FINITE ELEMENT ANALYSIS AND MEASUREMENT ON THE RELEASE OF RESIDUAL STRESS AND NON-LINEAR BEHAVIOR IN WELDMENTS BY MECHANICAL LOADING(I) - EXPERIMENTAL EXAMINATION-

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ABSTRACT

Residual stress by welding should be reduced because that decreases the reliability on strength of welded structure. The reason is that the total stiffness of structure decreases by non-linear behavior of weldment under external load. The release of residual stress by mechanical loading and unloading is often performed in the fabrication of box structure for steel bridge. The proper degree of loading and unloading is significant at release method of residual stress by mechanical loading because that degree is changed by material and geometric shape of welded structure. Therefore, the simulation model that could exactly analyze the release of residual stress by mechanical loading is to be necessary. This simulation model should be established on the based of variable and accurate measurement data.

In this study, the non-linear behavior of weldments under external loading and unloading, such as the decrease and increase of structure stiffness, was investigated by monitoring of nominal stress and strain. Tensile loading and unloading test under variable load was performed and the proper degree of stress relaxation was measured by sectioning technique using strain gauge.

KEYWORDS

Structure Stiffness, Welding Residual Stress, Release of Residual Stress, MSR Method, Tensile Loading & Unloading.

1. Introduction

Requirements for high reliability in steel structure have invariably led to the manufacturing of more performance about strength and deformation. By the way, during the fabrication of welded structures, residual stress corresponding with yield stress of base metal is produced due to local high heat input and cooling in a welding joint. This residual stress decrease the reliability on strength of welded structure because reduce the total stiffness of structure by non-linear behavior of weldment under external load.

In other words, when the local welding residual stress is superposed by external load, especially repeated load, the total shape of welded structure could be deformed. The reason is that the non-linear behavior of structure could come into existence under allowable load due to residual stress. In that case, the more large deformation than allowable criterion could occur and then the reliability on strength of structure decrease. Therefore, the release of welding residual stress is indispensable for the manufacturing and construction of steel structure with high reliability.

The mechanical stress release (MSR) method with loading and unloading is mainly used for the residual stress release of large steel-structure. For the effective application of this MSR to structure construction, it is necessary that the real understanding about non-linear behavior of welded structure under allowable load and the establishment of simulation model. The non-linear behavior means that the total stiffness of welded structure decrease under external load due to residual stress but the stiffness recovers by the release of residual stress after the application of MSR method. Although there have been many studies about MSR method, their contents have been not about non-linear behavior of structure but mainly about the degree of the release of welding residual stress.

In this study, therefore, the appearance of decrease and recovery of structure stiffness was examined through tensile loading and unloading test under allowable and yielding load. The degree of residual stress release by variable load conditions was also examined.

2. Experiment Procedure

2.1 Specimens and welding condition

Six mm thick plates of SS400 which the chemical composition and mechanical properties are shown in Table 1 and 2, were first heat treated 30 min at 600 °C in order to relieve residual stress due to rolling and milling for groove angle.

Table 1 Chemical composition (%)

C	Si	Mn	P	S
0.143	0.00693	0.6565	0.015	0.00898

Table 2 Mechanical properties

Ultimate tensile Strength (MPa)	Yield Strength (MPa)	Elongation(%)
417	292	39

Fig. 1 shows the shape of specimen and Fig. 2 represents schematic for welding. The welding conditions are listed in Table 3.

