Finite Element Analysis and Measurement on the Release of Residual Stress and Non-linear Behavior in Weldment by Mechanical Loading(I) -Finite Element Analysis-

K. B. Jang, J. H. Kim and S. M. Cho

Abstract

In previous study, the decrease and recovery of total stiffness in welded structure was discussed on the basis of experimental examination through tensile loading and unloading test of welded specimen. The recovery of structure stiffness was caused by the release of welding residual stress through mechanical loading.

In this study, analysis model that is indispensable for the effective application of MSR method was established on the basis of test and measurement result. Thermal elasto-plastic analysis for welding process was performed by non-coupled analysis. Analysis results of welding process were transfer to elasto-plastic model for tensile loading & unloading by restart technique. In elasto-plastic analysis model for mechanical loading & unloading, hardening appearance of weld metal was considered by rezoning technique and tying technique was used for JIG condition of test machine.

Key Words : Structure stiffness, Release of welding residual stress, MSR method, Thermal elastic plastic analysis, Tensile loading & unloading.

1. Introduction

In previous study, it was verified that the total stiffness of welded structure decrease due to welding residual stress and then the non-linear behavior of weld and base metal appear although applied load is under allowable load. This decrease of structure stiffness could degrade the strength reliability of structure, especially, in circumstance under repeated load. That reason result from the effect of welding residual stress, therefore, residual stress should be release by something method. For the release of welding residual stress, PWHT (Post Weld Heat Treatment) have been mainly used in construction field, but its application for large structure such steel bridge and building is difficult so that MSR (Mechanical Stress Release Method) method[1-5] is gradually used for that case.

Analysis model that could simulate the elastic-plastic behavior of welded structure by mechanical loading and unloading is indispensable for the effective application of MSR method. In this study, therefore, on the basis of previous experimental examination, simulation model that could analyze both qualitatively and quantitatively the non-linear behavior of welded structure (decrease and recovery of stiffness) under mechanical loading and unloading was established.

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2. Finite element analysis and results

2.1 Scheme of analysis model

Analysis model have three parts. Fig. 1 show the schematic of analysis model. In thermal analysis for welding process, activated and deactivated technique for bead element and maximum temperature change allowed per increments was set 20° C for the accuracy of analysis results. Non-coupled analysis was used in mechanical analysis for welding residual stress, in other words, temperature profile of each nodes by thermal analysis was inputted as thermal load. The welding residual stress of model after welding was calculated from this non-couple analysis.

Elastic-plastic analysis for mechanical loading and unloading was newly performed as model had residual stress distribution of as-welded conditions for saving calculating time. In this case, restart technique by MARC was used. Another important thing before tensile loading and unloading is that the hardening appearance of weldment should be considered. Mechanical material properties of model before tensile loading and unloading, therefore, should be changed to properties hardened after welding. Rezoning technique was used for considering this hardening.

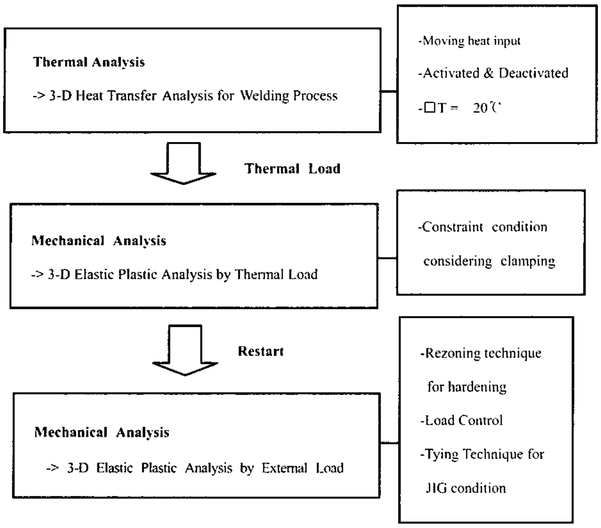

Fig. 1 Analysis procedure for this study

2.2 Thermal analysis and results

Fig. 2 shows mesh generation of model. Arc heat source moved 10mm by 10mm for accurate thermal analysis. The number of total element and node is 6800 and 8109.

