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Citation	Transactions of JWRI. 2010, 39(2), p. 88-90
Version Type	VoR
URL	https://doi.org/10.18910/9309
rights	
Note	

Transactions of JWRI, Vol.39 (2010), No. 2

Prediction and measurement of welding distortion of thin shell structure†

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KEY WORDS: (Welding Distortion) (Inherent Deformation) (Shell Structure) (Elastic Analysis) (Thermal-Elastic-Plastic computation) (Finite Element Method)

1. Introduction

In the manufacturing industry, welding is commonly used as a main joining process to assemble various parts to a welded structure. However, welding distortion always occurs during the welding process because of non-uniform expansion and contraction caused by the heating and cooling cycle at the weld and surrounding base material [1]. Distortion due to welding not only degrades the performance of a welded structure but also increases its production cost. In fact, it is impossible to completely eliminate welding-induced distortion, but a welded structure can be produced within a small tolerance through minimizing the welding-induced distortion [2]. Therefore, prediction and control of welding distortion have become of critical importance during assembly processes.

2. Experimental procedure

The research object is a spherical structure which consists of 16 bent thin shells and 2 circular polar plates. The spherical structure has been pre-assembled by tack welds. The dimensions of this spherical structure are shown in **Fig. 1**. To evaluate welding distortion, five typical points as shown in **Fig. 2** have been selected to measure the displacements after each welding line.

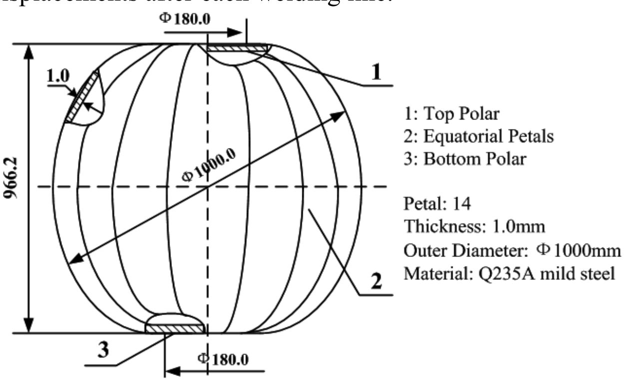

Fig. 1 Dimensions of the spherical structure

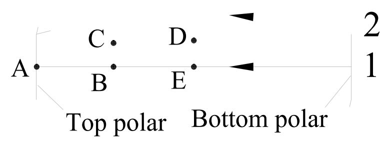

Fig. 2 Position of measuring points

3. Computational Approach

The computational approach for welding distortion of the spherical structure is divided into two steps. In the first step, the inherent deformations in a butt welded joint are estimated by a three dimensional thermal-elastic-plastic FEM. Then, in the second step, welding distortion induced by sequential welding of the spherical structure is computed by an elastic FEM in which the inherent deformations predicted in the first step are used as the input data.

[1] Estimation of inherent deformation using thermal-elastic-plastic FEM.

The dimensions of a butt welded joint are 400mm× 400mm×1mm, shown in **Fig. 3**. The base metal is a low carbon steel and the welding condition is shown in **Table. 1**.

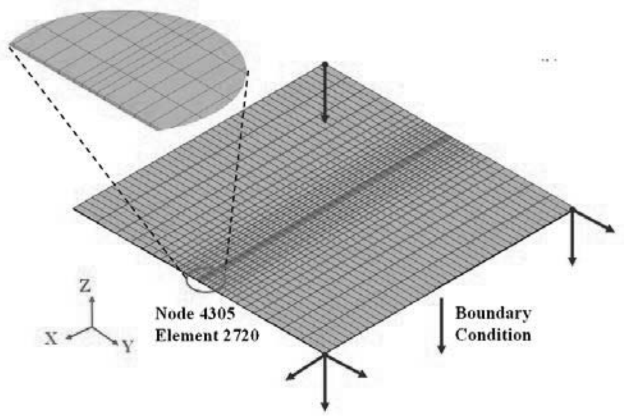

Fig. 3 Dimension and mesh of model

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Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka 567-0047, Japan

Table 1 welding condition

Current(A)	Voltage(V)	Velocity(mm/s)
70	20	12

Using the software JWRIAN, temperature field, displacement and plastic strains are estimated. **Figure 4** shows the distribution of longitudinal and transverse plastic strains along the central cross section of the model. According to the definition of inherent deformation [3], integration of plastic strains gives the inherent deformations as shown in **Table. 2**.

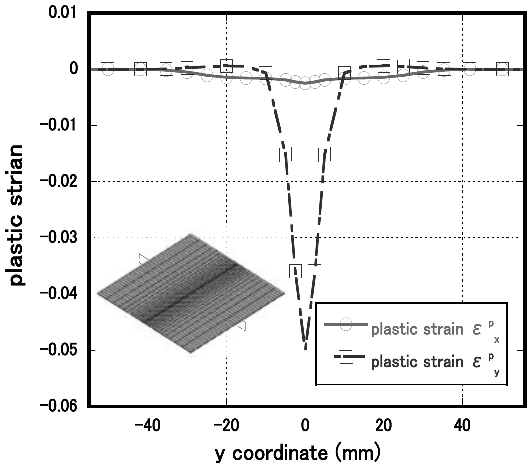

Fig. 4 Distribution of strains in the central cross section

$$\delta_x = \frac{1}{h}\iint \varepsilon_x^p dydz \quad \delta_y = \frac{1}{h}\iint \varepsilon_y^p dydz$$

$$\theta_x = \int \varepsilon_x^p (z - \frac{h}{2})/(h^3/12)dydz$$

$$\theta_y = \int \varepsilon_y^p (z - \frac{h}{2})/(h^3/12)dydz$$

Where, δ_x , δ_y and ε_x^p , ε_y^p are the inherent deformations and plastic strains at longitudinal and transverse direction, respectively. θ_x, θ_y are longitudinal and transverse bending.

