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Author(s)	Deng, Dean; Murakawa, Hidekazu; Ma, Ninshu; Serizawa, Hisashi
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Application of inherent deformation and interface element to prediction of welding distortion during assembly process†

DENG Dean *, MURAKAWA Hidekazu **, MA Ninshu ** and SERIZAWA Hisashi **

KEY WORDS: (Inherent Deformation) (Interference Element) (Numerical simulation) (Welding Distortion)

1. Introduction

Fusion welding processes are widely used to assemble large thin plate structures such as ships, automobiles and passenger trains because of the high productivity. However, welding-induced distortion often inevitably occurs during the assembly process. Welding distortion not only reduces fabrication accuracy of a welded structure but also decreases productivity due to correction works. If welding distortion can be predicted using a practical method beforehand, the prediction will be helpful for taking appropriate measures to control the dimension accuracy. In this study, an elastic FEM approach to welding distortion for large and complex welded structures is developed based on inherent strain theory and interface element formulation [1-3]. Welding distortions in two typical structure models (model A and model B) are simulated using the proposed method. Model A is employed to show how the gap and misalignment generate during the assembly. Model B is a large thin plate structure, and it is used to compare the welding distortions computed by large- deformation theory and small-deformation theory.

2. Finite Element Models

In this study, a two-step computational procedure [1] is used to simulate welding distortion occurring during the assembly process. At the first step, the inherent deformations of each type joint are estimated by thermal elastic plastic FEM using a small model. In the thermal elastic plastic FE analysis, the detailed welding conditions and temperature dependent thermal physical/mechanical properties are considered. At the second step, the total distortion of the large model is estimated by the developed elastic FEM based on inherent strain theory and interface element method. In this step, the welding distortion induced by heat input is simulated by inherent deformation, while the formation of gap/misalignment, the welding sequence and the gap correction is modeled by interface elements.

Figure 1 shows the mesh division and boundary conditions of Model A. This model consists of one skin plate, two longitudinal stiffeners and two transverse stiffeners. The length, width and thickness of skin plate are 4000mm, 2000mm and 9mm, respectively. The thickness of both the longitudinal stiffener and the transverse stiffener is 12mm. The size of each mesh is 50mm×50mm. Using this model, five cases as shown in **Table 1** are examined to investigate how the gap and misalignment generate during the assembly, and how welding sequence and gap correction affect the final distortion. It is assumed that the fillet joints and cross-shaped in model A are performed by a single-sided welding process. The welding conditions of each joint are the same as Ref.[1].

Table 1 Simulation cases of Model A

Case	Detailed information
A0	Weld all parts at the same time
A1	1) Weld transverses/longitudinal stiffeners 2) Correct gaps 3) Weld stiffeners and skin plate
A2	1) Weld long. Stiffeners and skin plate 2) **Strongly** correct the gaps between trans. stiffeners and skin plate 3) Weld transverse stiffeners and skin plate 4) Weld longitudinal stiffeners and Trans. stiffeners.
A3	1) Weld long. Stiffeners and skin plate 2) **Weakly** correct the gaps between trans. stiffeners and skin plate 3) Weld transverse stiffeners and skin plate 4) Weld longitudinal stiffeners and transverse stiffeners.
A4	1) Weld Trans. Stiffeners and skin plate 2) **Strongly** correct the gaps between longitudinal stiffeners and skin plate 3) Weld longitudinal stiffeners and skin plate 4) Weld longitudinal stiffeners and transverse stiffeners.

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* College of Materials Science and Engineering, Chongqing University, China

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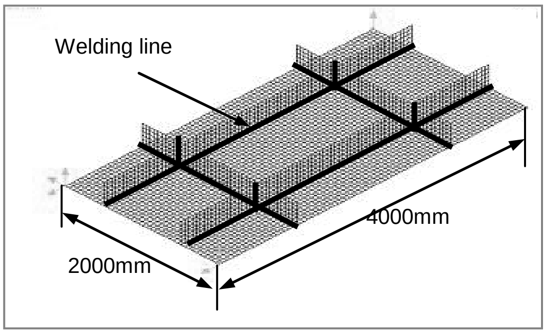


Fig. 1 Finite element model A (Model A)

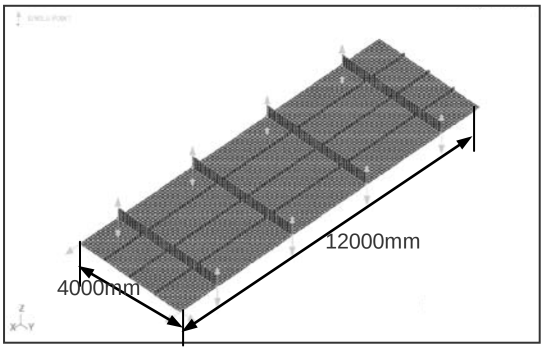


Fig. 2 Finite element model B (Model B)

Figure 2 shows the mesh division and the restraint conditions of model B. The length of skin plate is 12000mm, the width is 4000mm, and the thickness of skin plate is 6mm. The thickness of both longitudinal stiffeners and transverse stiffeners is 9mm. The size of each mesh is 100mm×100mm. Because the sink plate is very thin, it can be expected that buckling distortion will possibly occur during welding. Using this large model, two cases are simulated to compare the predictions of welding deformation calculated by large deformation theory and small deformation theory. Case B-1 is based on large deformation theory, while Case B-2 is based on small deformation theory.

