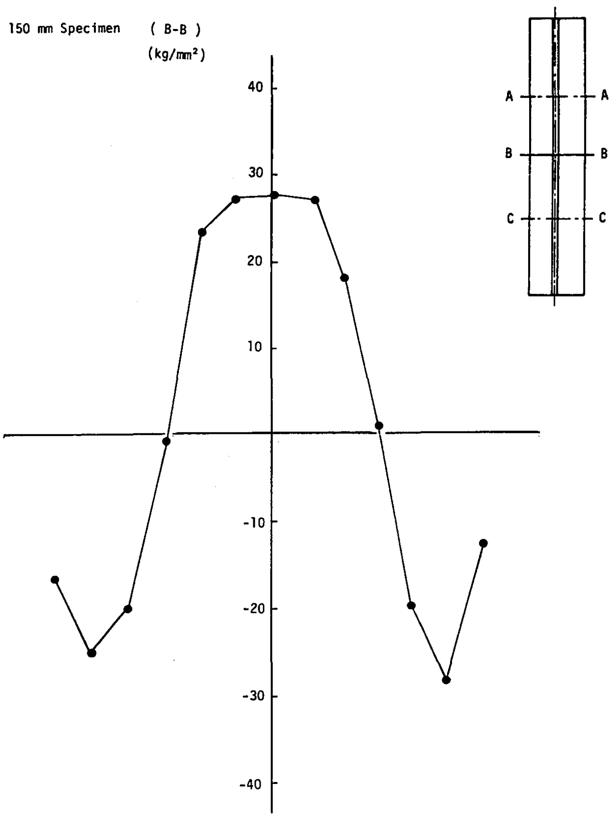

Fig. 4 An example of initial residual stress distribution in SAW test specimen

The fatigue test was conducted using Shimadzu Servopulser at the frequency of 2 Hz and stress ratio R=0 and the stress range of 6.67 kg/mm^2. Residual stress was measured by cut-in method as shown in **Fig. 3**. An example of initial residual stress measured is shown in **Fig. 4**. The redistribution of welding residual stress with the extension of a fatigue crack was studied by sticking wire strain gages at the points shown in **Fig. 5**.

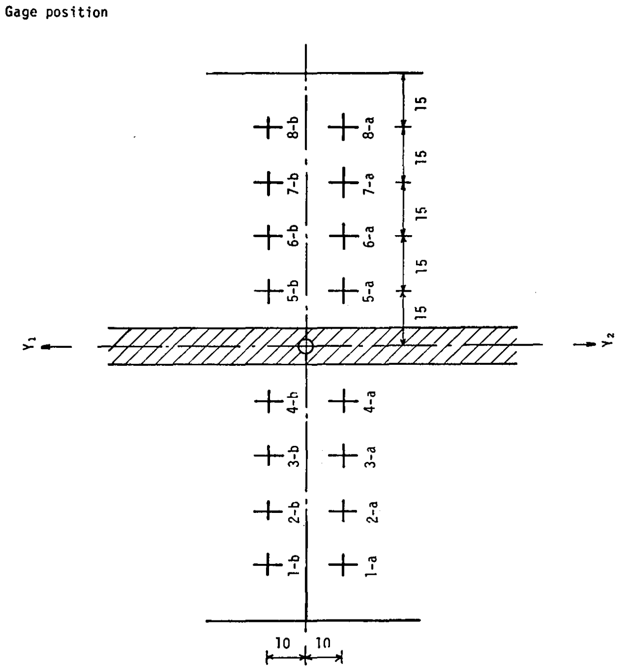

Fig. 5 Location of gages for measuring the change of residual stress distribution with crack extension

3. Results and Discussion

The results are shown in **Figs. 6-18**. It is interesting to note that the value of residual stress at the tip of the fatigue crack is always almost $\geqslant 0$. A little negative values were obtained in some cases but this is considered due to the errors in measurement. These results resemble both qualitatively and quantitatively the result of the redistribution of welding residual stress obtained by sawing[1]. Therefore, these results may indicate that in the case of fatigue crack propagation, the amount of the change of welding residual stress due to cyclic loading may not be so appreciable as in the case of unnotched specimens and that the phenomenon of the redistribution of welding residual stress due to crack extension may be more important. This point will be further investigated by experiments by changing parameters such as stress levels, etc. In any case, this point is considered to be quite important not only from the standpoint of engineering science, but also from the standpoint of engineering applications.

