Distortion Control of the Curved Panel Using Elastic Bending Method

H. G. Kim, S. B. Shin, and J. G. Youn

Abstract

Finite element analysis (FEA) and experimental studies on an elastic bending method have been performed in order to control the angular distortion at the fillet weldment for curved panel. Process parameters for the elastic bending method such as clamping span and release time were analyzed with reference to welding condition and geometric effect of the curved panel, which can minimize or prevent the angular distortion by producing a proper skin stress to the fillet weldment. The amounts of the angular distortion decrease almost in a linear manner with an increase in the skin stress. The skin stress required for non-angular distortion at the fillet weldment is strongly dependent on the plate thickness, not the heat intensity applied. The clamping span for obtaining uniform skin stress was defined as functions of the plate thickness and length of the free edge. Clamp should be removed after the fillet weldment is cooled down to room temperature for non-angular distortion. Effectiveness of the elastic bending method established was verified by its application to an actual curved panel.

Key Words : Curved panel, Angular distortion, Elastic bending, Skin stress, Clamping span.

1. Introduction

Curved panels are typical components of the curved hull for fore-ship and after-ship structure. These are generally manufactured by a semi-automatic welding process such as flux cored arc welding after fitting up the longitudinal and transverse stiffeners to a curved plate. In shipbuilding, the production cost for curved panels is generally high. This is mainly associated with use of a semi-automatic welding process and forming process with a manual line heating and cold bending. In order to reduce the production cost for curved panels, forming and welding process should be either mechanized or automated. To do this, comprehensive researches on this topic have been carried out[1-3]. The authors have also tried to apply a mechanized welding process for manufacturing curved panels. A major obstacle for the application of the mechanized welding process is the welding distortion, in particular angular distortion at the fillet weldment of the curved panel. It is, therefore, very important to control angular distortion at the fillet weldment. Many control technologies for the angular distortion have been reported: simple restraint method, line-heating method and elastic bending method. Elastic bending method was found to be very effective, compared with the others[3]. A key factor for the elastic bending method is the application of a proper skin stress to the fillet weldment, which is the maximum bending stress acting on the surface of the fillet weldment.

In this study, process parameters for the elastic bending method such as clamping span and release time have been investigated with reference to welding condition and geometric effect of the curved panel in order to obtain a proper skin stress required for non-angular distortion at the fillet weldment. These investigations were made using a finite element

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analysis (FEA) and experimental studies and provided a basis for the application of the elastic bending method to an actual curved panel. Validation of the elastic bending method has been evaluated using actual curved panels for a ship structure

2. FEA and experimental procedure

A schematic diagram of FEA model for investigating process parameters of the elastic bending method is shown in Fig. 1. The variables used for FEA are the heat intensity, plate thickness, plate curvature, clamp span and clamp release time as shown in Table 1. Heat transfer analysis was performed using 2-dimensional heat transfer model with a quasi-stationary condition. Mesh design for the FEA consisted of 8-nodes isoparametric plane element. In thermo-mechanical analysis, material properties were postulated to behave as an isotropic, elasto-plastic and strain hardening continuum. Yielding of the material was assumed to be governed by von-Mises criteria.

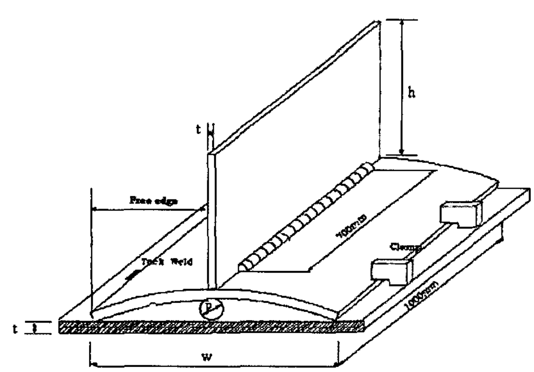


Fig. 1 Schematic diagram of FE analysis model[4)]

Experiment was performed to verify the results of FEA and to evaluate the validity of the elastic bending method to actual curved panels. Experimental models were the curved panels for an engine room block in an after-ship structure. Deformed profiles of the curved panels after manufacturing were evaluated by a 3-dimensional measuring instrument. Accuracy of the curved panel was evaluated in terms of the amounts of similarities (δ) at the curved panels, which is defined in a following equation.