Initial temperature of model was 20° C and thermal properties of material were input as a function of temperature. Natural convection and Radiation was considered in heat loss. The heat input rates from arc to base metal were given by the body flux. Addition of filler metal was simulated as activated and deactivated element technique. Fig. 3 shows the temperature distribution of model when arc heat was in the middle of longitudinal direction.

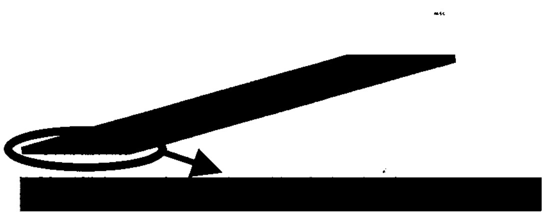

Fig. 2 Mesh generation

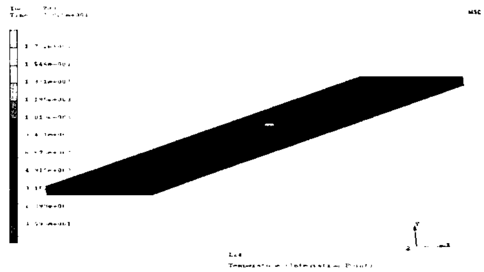

Fig. 3 Temperature distribution at 28.28 sec after welding

Temperature profile acquired through this analysis was changed to thermal load and then applied to external load in next mechanical analysis.

2.3 Mechanical analysis for welding process and results

Stress analysis for welding process is thermal elastic-plastic analysis so that stress-strain curve for base metal is needed. To consider the hardening of weldment, hardness profile of weldment is also needed. Tensile test of base metal and hardness measurement were done in previous study. Fig. 4 shows the stress-strain curves of base metal, HAZ, and weld metal acquired through each test. The gradient of curve from yielding to start point of real plasticity start was assumed as 1/100 times of Young's Modulus.

Fig. 5 shows boundary conditions for analysis. Only thickness direction of nodes in clamping part was constrained. Two nodes in welding starting element was constrained for removing of rigid body motion in mechanical analysis. Mechanical properties were naturally considered as a function of temperature.

The distribution of residual stress by analysis is compared with measurement result in Fig. 6. This shows that the measured values of experiment and analysis coincide well.

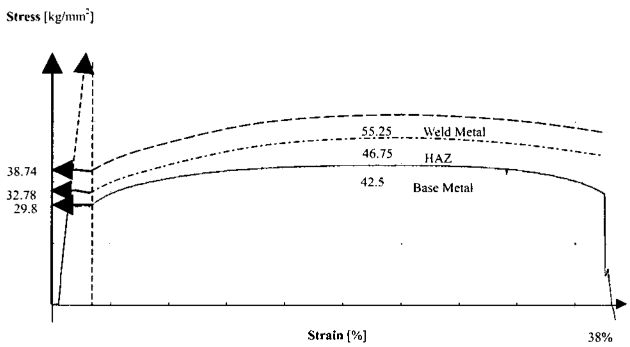

Fig. 4 Stress-strain curves of base metal, HAZ, and weld metal

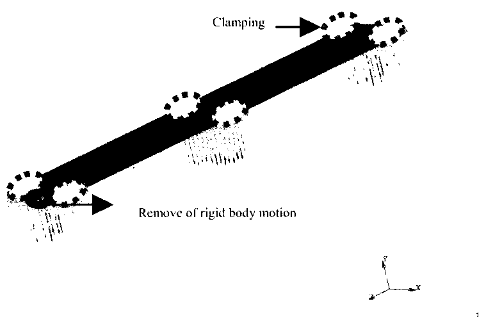

Fig. 5 Boundary conditions

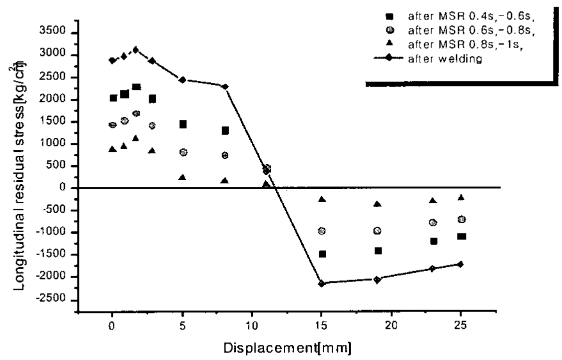

Fig. 7 Analysis results for the release of residual stress under variable load conditions

