Investigating the influence of external restraint on welding distortion in thin-plate welded structures by means of numerical simulation technology

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Abstract: Welding-induced deformation not only degrades the fabrication accuracy of a welded structure but also decreases the productivity due to correction work. Accurate prediction of welding distortion will be helpful in controlling the dimension accuracy. In this study, the main objective is to clarify the influence of external restraint on welding distortion in three different thin-plate steel welded structures by means of numerical simulation technology. A two-step computational approach was employed to simulate welding distortion in each welded structure. In the first step, the thermal elastic plastic finite element method (T-E-P FEM) was used to obtain inherent deformation for each typical joint. In the second step, an elastic FEM based on inherent strain theory was used to compute welding deformation for three thin-plate panels with different thickness and shape. In addition, the effects of external restraint on welding deformation in a thin-plate panel with 5 mm thickness, a thin-plate panel with 10 mm thickness, and an asymmetric curved panel with 10 mm thickness were investigated.

1. Introduction

In practical engineering, the external constraint method is often used to on-line control the welding deformation [1]. However, for welded structures with different shape and thickness, the effect of external restraint on the final welding distortion maybe is also different. In the current study, we used three thin-plate panel steel models with different shape and thickness to examine the effect of external restraint on the final distortion based on simulation results. A two-step computational approach was employed to simulate welding distortion in each model [2]. In the first step, the thermal elastic plastic finite element method (T-E-P FEM) [3] was used to obtain inherent deformation for each typical welded joint involved in thin-plate welded structures. In the T-E-P FE models, the moving heat source, temperature-dependent material properties, thermal and mechanical boundary conditions were carefully taken into account. In the second step, an elastic FEM based on inherent strain theory [4] was utilized to compute the total welding deformation for each thin-plate panel model. Through comparing the deflection distributions, the effect of external restraint on welding distortion in three typical thin-plate panel structures was discussed.

2. Inherent deformation obtained by T-E-P FEM

In this study, we adopted two thin-plate flat panel models and an asymmetric curved panel model to study the influence of external restraint on welding deformation. In the two thin-plate flat panel models,
the basic sizes are identical to each other, and only their thicknesses are different. In model A, the thickness of all parts is 5 mm, and that of each part in Model B is 10 mm. The thickness of asymmetric curved panel model (Model C) is also 10 mm. The finite element grids of Model A (or Model B) and Model C are shown in Fig. 1(a) and (b), respectively. The material of each model is Q345 steel. There are two typical joints in each model. One is T-joint between the skin plate and the stiffeners, and the other is cross-shaped joint between the longitudinal stiffeners and transverse stiffeners. Due to space limitation, we only introduce the inherent deformations of the T-Joint obtained by T-E-P FEM. Moreover, the detailed information on T-E-P FEM is also omitted. For each T-joint, we have used two cases to compute the inherent deformation. One case is free (without restraint), and the other case is restrained by jigs. As an example, Fig. 2 shows the finite element mesh, deflection distributions of T-joints with 5 mm thickness calculated by T-E-P FEM. Comparing Fig.2 (b) (without restraint) and Fig.2 (c) (with restraint), we can find that external restraint reduced the out-of-plane deformation to a large extent. The inherent deformations of each T-joint are summarized in Table 1.

**Fig. 1** Finite element models of thin-plate panel and asymmetric curved panel

**Fig. 2** Finite element model and deflection distributions of Model A.

**Table 1** Inherent deformations of T joints

| Joint                | Restraint condition | Tendon Force | Trans. Shrinkage | Angular distortion |
|----------------------|---------------------|--------------|------------------|--------------------|
| T-Joint (5mm)        | Free                | 145 (kN)     | 0.35 mm          | 0.030 (rad)        |
| T-Joint (5mm)        | Restraint           | 151 (kN)     | 0.28 mm          | 0.008 (rad)        |
| T-Joint (10mm)       | Free                | 281 (kN)     | 0.30 mm          | 0.048 (rad)        |
| T-Joint (10mm)       | Restraint           | 292 (kN)     | 0.27 mm          | 0.013 (rad)        |
3. Simulation Cases

In the current study, we used the elastic FEM based on inherent strain theory to simulate welding deformation for the three models as described above. For each model, two cases with different restraint conditions were calculated, so the number of total cases is six. Here, we use model A as an example to define the number of simulation case. For model A, Case A-1 is the case with external restraint, while Case A-2 is the case without restraint. For model B and model C, the method to define the case number is similar. Because the thickness of Model B is identical to that of Model C, the same inherent deformations were used in these two models.

4. Simulation results and discussion

4.1 Influence of external restraint on welding distortion of Model A

4.2 Influence of external restraint on welding distortion of Model B

Fig. 3 shows the contours of out-of-plane displacement and deflection distributions along line 1(defined in Fig.1) of Case A-1 and Case A-2. It is clear that buckling distortion produced in Case A-1 and Case A-2. Fig. 3(c) indicates that buckling mode of Case A-1 is slightly different from that of Case A-2. The comparison between Case A-1 and Case A-2 suggests that the external restraint cannot prevent buckling distortion even though it can reduce angular distortion of T joint as shown in Table 1. Theoretical analysis shows that the longitudinal shrinkage force (or Tendon force) is the main factor controlling buckling distortion, while the angular distortion seems to be insignificant factor. From the viewpoint of preventing buckling distortion, external restraint seems to be ineffective.
plate in Model B is twice as that in Model A, buckling distortion is hard to happen in Both Case B-1 and Case B-2. For such situation, external restraint can mitigate the total deformation.

**Fig. 5** shows the contours of out-of-plane displacement of Case C-1 and Case C-2. It is clear that a very large twisting deformation generated in Case C-1, while the total deformation of Case C-2 is relatively small. **Fig.5(c)** compares the deflection distributions along line 1. The maximum deformation of Case C-1 is about 70 mm, while that of Case C-2 is only several millimeter. This information suggest that external restraint can effectively reduce the twisting distortion.

**Fig. 4** Comparison of welding deformation between Case B-1 and Case B-2. (Model B: flat panel model, thickness=10 mm.)

**Fig. 5** Comparison of welding deformation between Case C-1 and Case C-2. (Model C: curved panel model, thickness=10 mm.)

**5. Conclusions**

Based on the simulation results of three thin-plate low alloy high strength steel models obtained by the elastic FEM, the influences of external restraint on their final deformation were investigated. The following conclusions can be drawn.

1) For the flat panel model with 5 mm thickness, the external restraint cannot effectively prevent buckling deformation, and it just changes the bucking mode.

2) For the flat panel model with 10 mm thickness, the external restraint can reduce the out-of-plane deformation to a certain extent.
3) For the asymmetric curved panel model, the external restraint can effectively mitigate the twisting distortion. This is of great significance to how to control twisting distortion for curved plate welded structures used in ships or trains.

References
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