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곡판의 맞대기 용접변형 거동에 관한 연구

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On the Weld-Induced Deformation Analysis of Curved Plates

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ABSTRACT: *A three-dimensional finite element (FEM) model has been developed to simulate the deformation due to bead on plate welding of curved plates with curvature in the weld direction. By using traditional method such as thermal-elastic-plastic FEM, the weld-induced deformation can be predicted accurately. However, this method is not practical approach to analyze the deformation of large and complex structures such as ship hull structures in view of time and cost. This study is classified from the aspect of equivalent load based on inherent strain near the weld line. Therefore, the residual deformation can be simply computed by elastic analysis. Further more, a practical solution is proposed to consider the contact between the plate and the positioning jig by judging the reaction forces of the jig at calculation step and the effect of the longitudinal curvature is closely considered.*

1.Introduction

Welding is a key technology for building metal structures such as ships and bridges (Yu Takeda, 2002). However, welding generally produces weld-induced distortion due to non-uniform temperature distribution. Therefore, the transient thermal elasto-plastic FEM (T-E-P) analysis by finite element method may be utilized (Kim et al, 1997). However, this method is not a practical approach to solve the deformation of large and complex structures in view of time and cost. In this study, the weld-induced deformation in both flat and curved plates are defined by using the simplified method and the effect of longitudinal curvature on deformation is closely examined.

2. Modelling for Numerical Analysis

A 3-dimensional finite element model of a rectangular butt-joint weld in a mild steel curved plate with dimension L×B = 1000 mm × 1000 mm, thickness h = 12 mm was tested with the welding conditions as shown in Table 1. Fig. 1 shows full finite element (FE) model with its coordinate system a half of the whole shell with fixed positioning jigs is shown in Fig. 2.

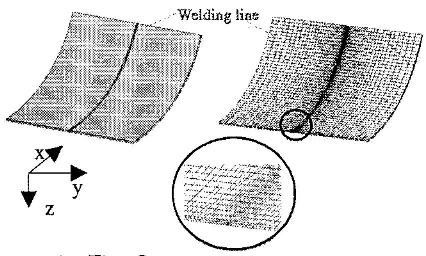

Fig. 1 Full FE model with its coordinate system.

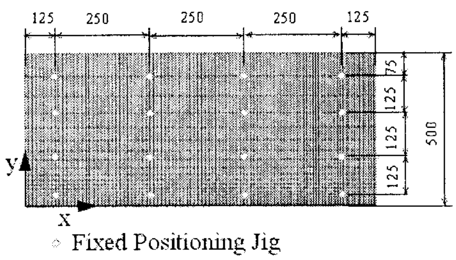

Fig. 2 Half FE model with fixed positioning jig.

Gaussian heat flux distribution was utilized and the shell surface's temperature changes due to the combined effects of two conditions, namely, 1) conduction within the specimen, and 2) convection and emission from the specimen surface's temperature to the surrounding air temperature that assumed to be 30°C (Michaleris et al. 1997). The temperature

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dependent mechanical and physical properties of mild steel are shown in Figs. 3 and 4. The restraint boundary is more difficult to realize because the contact points between the plate and the positioning jig must be modeled as gap elements. Therefore, the problem should be solved by nonlinear analysis but such approach takes much time and cost (Yu Takeda. 2002). So, this problem is deal with the following step-by-step elastic analysis that neglects the deformation due to slipping.

(1) In the initial step, vertical movement is constrained at every fixed positioning jig, by assuming that every poisoning jig is effective to restrict the lateral deformation of the plate as Fig. 2 shown above. On that assumption, reaction forces can be easily calculated at positioning points.

(2) In the second step, reaction forces are checked at every jig whether the sign of reaction is positive or negative. As the reaction force is negative, then the constraint at that point should be released.