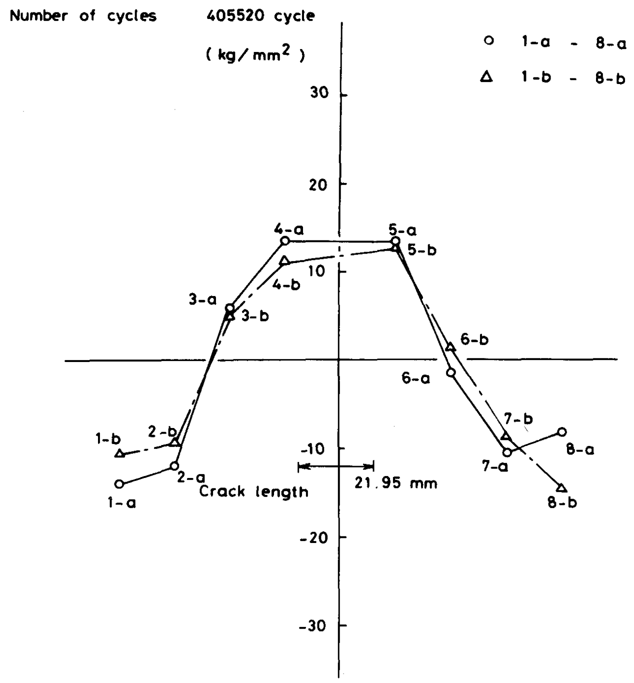

Fig. 6 Redistribution of residual stress with fatigue crack extension (crack length=21.95 mm)

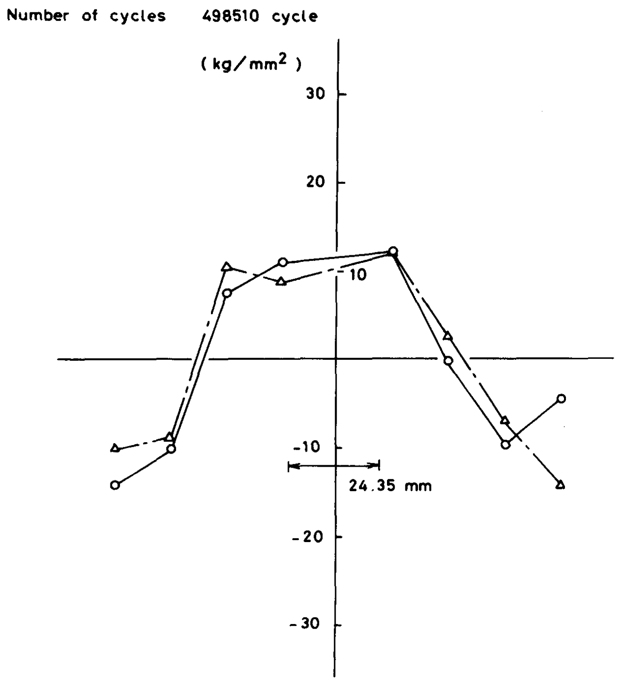

Fig. 7 Redistribution of residual stress with fatigue crack extension (crack length=24.35 mm)

