Influence of Welding Residual Stresses on Fatigue Crack Initiation Life†

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KEY WORDS: (Fatigue) (Residual Stress)

1. Introduction

This experimental study intends to investigate the influence of welding residual stresses on fatigue crack initiation life.

Crack initiation lives of four groups of specimens, whose welding residual stresses were varied by stress relief annealing, were compared and the influence of welding residual stresses were discussed.

2. Specimen

The material of the specimen was a mild steel plate of 41 kg/mm^2 in tensile strength. Its mechanical properties and chemical composition are shown in **Table 1.**

Table 1. Mechanical Properties and Chemical Composition

Material	Yield Stress (kg/mm^2)	Tensile Strength (kg/mm^2)	Elongation (%)
SS41	29	45	32

Chemical Composition (%)				
C	Si	Mn	P	S
0.12	0.23	0.99	0.013	0.006

The shape and dimensions of the all specimens were the same, but residual stresses were varied by the following heat treatment:

- As weld (As Weld)
- Stress relieved at 380°C (380SR)
- Stress relieved at 500°C (500SR)
- Stress relieved at 620°C (620SR)

The configuration of specimens is shown in **Fig. 1.** It was decided by the capacity of fatigue testing machine.

The specimens were welded by micro-submarged-arc-welding as bead-on-plate. The welding conditions are shown in **Table 2.**

Through thickness open-hole with 1.5 mm diameter was drilled after stress relief annealing and before residual stress measurement. The size of this hole is followed after the allowable size of a blow-hole by the Specification for Honshu-Shikoku Bridges.

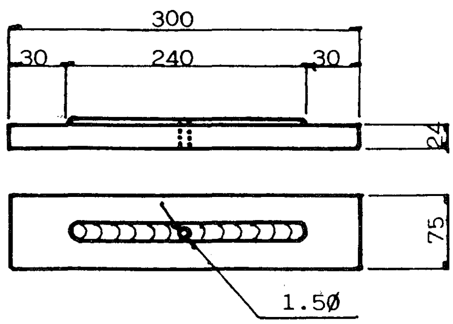

Fig. 1 Specimen Configuration

Table 2. Welding Condition

Wire	Y-CS50, 1.6dia
Flux	NF16
Current	270 (A)
Voltage	30 (V)
Speed	52 (cm/min)
Heat Input	9300 (J/cm)

3. Residual Stress

Stress relief annealing was used for the reduction of welding residual stress. The stress relief annealing was performed by electric furnace. The time for going up to the aimed temperature was 15 hours, and keeping time was 1 hour. The specimens were taken out from the furnace after the temperature of specimens went down to 100°C. The temperature was controlled by C-A thermocouples. The aimed temperature for stress relief were 380°C, 500°C, 620°C.

Welding residual stress was measured by cutting method with strain gage. The direction of strain gages were

† Recieved on April 30, 1984
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Transactions of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka 567, Japan

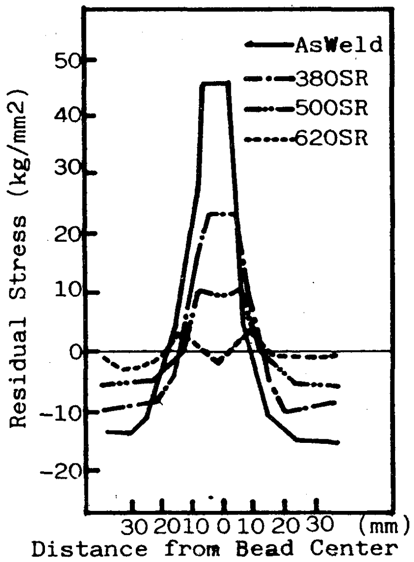

Fig. 2 Residual Stress Distribution

parallel to the longitudinal of the specimen.

The results of residual stress measurement are shown in **Fig. 2.**

From this results, it is found that the residual stresses on welding bead are tensile stress except for 620SR specimen. As nominal tensile strength of the wire used is 50 kg/mm^2, maximum tensile residual stress 45 kg/mm^2 of As Weld specimen is acceptable value.

While the residual stress on welding bead of 620SR specimen is compressive, and the value is nealy equal to 2.5 kg/mm^2. As this compressive residual stress 2.5 kg/mm^2 is very small, this result may have been disturbed by the error of measurement.

4. Testing Procedure

Fatigue test was performed under load controlled three-point bending condition by a electro-hydraulic closed loop servo fatigue testing machine. The frequency was 20 Hz and the stress ratio was 0.1 with constant amplitude.

Failure life (Nf) was distinguished between crack initiation life (Nc) and crack propagation life (Np) macroscopically.