$$\delta = 1 - \sqrt{\frac{\sum_{i=1}^{N_x}\sum_{j=1}^{N_y} d_{ij}^2}{N_T}}, d_{ij} = \frac{g_{ij} - c_{ij}}{g_{\max}}$$

where,

- δ : Similarity
- N_T : Total number of a grid point
- N_x, N_y : Number of grid point of the length and width direction
- D_{max} : Maximum displacement of the designed curve
- D_{ij}-M_{ij} : Difference between designed and measured curve at grid points (i, j)

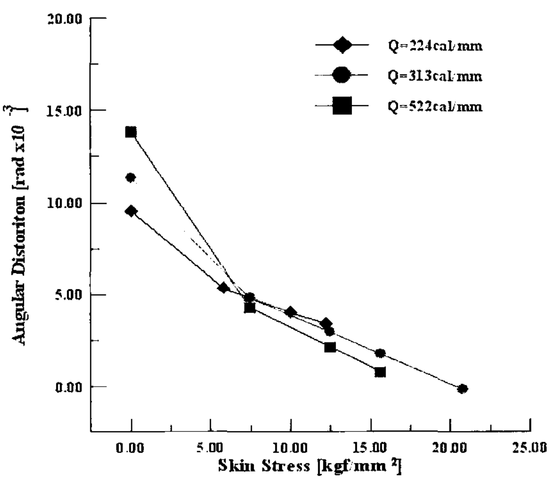
Table 1 Variables used for FEA

Heat Intensity [cal/mm]		224, 313, 522
Dimension	Flange (t×w) [mm]	10 - 25×500
	Web (t×h) [mm]	10 - 25×300
Clamp	Span [mm]	100 - 2000
	Release time [sec]	20 - 1800

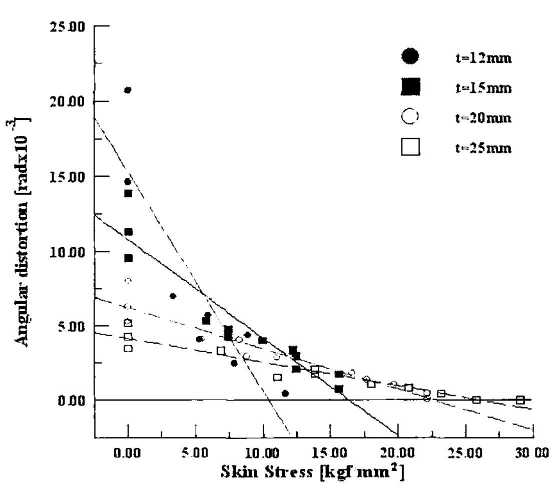
3. Results and discussion

3.1 Skin stress for non-angular distortion

Skin stress controlling the angular distortion at the fillet weldment is generally known to be dependent on heat intensity and plate thickness. In order to confirm this, the relationship between the angular distortion and skin stress has been analyzed with respect to heat intensity and plate thickness. Fig. 2(a) shows the variation of the angular distortion at the fillet weldment as functions of skin stress and heat intensity for 15mm thick plate. The angular distortion decreases almost in a linear manner with an increase in skin stress, regardless of the heat intensity applied. The skin stress required for non-angular distortion at the fillet weldment is converged into a constant value. That is, the skin stress for non-angular distortion is independent of the heat intensity applied controlling the bending rigidity. Effect of plate thickness on the skin stress is



(a) Heat intensity



(b) Plate thickness

Fig. 2 Variation of the angular distortion at the fillet weldment with skin stress

shown in Fig. 2(b). The skin stress for non-angular distortion is strongly dependent on the plate thickness. Based on the results in Fig. 2, it can be deduced that the skin stress for non-angular distortion at the fillet weldment is a function of plate thickness.

3.2 Clamping span

The clamping span, which can produce an uniform skin stress field along the fillet welding line, was calculated by FEA. The variables used for FEA were the free edge length and plate thickness at the fillet weldment as shown in Table 2. The uniform skin stress, that is, the allowable difference between the maximum and minimum skin stress applied to the welding line by a clamp can be defined within 10 % in this study. Fig. 3 shows the variation of the clamping spans for obtaining an uniform skin stress with free edge length for various plate thickness. For free edge length less than about 400mm, the clamping span obtaining the uniform skin stress at the welding line depends both on the free edge length and the plate thickness. The clamping span increases in a linear manner with an increase in the free edge length, regardless of plate thickness. For a given free edge length less than about 400mm, the clamping span is proportional to plate thickness. However, the clamping span for obtaining the uniform skin stress could be defined as a function of the free edge length for a longer free edge length than 600mm as shown in Fig. 3. This tendency could be explained by St. Venants principal[5].