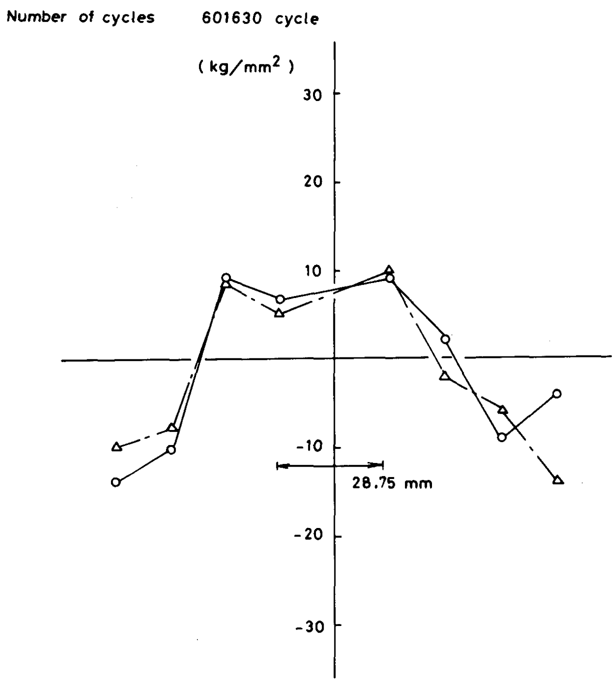

Fig. 8 Redistribution of residual stress with fatigue crack extension (crack length-28.75 mm)

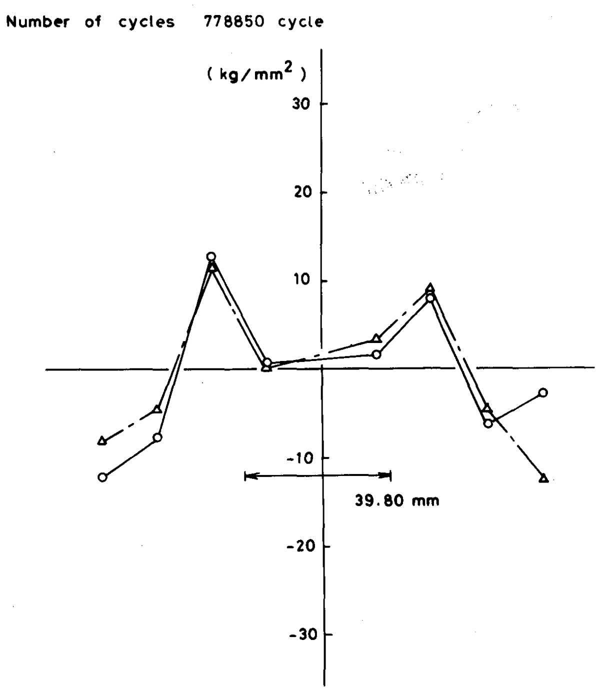

Fig. 10 Redistribution of residual stress with fatigue crack extension (crack length=39.80 mm)

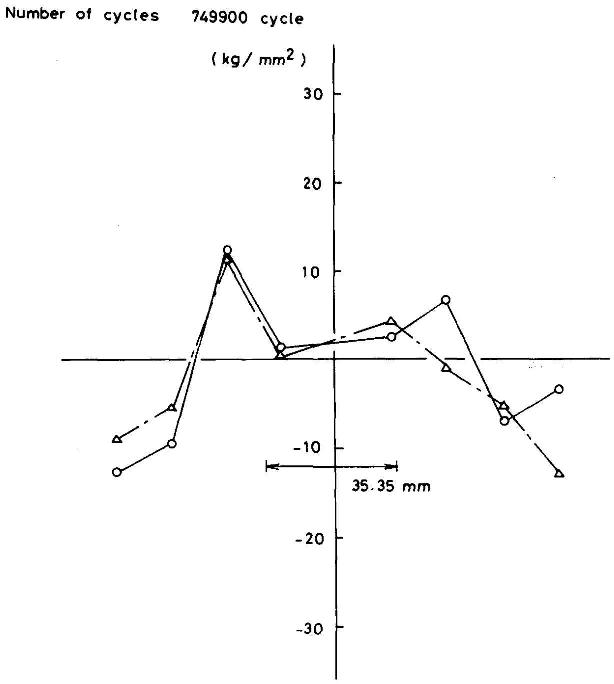

Fig. 9 Redistribution of residual stress with fatigue crack extension (crack length=35.35 mm)