Crack initiation life (Nc) is the number of cycles when the fatigue crack was detected by a certain way, and crack propagation life (Np) is the number of cycles from the crack initiation to the failure of specimen. Therefore, this relationship is shown as Nf = Nc + Np.

As usual, the measurement of the crack initiation life (Nc) and the failure life (Nf) have been made by visual observation. However, visual observation sometimes causes the scatter of data. When crack initiates from the inside of the specimen, crack is observed after some delay. So, visual observation is inconvenient for experimental studies.

In this study, the location of crack initiation was observed by beach mark method. As the result, the location of crack initiation was confirmed as the edge of open-hole on the surface welding bead. Crack gage and beach mark methods were compared in measuring the crack initiation life (Nc) and crack propagation life (Np).

As crack initiation point was in weld metal, beach mark was not clear. While the crack gage method was convenient to detect the surface crack. From the comparison of the two methods, the crack gage was adopted to measure the crack initiation life (Nc).

The location of crack gages is shown in **Fig. 3**.

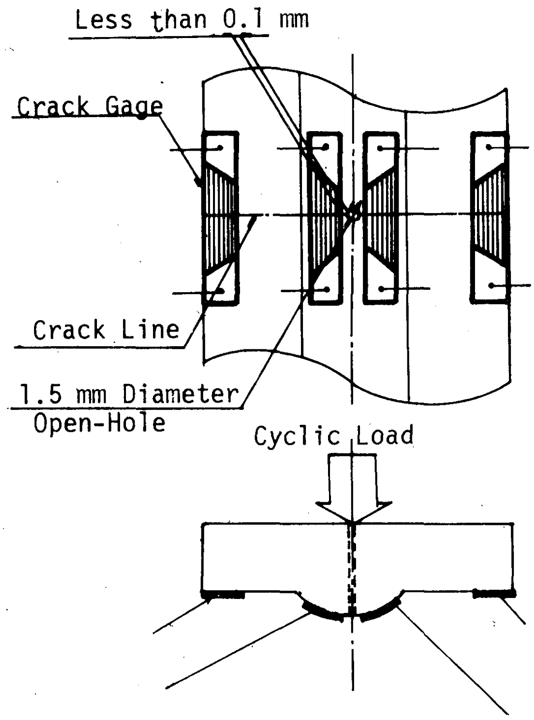

Fig. 3 Location of Crack Gage

The crack gages were attached to the point less than 0.1 mm away from the drilled hole edge. Therefore, crack initiation life (Nc) was measured as crack propagation less than 0.1 mm. Failure life (Nf) was measured by the crack gage attached to the side edge of the specimen.

5. Test Results and Discussions

Figure 4 shows failure life (Nf), initiation life (Nc), and propagation life (Np) for all specimens of each stress range.

From this figure, it is found that as the welding tensile residual stress decreases, the failure life (Nf) increases. This tendency is remarkable as stress range becomes lower.

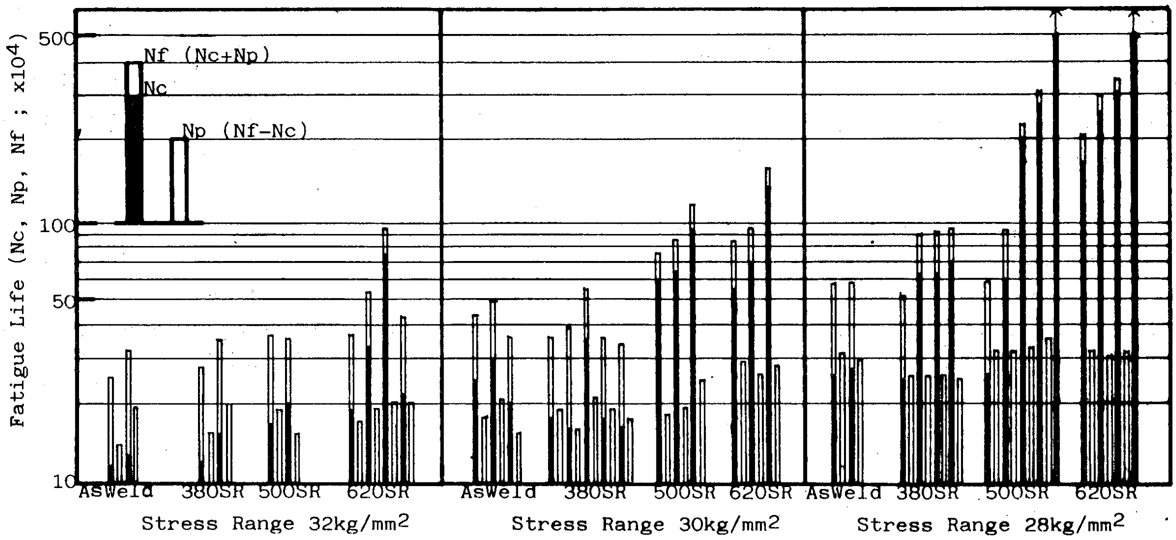

Fig. 4 Fatigue Life Correlation; Failure Life (Nf), Initiation Life (Nc), and Propagation Life (Np)

Next, failure life (Nf) is divided into crack initiation life (Nc) and crack propagation life (Np).