Table 3 Welding conditions

Groove angle	Current	Voltage (V)	Speed (cm/min)	Pass
40	250	26	59	1
50	250	27	49	1
60	250	28	35	1

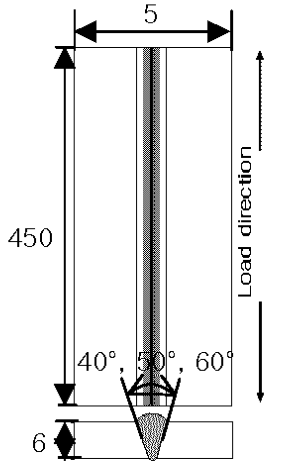


Fig. 1 Dimension of specimen [mm]

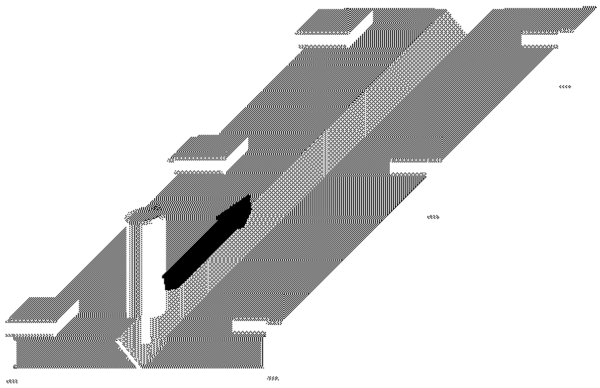


Fig. 2 Schematic of welding

Welding specimens are three kinds of groove in order to examine the non-linear behavior of weldments with weld portion. After welding, the thickness of specimen is diminished into 4.75mm by grinding for tensile loading and unloading test.

2.2 Tensile loading and unloading tests

An electro-hydraulic servo system fatigue test machine was used for tensile loading and unloading tests. Tensile load was applied under the load-controlled condition with 0.4, 0.6, 1.0, 1.2 times of yielding load. Fig. 3 shows each load conditions. Non-linear behavior on stress-strain of weld specimen was examined through strain monitoring using strain gauge in weldmetal (center line) and base metal (thickness surface). Fig. 4 shows the appearance of test.

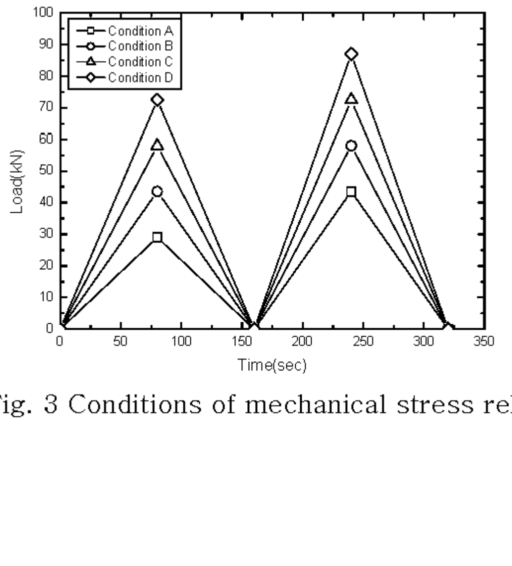


Fig. 3 Conditions of mechanical stress release

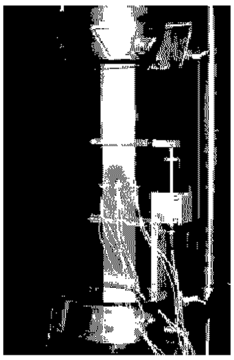


Fig. 4 Appearance of tensile loading & unloading test

After tensile loading and unloading test, the release of residual stress was measured by sectioning method. The distribution of residual stress in as-welded specimen was also measured. The arrangement of strain gauge for as-welded specimen is shown in Fig. 5.

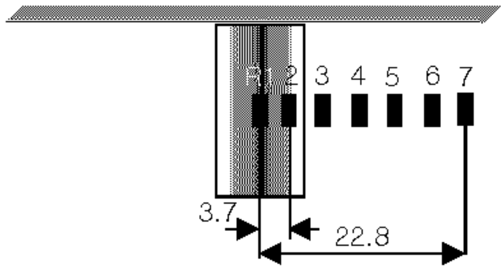


Fig. 5 Arrangement of strain gauge for measurement of residual stress in as-welded specimen

2.4 Hardness test

To analogize the mechanical properties of weld metal and HAZ, the hardness profile from weld metal to base metal in cross section of each specimen was measured by 0.5mm distance, 1kg test load, and 15sec dwell time. The result showed that the hardness of weld metal and HAZ was 1.3, 1.1 times that of base metal.