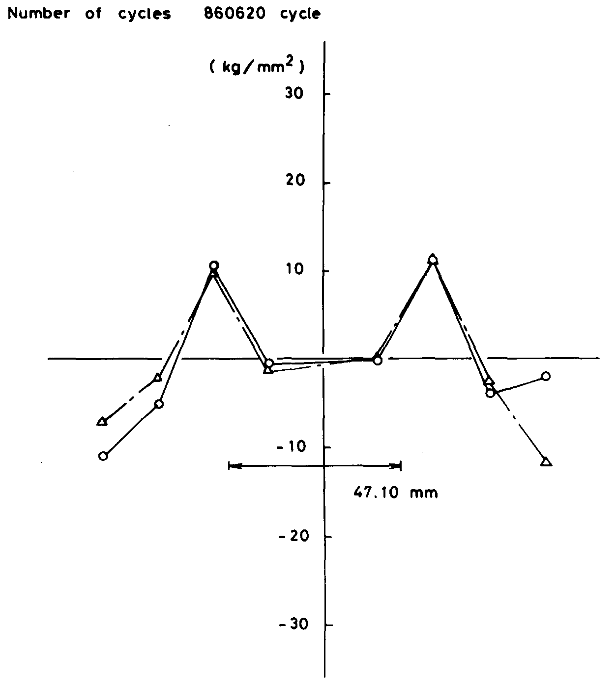

Fig. 11 Redistribution of residual stress with fatigue crack extension (crack length=47.10 mm)

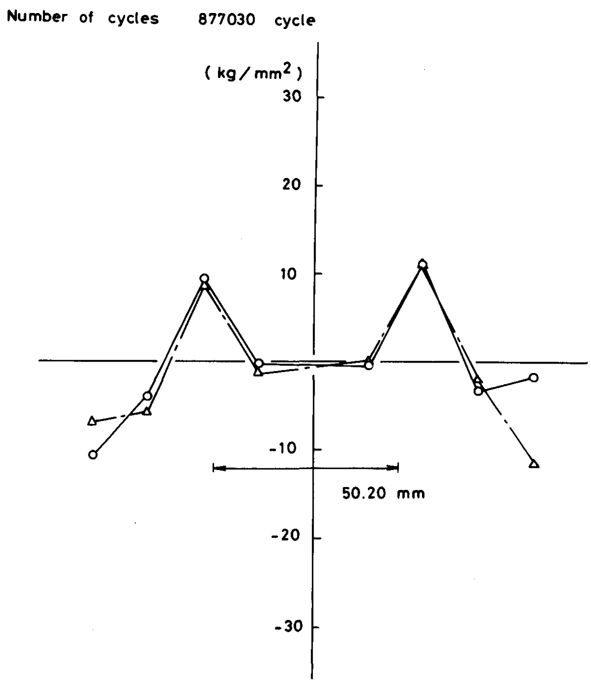

Fig. 12 Redistribution of residual stress with fatigue crack extension (crack length=50.20 mm)

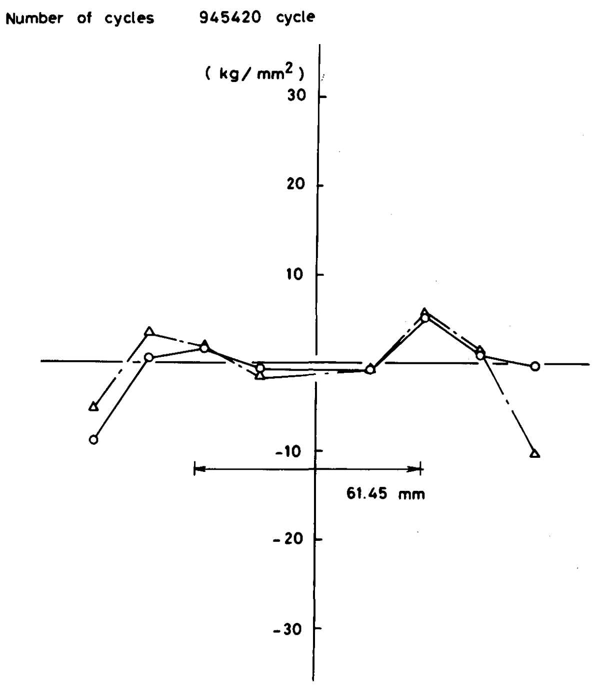

Fig. 13 Redistribution of residual stress with fatigue crack extension (crack length=61.45 mm)