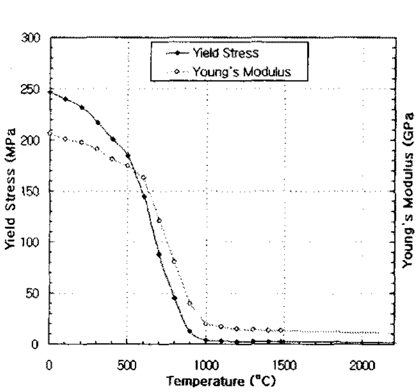

Fig. 3 Temperature-dependent mechanical properties

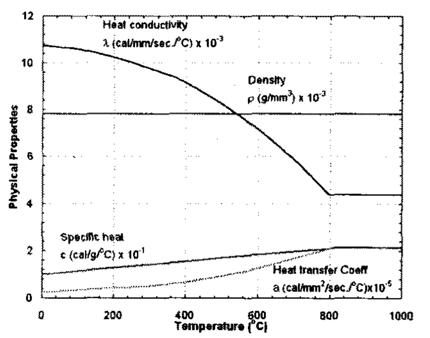

Fig. 4 Temperature-dependent physical properties

The total strain due to welding can be written as Eq. (1):

$$\epsilon = \epsilon^e + \epsilon^p + \epsilon^{th} + \epsilon^{tr} \quad (1)$$

$$\epsilon^* = \epsilon^{th} + \epsilon^p + \epsilon^{tr} = \epsilon - \epsilon^e \quad (2)$$

where, ϵ = Total Strain; ϵ^e = Elastic Strain

ϵ^p = Plastic Strain; ϵ^{th} = Thermal Strain

ϵ^{tr} = Phase Transformation Strain

The analysis of weld-induced deformation can be simplified by using spring model as shown in Fig. 5 with the thermal history of plastic strain is assumed as in Fig. 6.

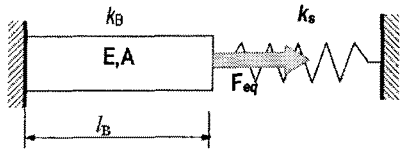

Fig. 5 The simple spring model used for analysis

By using the simple spring model, the equivalent force and equivalent strain are computed as Eq. (3) and Eq. (5) below.

$$F_{eq} = EA\epsilon^* = EA(\epsilon^{th} + \epsilon^p) \quad (3)$$

$$\Delta l_B^{eq} = \frac{F_{eq}}{k_s + k_B} = \frac{EA}{k_s + k_B}(\epsilon^{th} + \epsilon^p) \quad (4)$$

$$\epsilon^{eq} = \frac{\Delta l_B^{eq}}{l_B} = \frac{EA}{l_B}\frac{1}{k_s + k_B}(\epsilon^{th} + \epsilon^p) \quad (5)$$

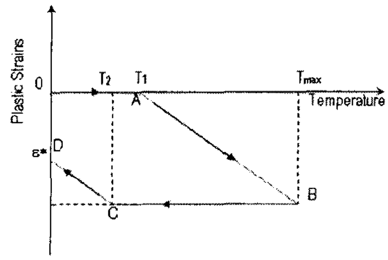

Fig. 6 Thermal history of plastic strain

In the FE model, the equivalent restrained forces are obtained by using the inherent strain as Eqs. (6) and (7) and the total equivalent transverse and longitudinal forces can be calculated by using Eq. (8). (Yu Luo, 1999)

$$f_{x_i} = \frac{AE}{l}\sum_{j=1}^{N_i} \epsilon^*_{px_j} l_j \quad (6)$$

$$f_{y_i} = \frac{AE}{l}\sum_{j=1}^{N_i} \epsilon^*_{py_j} l_j \quad (7)$$

Where: l_j is the finite element length.

$$f_x = \sum_{i=1}^{N} f_{x_i} \text{ and } f_y = \sum_{i=1}^{N} f_{y_i} \quad (8)$$

3. Numerical Results and Discussions

In this study, four cases with different values of curvature, namely, 1/R = 0.001, 0.0005 (welding on the convex side of the plate) and 1/R = -0.001, -0.0005 (welding on the concave side of the plate) are analyzed. The effect of curvature on vertical deformation is plotted in Figs. 7 and 8. It can be seen that the more flat the plate is, the more deformation is obtained.