Table 2 Variables used for FEA

Thickness [mm]	10 - 20
Free edge [mm]	100 - 1500
Clamping span [mm]	100 - 2500

3.3 Clamping release time

Variation of the angular distortion and maximum temperature at the fillet weldment is shown in Fig. 4 with reference to clamping release time for plate thickness of 12mm, heat intensity of 313 cal/mm and skin stress of 10.78kgf/mm^2. As the clamp release time increases, the amount and reduction rate of the angular distortion decreases down to zero and room temperature, respectively. Although the angular distortion caused by a fillet welding is fully developed within 10-30 seconds after welding, the clamp producing the skin stress should be removed after the weldment is cooled down to ambient temperature.

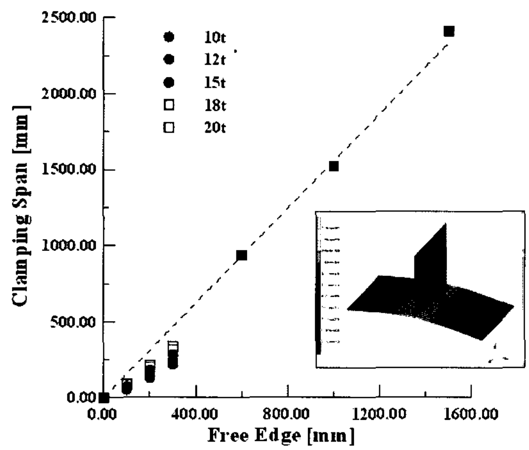


Fig. 3 Variation of the clamping span for obtaining the uniform skin stress along the welding line at the fillet weldment with length of free edge for various plate thickness

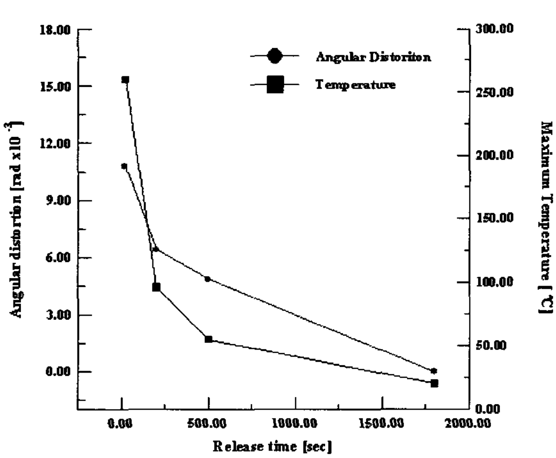
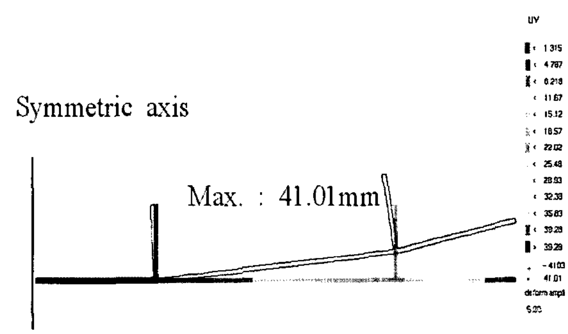


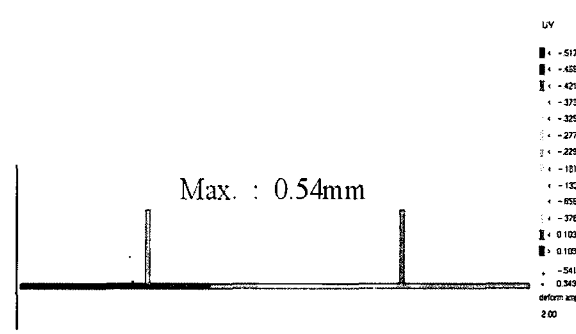
Fig. 4 Variation of the angular distortion and maximum temperature with clamping release time