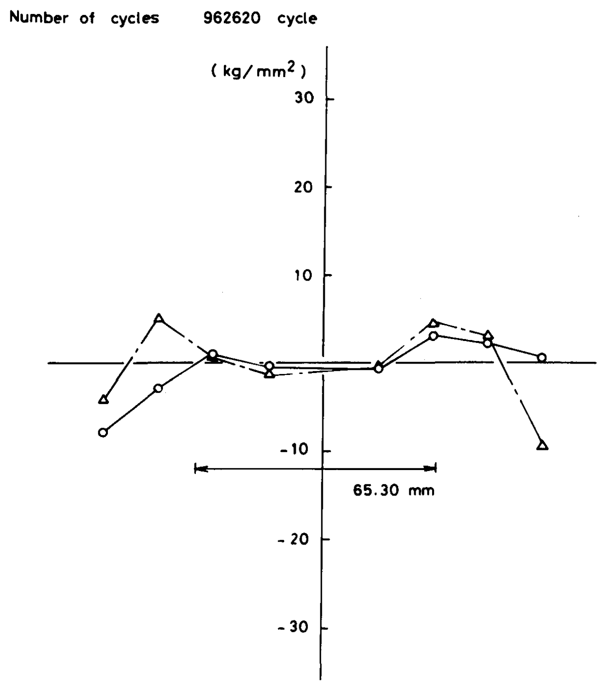

Fig. 14 Redistribution of residual stress with fatigue crack extension (crack length=65.30 mm)

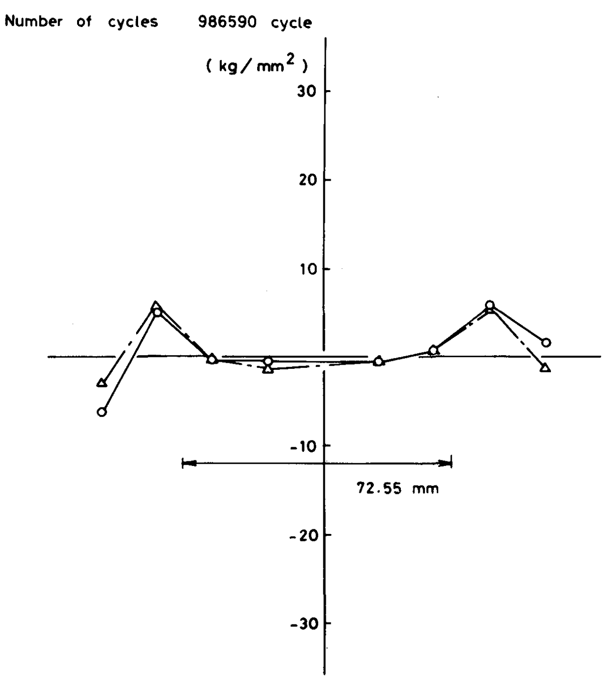

Fig. 15 Redistribution of residual stress with fatigue crack extension (crack length=72.55 mm)

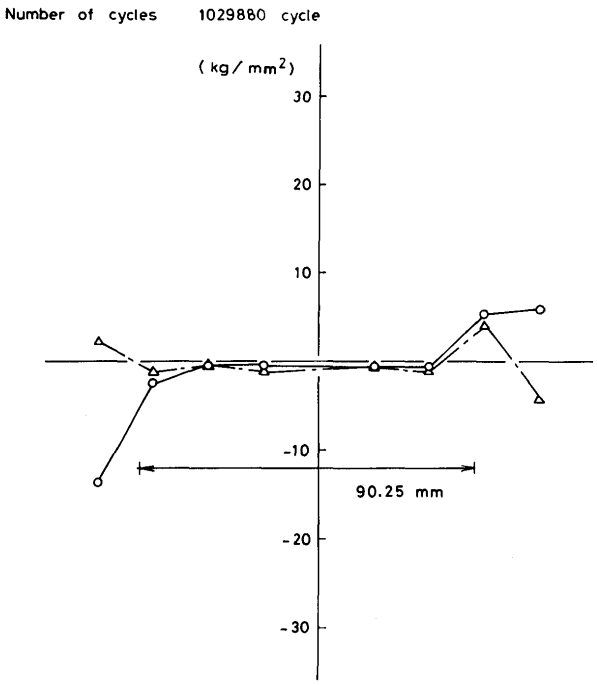

Fig. 16 Redistribution of residual stress with fatigue crack extension (crack length=90.25 mm)