Table 1 Welding Conditions

Parameter	Value
Speed (mm/sec)	7.0
Thermal efficiency	0.75
Q (J/mm)	1296.0
Q/h^2 (J/mm^3)	9.0

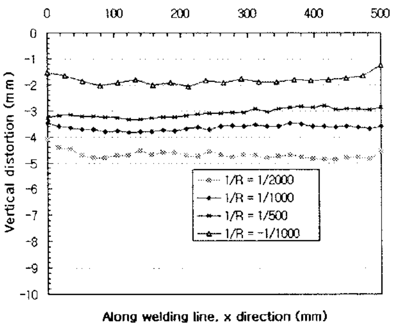

Fig. 7 Vertical distortion along x- direction at y = 0

Fig. 9 shows the effect of curvature on the distribution of transverse inherent shrinkage along the welding line (at y = 0). As it can be seen clearly that the effect of longitudinal curvature on the transverse shrinkage is quite small. The deformation is almost attained to the constant value between two ends of the plate.

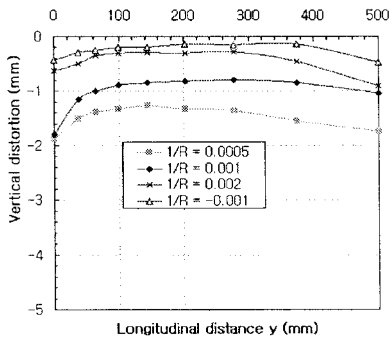

Fig. 8 Vertical distortion along y- direction at x=500mm

The deformation along the transverse section at the center of plate and that along the welding line are shown in Figs. 10 and 11. The results from T-E-P analysis are compared with the simplified method and it can be observed that they are almost agreed well together along the y-direction but a little lower along the welding line.

It can be seen that the increase of curvature will increase the longitudinal deflection for both concave and convex sides with the minimum value around -2.0 mm. Contrarily, the transverse (lateral) bending decreases with the increase the magnitude of curvature and attains to the maximum value around 10.0 mm as in Figs 12 and 13. The error in the prediction of the elastic analysis is relative small for lateral bending but bigger for longitudinal bending that comes from neglecting of the difference of tendon force between the curved plate and flat plate along weld line during welding process as shown in Fig. 16 shown below.

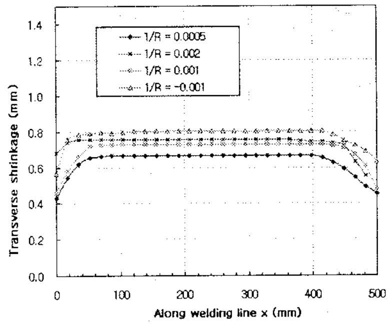

Fig. 9 Transverse shrinkage along x- direction at y=0

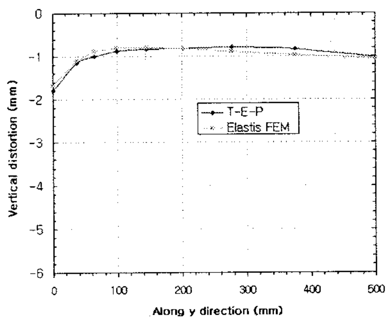

Fig. 10 Vertical displacement along y direction at x = 500mm (1/R=0.005)

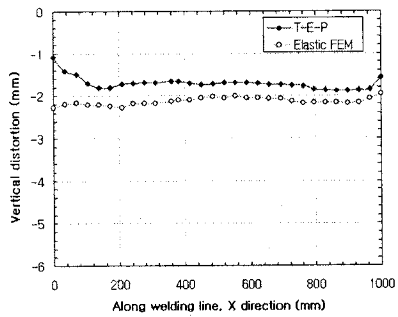

Fig. 11 Vertical displacement along x- direction at y = 0 (1/R=0.005)

Fig. 14 shows the effect of curvature on maximum inherent transverse shrinkage that the variation of shrinkage is not much and they can be treated as constant value within allowable error. The influence of curvature on tendon force is shown in Fig. 15 with the maximum value of tendon force occurs at 1/R = -0.0005, and then it decreases according to increasing of the curvature for both concave and convex side.