Similar to model A, the welding deformations in each weld joint of model B are estimated by thermal elastic plastic FEM [3]. The net total heat input used in the fillet joint of model A is 1000 J/mm, while that used in cross-shaped join is 1440J/mm. All fillet joints are performed by a double-sided welding procedure, while the cross-shaped joints are welded by single-sided welding process. It is assumed that all parts in model B are fixed by tack weld before welding.

3. Simulation Results

Limited by space, the detailed computational approach is not provided in the present paper. Here, we briefly discuss the simulation results of model A and model B.

Figure 3 shows the remaining gap and misalignment in Case A-3 after the transverse stiffener and the skin plate were positioned. Because the initial gap generated between transverse stiffener and the skin plate was weakly corrected, the remained gap can be clearly seen and the maximum value is approximately 4mm. **Figure 4** shows the deflection distributions along line 1 in the five cases. This figure indicates that both welding sequence and gap correction significantly affect the final welding distortion. Here, it should be stressed that the welding conditions (heat inputs) used in each case are identical regardless of how the gap has been corrected. Generally, the larger gap is, the more heat input is needed. For this issue, we will discuss it in our future researches.

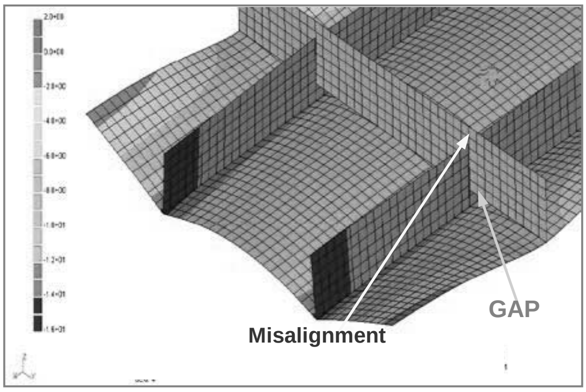


Fig. 3 Remained gap and misalignment after the transverse stiffener and the skin plate were weakly positioned

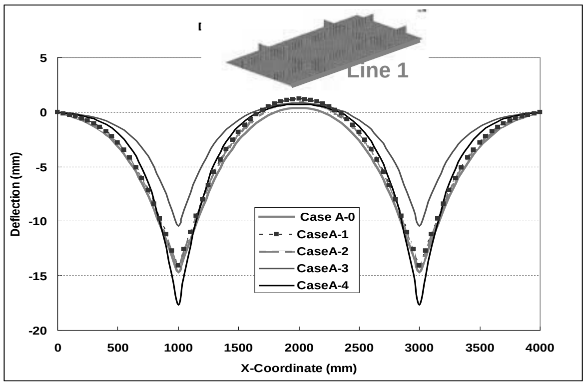
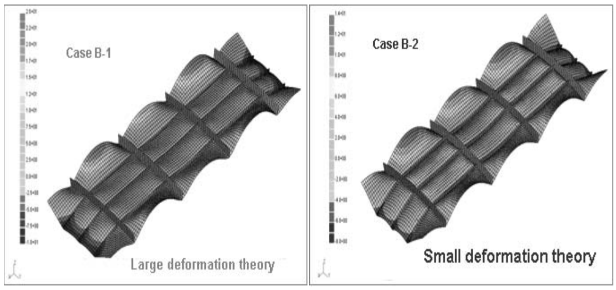


Fig. 4 Deflection distributions along line 1 (Model A)



(a) Large deformation theory (b) small deformation theory

Fig. 5 Deflection distributions of model B

Figure 5 shows the deflection distributions predicted by large deformation theory (Case B-1) and small deformation theory (Case B-2). It is clear that the deformation mode of Case B-1 is different from that of Case B-2 especially in the central panels. **Figure 6** compares the deflection distributions along line 1 predicted by the two cases. This figure shows that the maximum deflection of Case B-1 is

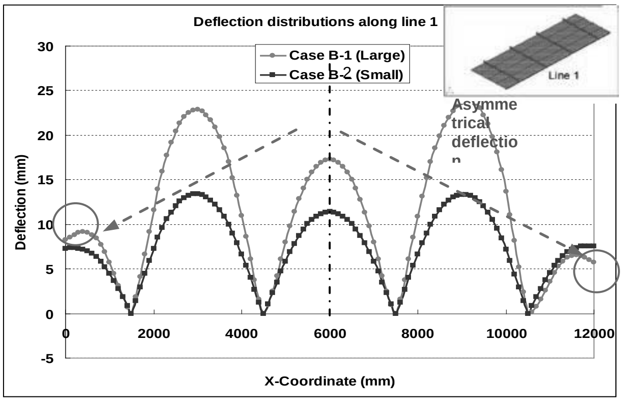


Fig. 6 Deflection distributions along line 1 (Model B)

significantly larger than that of Case B-2. Moreover, because of buckling distortion produced in case B-1, the deflection along line l has an asymmetrical distribution with respect to the center- line. Whereas, the deflection along line 1 of case B-2 has a symmetrical distribution.

4. Conclusions

1) During the assembly process, besides welding process, welding sequence and gap correction have a significant influence on the final deformation.
2) For large thin welded structures, because of the propensity of buckling distortion, it is necessary consider geometrical nonlinear problem.

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