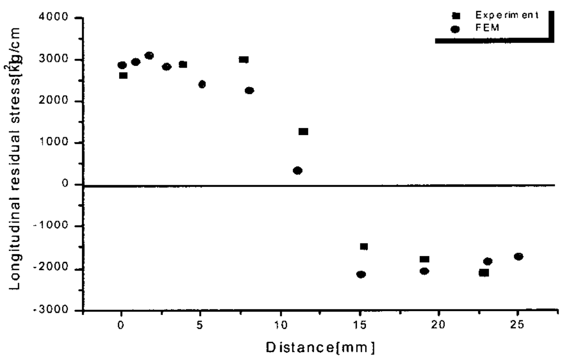

Fig. 6 Comparison of residual stress distribution by analysis and experiment

2.4 Mechanical analysis and result for external loading and unloading

With analysis results of residual stress by restart technique in MARC, analysis of tensile loading and unloading was newly performed. To realistically consider the behavior of constraint by JIG, tying condition was used in nodes restricted by JIG. Nodes connected with tying condition behave identically under loading, in other words, model does not deform toward tying direction.

Analysis was performed in case of $0.4\sigma_y$-$0.6\sigma_y$, $0.6\sigma_y$-$0.8\sigma_y$, and $0.8\sigma_y$-$1.0\sigma_y$ among test conditions. Fig. 7 shows the release of residual stress with the conditions of each loading and unloading. Comparing with experimental results in previous study, the release degree of residual stress is a little low. The reason seems to be that the hardening degree of weldment was a little excessively considered in analysis.

Local behavior of longitudinal stress-strain in variable location of specimen was examined from analysis results. Fig. 8 shows the local behavior of variable position in case of $0.8\sigma_y$-$1.0\sigma_y$ load condition. Yielding point of nodes (3246, 3486, 3946, 5146, 4666) in weld metal and HAZ is higher than that of base metal because weldment hardening was considered by rezoning technique. Node 4186 in base metal that residual stress is nearly zero behave non-linearly, distinctly, under yielding load because of local plastic strain in weld metal and HAZ with high residual stress. These local behaviors decrease the total stiffness of welded structure, but total nodes linearly behave during second cycle loading because stiffness recovers after first cycle load is unloaded.

3. Results

Simulation model that could analyze both qualitatively and quantitatively the non-linear behavior of welded structure under mechanical loading and unloading was made on the basis of experimental results of previous study. Following methods were used:

1) In thermal analysis for welding process, activated and deactivated technique for bead element and maximum temperature change allowed per increments was set 20° C for the accuracy of analysis results.
2) To save calculating time, non-coupled analysis was used in mechanical analysis for welding residual stress.
3) Restart method was used to connect welding process with tensile loading and unloading for saving calculating time. Rezoning and tying method was additionally used for considering weldment hardening and constraint condition by JIG.

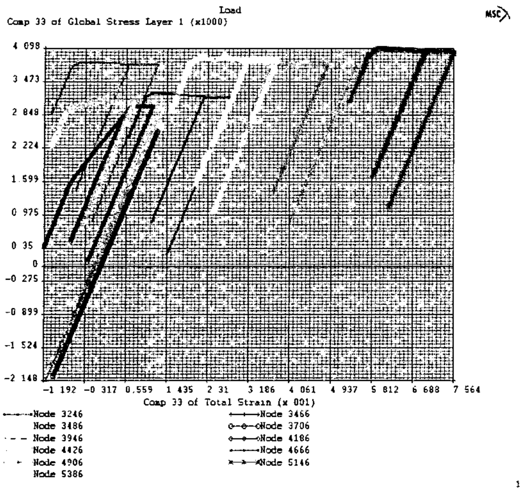

Fig. 8 Local behavior of longitudinal stress-strain in case of $0.8\sigma_y$-$1.0\sigma_y$ load condition

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