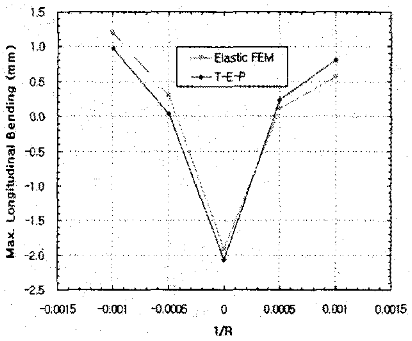

Fig. 12 Effect of curvature on longitudinal bending

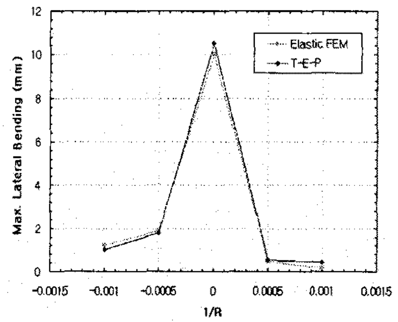

Fig. 13 Effect of curvature on lateral bending

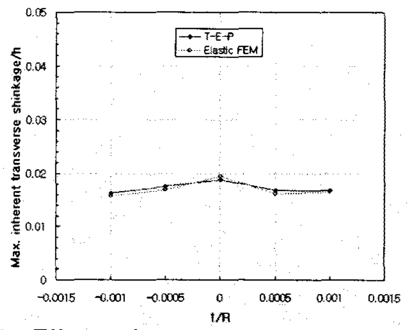

Fig. 14 Effect of curvature on maximum inherent transverse shrinkage

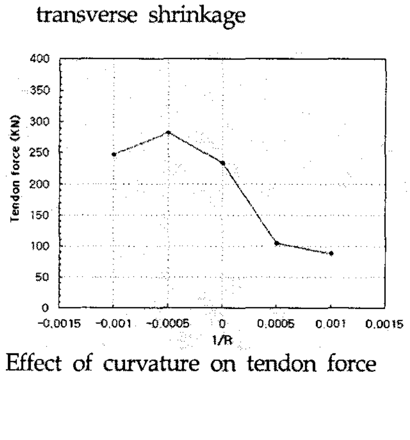

Fig. 15 Effect of curvature on tendon force

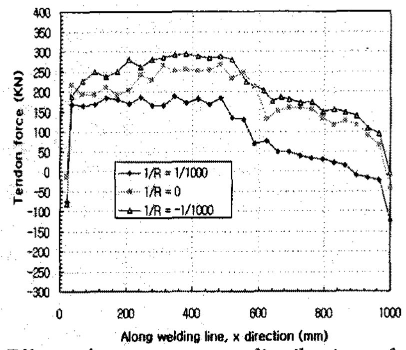

Fig. 16 Effect of curvature on distribution of tendon force along welding line

5. Conclusions

Based on the results from this parametric study, the simplified modeling process for simulating welding distortion using a general purpose FE package, ANSYS, described here is reliable and instructive. By applying the equivalent loading method based on inherent strain, a three-dimensional thermal elasto- plastic problem can be easily changed into elastic analysis and the results are agreed well. Therefore, this approach can be utilized for curved block of ship.

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References

Kim S.I, Lee J.S, Han J.M, Cho Y.K, Kang J.K, Lee J.Y, (1997). "A study on the accuracy control of block assembly in shipbuilding", ICCAS, pp 367-381.

Michaleris P., DeBiccari A. (1997). "Prediction of welding distortion", Welding Journal, Vol 76, No. 4, pp 172s-180s

Yu Luo et al. (1999). "Welding deformation of plates with longitudinal curvature", Trans. JWRI, Vol. 28, No. 2, pp. 57-65.

Yu Takeda. (2002). "Pridiction of butt welding deformation of curved shell plates by using inherent strain method", J. of Ship Production, Vol. 18, No. 2, pp. 99-104.