Crack initiation life (Nc), together with failure life (Nf), increases as welding tensile residual stress becomes lower. Such tendency is also cosiderable as stress range becomes lower.

However, crack propagation life (Np) is not so influenced by welding tensile residual stress and stress range as compared with crack initiation life (Nc). Also, this tendency can be seen in **Fig. 5**. That is, crack initiation life (Nc) increases as welding residual stress and stress range become lower, while crack propagation life (Np) is rather constant, $1.5 \times 10^5 \sim 3.0 \times 10^5$ cycles, for all specimens in each stress range.

From this results, it is understood that the increase of failure life depends on crack initiation life (Nc), and not so much on crack propagation life (Np).

Figure 4 also shows that failure life (Nf) is scattered widely in each specimen at the same stress range. However, crack propagation life (Np) is comparatively constant in each specimen at the same stress range.

Therefore, it is understood that the scatter of fatigue life is caused by the scatter of crack initiation life (Nc), and such tendency is not influence by welding residual stress.

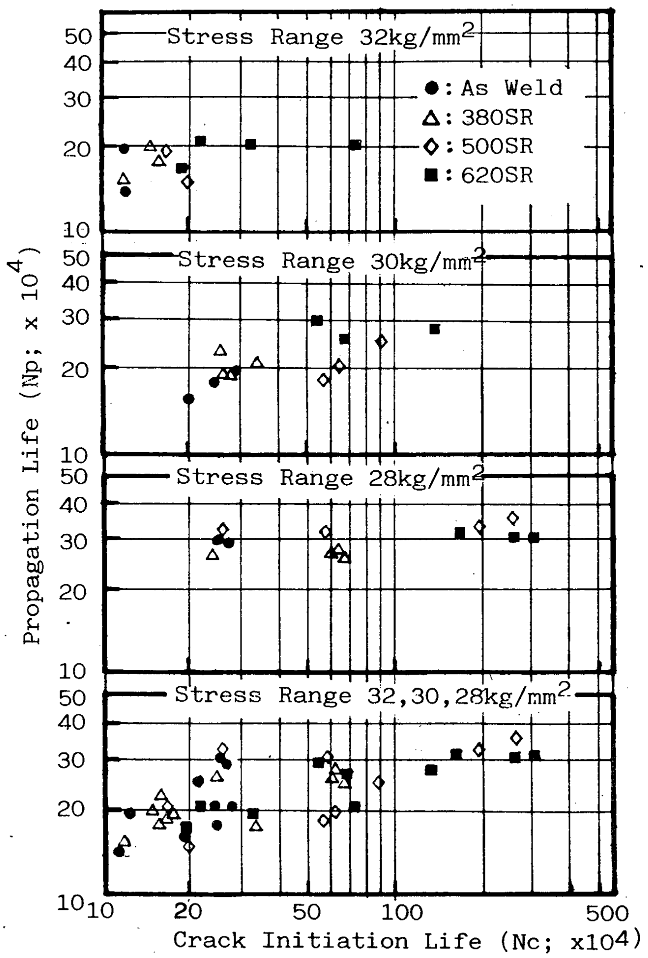

Fig. 5 Fatigue Life Correlation; Initiation Life (Nc), Propagation Life (Np)

6. Summary

In this study, total fatigue life (Nf) was divided into initiation life (Nc) and propagation life (Np). The influence of welding tensile residual stresses on crack initiation life (Nc) was studied experimentally.

Crack initiation life (Nc) was measured by crack gage attached to location of crack initiation that was edge of open-hole on surface of welding bead. Crack gage was attached less than 0.1 mm away from location of crack initiation. Therefore, crack initiation life (Nc) was measured as crack propagation less than 0.1 mm.

The results were as follows.

1. Crack initiation life (Nc) increases as welding tensile residual stress becomes lower. Specially, it is notable at near the fatigue limit, and influence of welding tensile residual stress becomes smaller as stress level becomes higher.
2. Influence of welding tensile residual stress on crack propagation life (Np) is smaller than that of crack initiation life (Nc).
3. Scatter of failure life (Nf) is caused by crack initiation life (Nc), and scatter of crack propagation life (Np) is little. This phenomenon is not affected by welding residual stress.

Acknowledgements

The authors would like to acknowledge Mr. H. SUZUKI, Research Associate for the valuable comments, and Mr. Y. NAKATSUJI, Technical Assistant, for helpful support in performing experiments.

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