Prediction of Welding Deformation With Inherent Strain Method Based On FEM

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Abstract

Inherent strain method is an economical and simply method in the prediction of the large structure’s welding deformation. Inherent strains are the residual plastic strains caused in welding process. They exist always in the welds and nearby where structures undergo a large thermal cycle, and are considered as a source causing the welding deformations. The key of using this method is how to know the inherent strains in advance during welding deformation analysis. In this document, the inherent strain is determined according to welding parameters and is first introduced with ANSYS code.

At first, a simple example on the welding deformation of T-joint with two fillet welds is given with different computation methods, and then inherent strain method is applied to the welding deformation analysis of the large complex structure – GM’s Buick’s chassis underframe assembly. Inherent strains of 21 welds used for connecting the four bridges of underframe are determined and the welding deformations are computed with ANSYS. To assure the accuracy of the numerical solution, two kinds of mesh sizes are used in the analysis. Results showed that 15mm near the welds is permitted for the underframe’ welding deformation prediction.

It can be concluded that ANSYS code can be used to the inherent strain method. Inherent strain method is the promising simple method in predicting the welding deformation of large complex structures. Further investigation is suggested for the instruction of practical production.

Introduction

Welding deformation is a common and important problem in industry. In the last decades researchers have made efforts to predict and control welding deformation. There are usually three ways to determine the welding deformation: 1) experiential formulas. 2) Thermal elastic-plastic FEM method. 3) Inherent strain method based on FEM [1, 2].

Experiential formulas are only fit for simple shape structures. Current thermal elastic-plastic method usually simulated either small or simple structures such as butt-jointed plates, or focus on the local weld zones of large structure without considering the surrounding structure. For three-dimension large structure, predicting the welding deformation using this method is almost impossible for the requirements of calculating time and large capacity computer memory. Comparing with the thermal elastic-plastic method, inherent strain method is an economical and simply method in the prediction of the large structure’s welding deformation. It requires only elastic FEM analysis in predicting welding deformation.

In this document, inherent strains method is used to predict the welding deformation of large complex structure – GM’s Buick’s chassis underframe assembly. The analysis method and results can be taken as references not only for the choices of welding sequence, welding parameters and fixture’s location, but also for welding deformation prediction of other car chassis.
**Definition of Inherent Strain**

In welding process the structure undergo a locally high temperature cycle. The thermal expansion of the welds and nearby areas are restricted by the constraint of surrounding metals where the temperature is rather low. The compressive plastic strains in the welds and nearby area will be caused and remained at room temperature after welding. The residual plastic strain, also named inherent strain, is considered as a source causing the welding stressed and deformations.

The longitudinal inherent strain and transverse inherent strain are the main factors determining welding deformation. If we know longitudinal inherent strain and transverse inherent strain of each weld and the position where strains exist and then take the inherent strains as initial strains, the welding deformation can be obtained by elastic FEM analysis.

The total volume $W_x$ of longitudinal inherent strain in unit length and the total volume $W_y$ of transverse inherent strain in unit length are related to heat input $Q$:

\[
W_x = KQ \\
W_y = \xi Q
\]

From thick plates to thin plates, coefficient $K, \xi$ can be introduced as:

\[
K = (0.255 - 0.335)\alpha / c\rho \\
\xi = (0.255 - 1.0)\alpha / c\rho
\]

where, $\alpha$ is the thermal expansion coefficient; $c$ the thermal capacity; $\rho$ the density. It is suggested that $K = 8.6 \times 10^{-7}\text{ cm}^3/\text{J}$ for the deformation analysis of a welded structure made of mild steel and the stiffness of structure is large enough.