Table 2 Inherent deformations

δ_x(mm)	δ_y(mm)	θ_y(rad)	θ_x(rad)
-0.064313	-0.16865	-0.00001	0.000007

[2]Elastic analysis with inherent deformation

Based on the inherent strain theory, welding induced distortion of the spherical structure can be calculated using the known inherent deformations. Part numbers of the spherical structure are shown in **Fig. 5**. The welding sequence is corresponding to the part member.

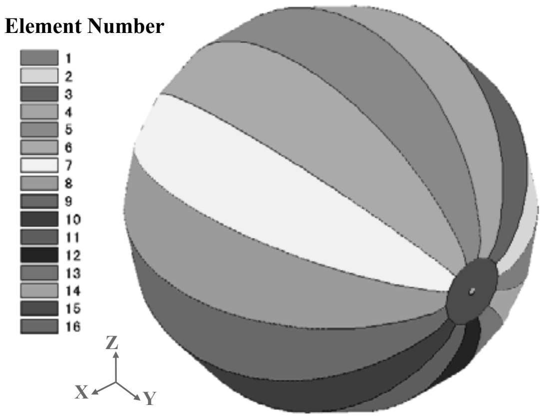

Fig. 5 Part numbers of spherical structure

After the last welding line, the radial displacement contour diagram of the spherical welded structure is shown in **Fig. 6** and the radial displacement of the selected points during sequential welding is shown in **Fig. 7**. Because of the strong constraint of tack welds, the circumferential length will be not changed due to welding. As a result, the points B and E have negative radial displacements (inward). The points C and D have positive radial displacements (outward). The largest deformation of the points B and E will occur after the first welding pass and the welding deformation will decrease with the progress of the other welding lines. The largest deformation at the point C and D will occur after the last welding line. The welding deformation increases after each welding line. The welding distortion of the point A is the negative radial displacement which always increases after each welding line and it increases dramatically when welding the circular polar plate. In addition, the computational results of typical points have a good agreement with the measured results as shown in **Fig 8.**

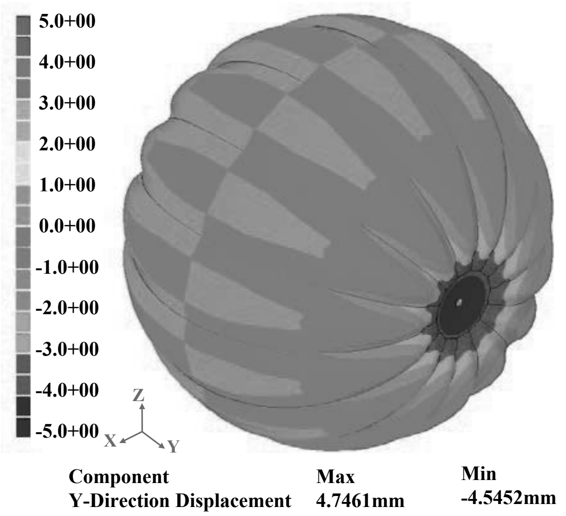

Fig. 6 Welding distortion of spherical structure

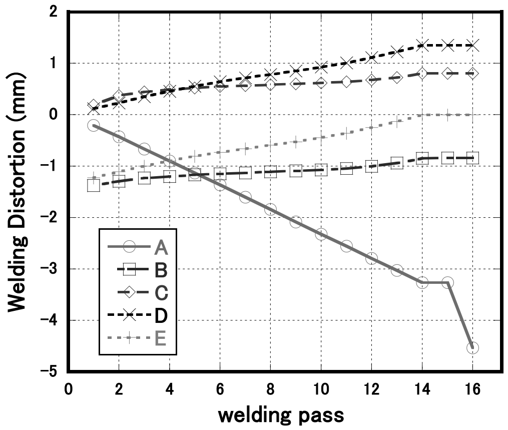

Fig.7 Radial displacement (Positive outward) of the selected points during sequential welding

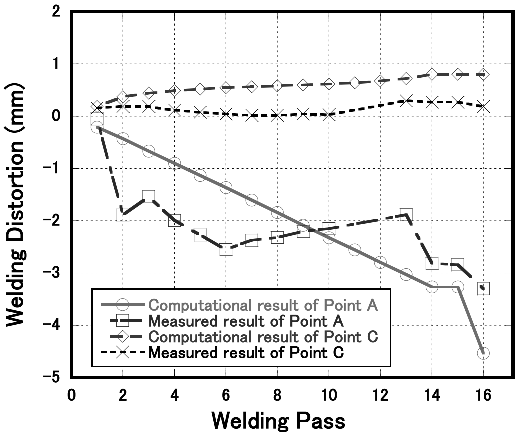

Fig. 8 Comparison between computational and measured result of point A and C

4. Conclusions

(1) Welding distortions of a spherical welded structure have been predicted by an elastic FEM using the inherent deformation estimated by thermal-elastic-plastic FEM.

(2) Computational results are in good agreement with measurements, furthermore, the welding distortion at the different points changes differently after each welding line.

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