EFFECT OF WELDING SEQUENCE ON THE RESIDUAL STRESSES OF PLATE WITH LONGITUDINAL STIFFENERS

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ABSTRACT

In this paper, a study on the residual stress of plate with longitudinal stiffeners is explained in terms of the welding sequences. In order to verify the results of numerical analysis, the hole drilling method (HDM) is performed, to measuring the residual stresses of the test plates in CO_2 Flux Cored Arc Welding (FCAW) under various welding conditions. The non-linear transient analysis technique for the numerical analysis in a large and complicate structure is considered. The residual stress of plate in consideration of the welding sequences and directions is evaluated by some numerical simulations and also by experiments. Comparison of numerical analysis results with experimental data shows the accuracy and validity of the proposed method.

KEYWORDS

Welding sequence, residual stress, 3D finite element analysis, hole drilling method

1. Introduction

Non-uniform temperature distribution of an arc welded structure causes the residual stress in it. Tensile residual stress of an arc welded structure increases the maximum stress and tends to reduce the fatigue strength and corrosion resistance. And the bad effects of residual stress on the welded structure are major concerns in the manufacturing industries. The design of structure considering residual stress, therefore, should be demanded. In particular, it is very important to estimate the residual stresses in accordance with welding sequences. To consider these problems, computer simulations and experiments should be performed when designing a structure. A numerical analysis of welding residual stress that is plastic behavior of weldment would require the three-dimensional thermal elasto-plastic analysis using the finite element method software. Lots of study works have been done to improve the accuracy of the Hole Drilling Method (HDM) to measure residual stress by many investigators. Among various experimental methods, HDM can be useful one for its reliability. The test method is often described as “semi-destructive” because the damage that it causes is very localized and in many cases does not significantly affect the usefulness of the specimen. In addition to computing time and HDD memory in numerical analysis would be very long and large. And experimental method described here is applicable in those cases; the stresses do not vary significantly with depth and do not exceed one half of the yield strength.

In this paper, a study for residual stress of shell plate in consideration of welding sequence of longitudinal stiffeners is introduced. First of all, in order to verify the validity of numerical analysis and experiment, HDM for experiments and 3D thermal elasto-plastic analyses using the ANSYS® software are performed to evaluate residual stresses in FCAW specimens under various welding condition. The shape of the arc heat input on heat affect zone is assumed to have a traveling Gaussian distribution. The numerical analysis techniques used for large and complicate structure such as boundary conditions, a number of degree of freedom, non-linear transient analysis technique was proposed. These techniques are the points to be specially considered. And residual stress of the shell plate in consideration of welding sequence or welding direction is evaluated by some numerical simulation and experiment. The comparison of numerical analysis results with experimental data shows the accuracy and validity of the proposed method. These results are graphed for several residual stresses.

2. Estimation of residual stress considering welding sequence

2.1 Analysis and experiment conditions

The welding test plate, to confirm the validity of the numerical analysis and experiment, was determined by reviews of De Garmo and Rendler. And the extensive reviews on the subject can be found in the references [1,2]. Thus, the bead on plate welding specimen has the dimensions length $L=500mm$, width $W=300mm$, thickness $h=8mm$. And the butt-welding specimen has the dimensions $L=500mm$, $W=300mm$, $h=15mm$. The feasibility of the present estimation method is validated through some numerical simulation and test. To calculate the residual stress in consideration of the welding sequences and directions, it is assumed that the plate has dimensions $L=400mm$, $W=800mm$, $h=8mm$ and longitudinal stiffener has dimension angle length $L=75mm$. The length and width of the plate were proposed by considering the minimum gap of the shell plate's longitudinal stiffener and efficiency of the numerical simulation or experiment. It was employed CO_2 Flux Cored Arc Welding as welding method. The material property of the test plate is the Mild Steel A Grade with shipbuilding welding structure steel. Table 1 shows the welding conditions.

Table1 Welding conditions

Welding	Size (mm)	Groove angle(。)	Root gap (mm)	Ampere (A)	Voltage (V)	Speed (cpm)	Heat input (cal/mm)
Bead on plate	500×300×8	-	-	280	30	48	250
V Groove	500×300×15	38	6	500	38	23	1181
Fillet	400×800×8	-	-	230	28	40	230

2.2 Numerical analysis method: ANSYS®

In numerical analysis, 3D heat transfer analysis was performed and then 3D residual stress analysis was performed under use of the temperature distribution result. Mechanical and thermal material properties for the analysis were employed the nonlinear material properties that vary according to the temperature. And bead regions were modeled closely by using the element birth & death technique. A test method to calculate the residual stress according to welding sequence includes four welding processes in numerical analysis and experiment. A present welding direction and order were determined by considering the automatic welding system. These welding analysis need a large computing time and HDD memory because analysis considers the variation of the non-uniform temperature distribution and elasto-plastic behavior. But these problems can be solved by appropriate control of the total degree of freedom for analysis model and non-linear transient analysis technique for thermal elasto-plastic analysis. Fig. 1 shows the finite element model for the welding structure and welding process model with regular welding direction.