3. Results and Discussion

The external appearance and cross section of welded specimen with groove angle is represented in Fig. 6. As groove angle increases, the portion of weld to total joint section increase.

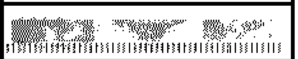
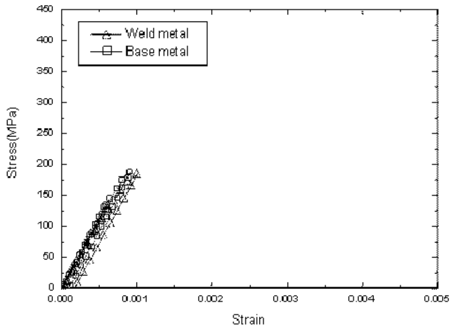
Groove Angle	40	50	60
Appearance			
Cross section			
Weld metal portion	8.7%	11.2%	15.4%

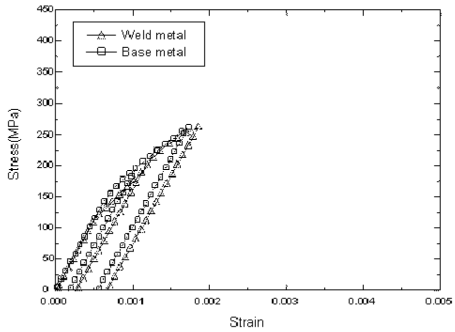
Fig. 6 Appearance and cross section of specimen

The local stress-strain behavior of weld metal and base metal by variable load condition is represented in Fig. 7(a)-(b). The non-linear behavior appears in the first cycle load due to the effects of welding residual stress although applied load is under yielding. This non-linear behavior in weld metal is appeared before base metal and non-linear behavior is also appeared in base metal although applied load is under allowable load. This means that the total stiffness of welded specimen decrease because of welding residual stress.

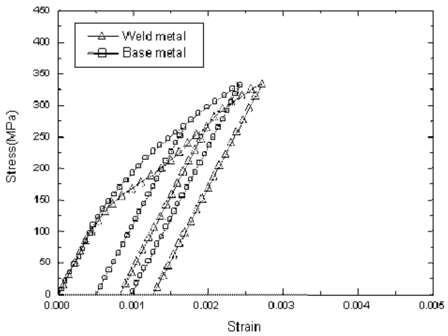
The welded specimen, however, linearly behave during second cycle loading because that stiffness recovers after first cycle load is unloaded.