3.3 Application

Validity of the skin stress required for non-angular distortion at the fillet weldment obtained from the analysis model has been evaluated by FEA for its application to an actual panel. Dimension of the panel and heat intensity for validity evaluation are shown in Table 3 and the applied skin stress was 16 kgf/mm^2 as determined in Fig. 2(b). The panel was simply supported at the bottom surface of lateral end stiffeners in order to apply an uniform skin stress at each fillet weldment. Fig. 5 shows the effect of skin stress on the distortion contour at the panel after the weldment is cooled down to room temperature. The maximum angular distortion at the free edge of the panel structure decreases from 41mm to -0.54mm by applying the skin stress of 16 kgf/mm^2. It indicates that the skin stress required for non-angular distortion at the fillet weldment obtained from the analysis model is almost equal to that at the panel structure.



(a) Skin stress = 0 kgf/mm^2



(b) Skin stress = 16 kgf/mm^2

Fig. 5 Effect of skin stress on the angular distortion contour at panel

Table 3 Variables used for FEA

Thickness [mm]	15
Width [mm]	3600
Stiffener span [mm]	900
Free edge [mm]	450
Heat intensity [cal/mm]	313

To confirm the FEA result given in Fig. 5, experiments were carried out on the actual curved panels used for an engine room block. Dimension of the curved panel and fabricating method including skin stress are given in Table 4. Fig. 6 shows the deformed profiles of two actual curved panels after fillet welding, combined with the design profile. Comparing with B curved panel, the curvature and similarity (δ) of A curved panel manufactured by a mechanized welding process under the elastic bending method are similar to those of the design panel as shown in Table 5. It means that the mechanized welding process under the elastic bending method can be an effective substitute for a conventional semi-automatic welding process for manufacturing of the curved panel. A difference is found between the deformed curvatures and the design curvature, regardless of the fabricating process applied in Fig. 6. It is attributed to both the initial distortion formed by forming process and the difference between calculated and applied skin stress.

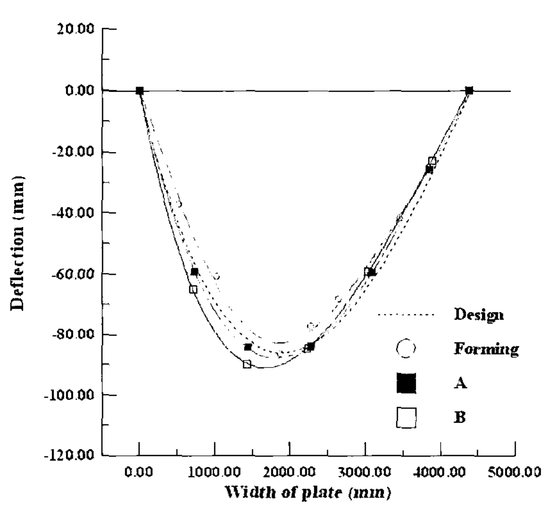


Fig. 6 Variation of profiles of the actual curved panel with manufacturing process

Table 4 Dimension and fabrication process actual curved panels

Types	A	B
Thickness [mm]	15	
Width × Length [mm]	4400 × 13700	
Curvature [1/mm]	3.5986E-5	
Free edge [mm]	700	
Welding Process	Mechanized	Semi-auto
Skin stress [kgf/mm^2]	Calculated : 8.2 Applied : 6.6	0

Table 5 Curvature and similarity of curved panel with fabricating process

Types	Curvature [1/mm]	Similarity
Design	3.5986E-5	1
A	3.9559E-5	0.9698
B	4.2465E-5	0.7689

4. Conclusion

In order to control the angular distortion at the fillet weldment for the curved panel, finite element analysis (FEA) and experimental studies on an elastic bending method have been performed. The main results obtained are summarized as follow.

1. Elastic bending method producing the skin stress by clamping can control the angular distortion of the actual curved panel.
2. Degree of the angular distortion decrease almost in a linear manner with an increase in the skin stress. The skin stress required for non-angular distortion at the fillet weldment is strongly dependent on the plate thickness, not the heat intensity applied.
3. The clamping span for obtaining uniform skin stress was defined as functions of the plate thickness and length of the free edge. Clamp should be removed after the fillet weldment is cooled down to room temperature for non-angular distortion.

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