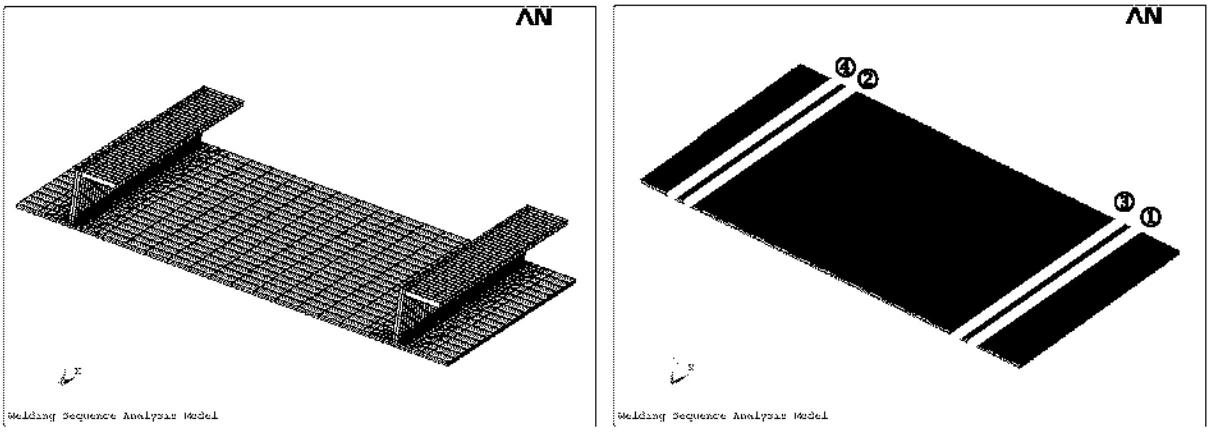

Fig. 1 Model for welding sequence analysis

2.3 Experiment: Hole Drilling Method

The hole drilling strain-gage method measures residual stresses near the surface of a material. The method involves attaching strain gages to the surface, drilling a hole in the vicinity of the gages, and measuring the relieved strains. The measured strains are then related to relieved principal stresses through a series of equations.

The method is often described as "semi-destructive" because the damage that it causes is very localized and in many cases does not significantly affect the usefulness of the specimen. In contrast, most other mechanical method for measuring residual stress substantially destroys the specimen.

The residual stress was tested on the rosette strain gage (KFG-3-120-D28-11, 3mm diameter) of the KYOWA Company in our experiment. The author carried out the experiment as follows: (1) a sufficient cooling of welded structure; (2) the gage attachment after surface treatment on measuring point; (3) the strain measurement by hole drilling method with 8 step hole depth; and the calculation of the residual stress is based on Kirsh's solution & ASTM E 837 standard [3]. To observe a dominant residual stress for welding process, experiment was run as drilling the hole by stages in this part of weld line on the basis of longitudinal stiffener. Table2 shows some numerical illustrations considering welding direction. Fig. 2 shows the shape of the test plate with strain gage attachment.

Table 2 Case for welding sequence

	case1	case2	case3	case4	case5
①	→	→	→	→	→
②	→	→	←	←	→
③	→	←	←	→	←
④	→	←	→	←	→

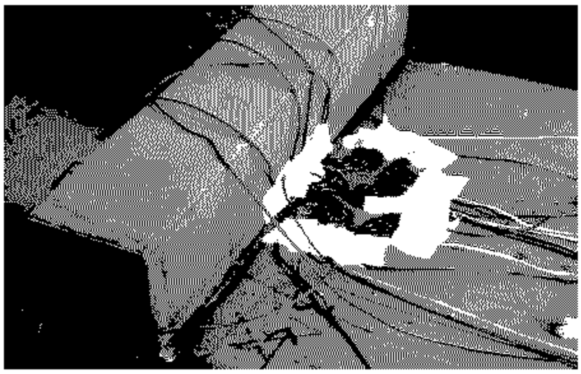

Fig. 2 Strain gage attachment

3. Results and discussions

In analysis result, stress concentration happens from part that is restricted for efficient analysis but the stress along the weld line shows very high stress state near the welding region.