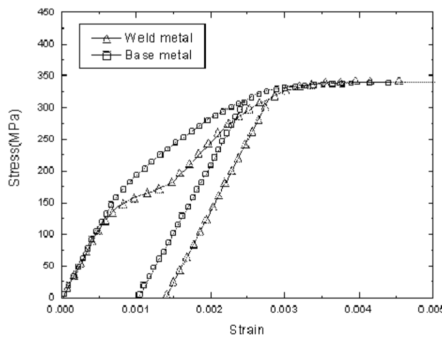
(a) Applied stress 0.4➔0.6σ_y



(b) Applied stress 0.6➔0.8σ_y



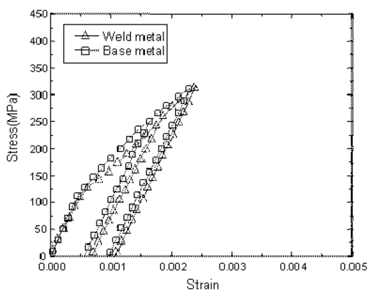
(c) Applied stress 0.8➔1.0σ_y



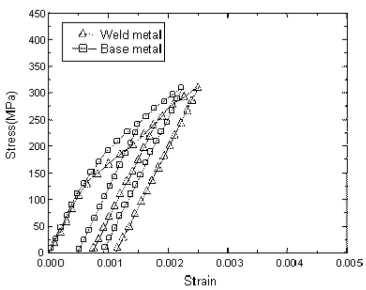
(d) Applied stress 1.0➔1.2σ_y

Fig. 7 Stress-strain behavior of weld metal and base metal

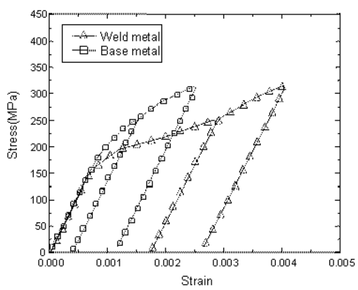
Fig. 8 shows the local stress-strain behavior of weld metal and base metal with groove angle. As groove angle increase, the portion of weld metal to total section of specimen increase and then plastic strain in first cycle increase. However, the starting point of non-linear behavior retard as the increase of groove angle because hardening region by welding become wider as large as groove angle.



(a) Groove angle 40°



(b) Groove angle 50°

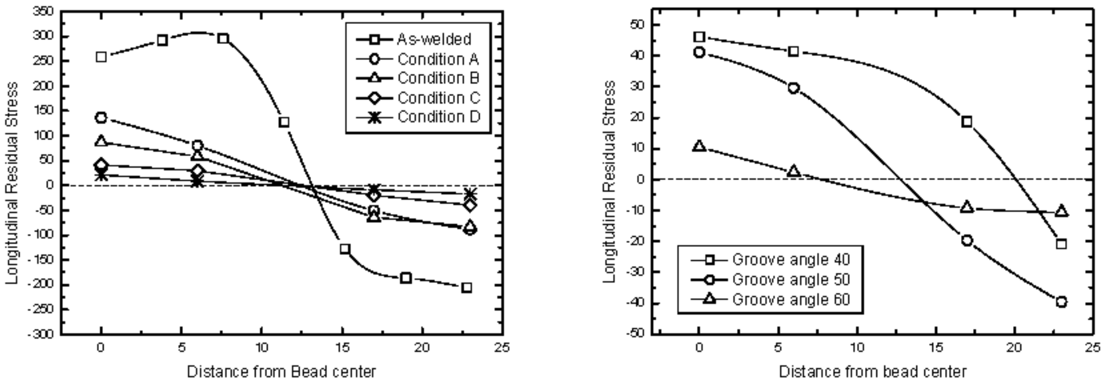


(c) Groove angle 60°

Fig.8 Stress-strain behavior of weld metal and base metal with groove angle (applied stress 0.8➔1.0σ_y)

Fig. 9 shows the residual stress distribution of specimen after tensile loading & unloading.

As applied load increase, the plastic strain of weld metal increase and then the final residual strain after unloading increase. That result in the increase of residual stress release. For the same load condition, the release of residual stress becomes larger with the increase of grove angle.



(a) Applied conditions (b) Groove angles(applied stress $0.8 \rightarrow 1.0\sigma_y$)

Fig. 9 Residual stress distribution of specimen after tensile loading & unloading

4. Conclusions

From the results of experiment that examined non-linear behavior of welds by MSR, the following conclusions were obtained.

1) The non-linear behavior of welded structure appears in the first cycle load due to the effects of welding residual stress although applied load is under allowable load. This means that welding residual stress decreases the total stiffness of structure. Therefore, welding residual stress should be controlled for the construction of precise welded structure.

2) Welded structure linearly behaves during re-loading after unloading because its stiffness recovers after first cycle load is unloaded.

3) As the portion of weld metal to total section of structure is lager, plastic strain in first cycle increase and then the release of residual stress become larger.

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