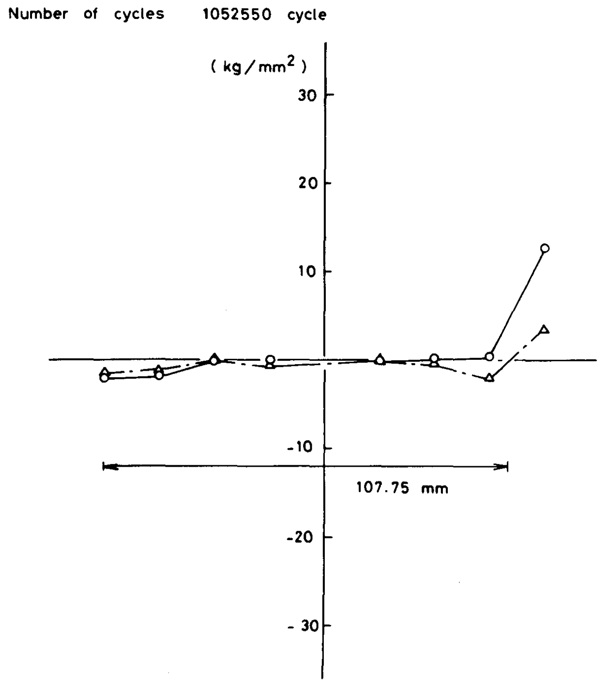

Fig. 18 Redistribution of residual stress with fatigue crack extension (crack length=107.75 mm)

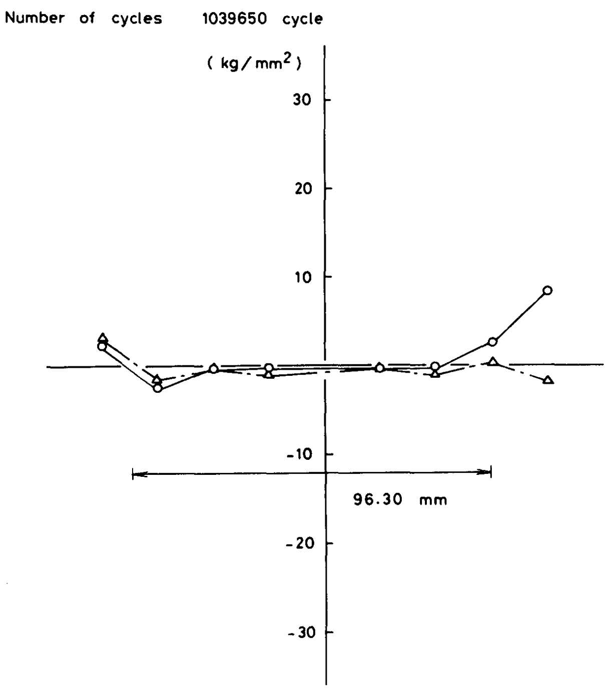

Fig. 17 Redistribution of residual stress with fatigue crack extension (crack length=96.30 mm)

4. Summary

This paper describes the preliminary study of the phenomenon of the redistribution of welding residual stress with fatigue crack extension as part of our systematic research program to clarify the effect of welding residual stress upon fatigue crack propagation based on fracture mechanics approach. For the reason that welding residual stress can be easily measured and evaluated so that it makes the analysis much easier for basic research, butt welded joint specimens were adopted and the redistribution of welding residual stress with fatigue crack extension from the center notch with the length of the bead width was studied for JIS SS 41 mild steel under the condition of submerged arc welding and stress ratio of R=0. And it was concluded that the decrease of welding residual stress due to cyclic loading was not appreciable and that the amount of the redistribution of welding residual stress due to crack extension was much larger at least for the stress range tested.

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