The compressive stress acts recede in welding if length of Y direction is relatively longer than length of X direction, the stress magnitude shows stress state that decrease gradually. On the contrary, it shows compressive stress state recede in welding line if length of X direction is relatively longer than length of Y direction. Fig.4 shows residual stress of direction that recede from the welding line. When we consider the distribution of whole stress, the result shows that value of residual stress about each welding process (case1 ~ case5) is calculated almost analogously. Fig.5 and Fig.6 compared experimental value with residual stress analysis result of inner and outer part that an experiment is available. The quantitative value of the analysis and an experiment of residual stress near region of heat effect have a different value but looks similar tendency almost recede in welding.

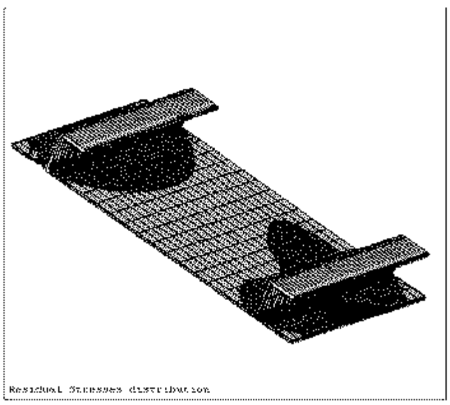

Fig. 3 Residual stress (σ_x) distribution

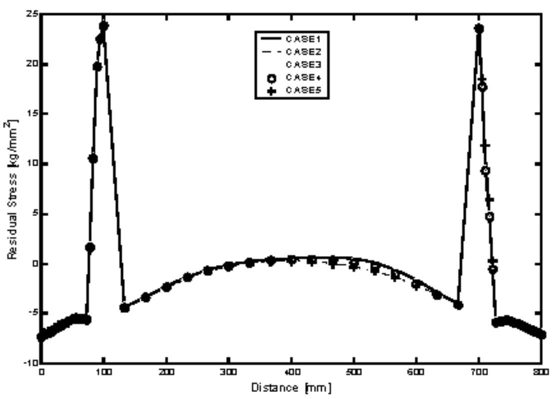

Fig. 4 Residual stress (σ_x) along Y-axis

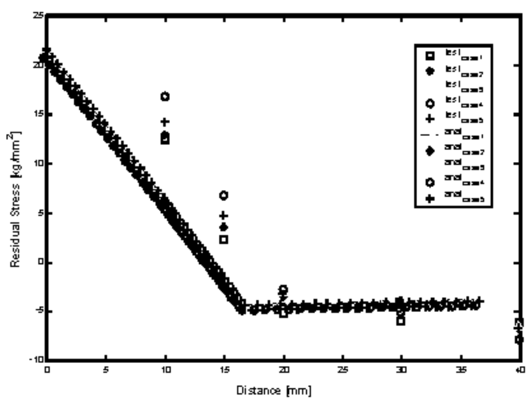

Fig. 5 Inner residual stress

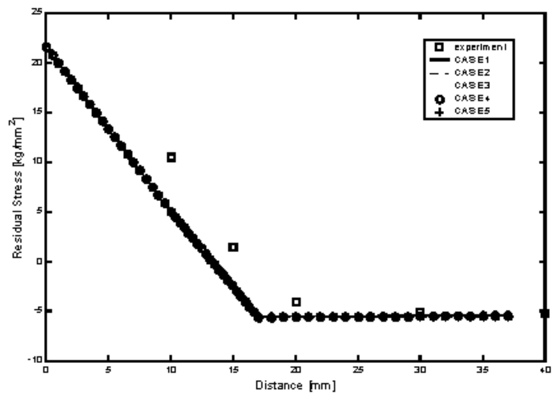

Fig. 6 Outer Residual stress

4. Conclusion

This paper investigated the residual stress of shell plate considering the welding process of the longitudinal stiffener. First, some illustrations show the tendency of welding residual stress by ratio of width to length about model of test plate shape by analytic method. And it is seldom difference of dominant residual stress of welding structure in change of welding process that consider welding direction. The comparison of the numerical analysis results with experimental data shows the accuracy and validity of the proposed method. Hereafter, many researches about finite element analysis techniques to perform analysis of large size and complicated structure must be conducted. And then, a research about welding sequence analysis that considers various kinds of welding process may have to consist continuously.

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