Longitudinal inherent strain $\varepsilon^*_x$ and transverse inherent strain $\varepsilon^*_y$ can be defined as:

\[
\varepsilon^*_x = \frac{W_x}{F_i} \\
\varepsilon^*_y = \frac{W_y}{F_i}
\]

$F_i$ is the zone area where $W_x$ and $W_y$ are distributed. For predicting welding deformation, using different area in a certain region is no effect on deformation analysis if the total volume of inherent strains and the location of its center do not change. In general, it is assumed that longitudinal inherent strain and transverse inherent strain were distributed in a rectangular $(2a \times h')$ as shown in Figure 1.

**Figure 1 - Assumed Area of Inherent Strains**
An Example of Realization Inherent Strain Method with ANSYS

Figure 2 is a cross section of T-joint with two fillet welds. The length of the joint is 1500mm, the heat input is 9kJ/cm. $Q$ can be divided into two parts: $Q_1$ applied to flange and $Q_2$ applied to web. Correspondingly, the residual plastic zone also is divided into two parts: $2a \times h' = 30\text{mm} \times 7\text{mm}$ for flange and $a \times h_2 = 15\text{mm} \times 9\text{mm}$ for web. The longitudinal strains of flange and web are 0.00272 and 0.00137 respectively. The transverse strains of the flange and web are 0.00353 and 0.0016. Using the above parameters of inherent strains as the initial strains, the welding deformations of T-joint can be calculated by elastic FEM. The deformation results of the T-joint in $y$ direction is shown as Figure 3. The comparison of the results of ANSYS FEM and simple formulas is listed in Table 1.

![Figure 2 - Cross Section of T-joint (unit: mm)](image1)

![Figure 3 - Welding deformation of T-joint](image2)
Table 1 - The Welding Deformation Of T-Joint

<table>
<thead>
<tr>
<th>Method used in Calculation</th>
<th>longitudinal flexivity f (mm)</th>
<th>Longitudinal shrinkage ∆L (mm)</th>
<th>Transverse shrinkage ∆b (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inherent strain</td>
<td>0.68</td>
<td>0.31</td>
<td>0.058</td>
</tr>
<tr>
<td>Simple formulas</td>
<td>0.65</td>
<td>0.33</td>
<td>0.057</td>
</tr>
</tbody>
</table>

From Table 1, it can be showed that the two results are agree well and ANSYS code can be used in the inherent strain method.

Welding Deformation Prediction of Buick’s Chassis Underframe

Previous investigations have showed that inherent strain method based on FEM can be used for welding deformation prediction of complex structure [3]. In this document, welding deformation of GM’s Buick’s chassis underframe was predicted with ANSYS. The underframe is consisted with four parts, i.e., front bridge, back bridge, left bridge and right bridge. Our purpose is to carry out welding deformation analysis of 21 weld beads, which are used to join the four bridges and denoted with SL1-SL10 and SR1-SR10 (see Figure 4). Four-node shell element is used in the analysis because the whole structure is jointed with thin plate. The total numbers of nodes and elements used in the analysis are 2279 and 2268 respectively. The mesh size near the welds is about 15mm. CO2 arc welding was adopted. The material properties are: Young’s modulus=210GPa, Poisson’s ratio=0.3. For underframe joined with thin plates, K=8.6×10⁻⁷cm³/J, ξ=2.8×10⁻⁶cm³/J is suggested according to equation (3) and (4) as well as relevant experimental curves [4]. The welding heat input can be estimated by crossover area of melted metal:

\[ Q = \theta F_h \]  \hspace{1cm} (7)

Where \( \theta \) is heating coefficient, for CO2 arc welding, \( \theta=37800 \text{J/cm} \), the crossover area of the melted metal is 0.045 cm² or so. So welding heat input \( Q=\theta F_h=1700 \text{J/cm} \);

The total volume of longitudinal residual plastic strains:

\[ W_x = KQ = 0.001462 \text{cm}^2 \]

The total volume of transverse residual plastic strains:

\[ W_y = \xi Q = 0.00476 \text{cm}^2 \]

The longitudinal residual strains and transverse residual strains of 21 welds were determined according to equation (5) - (6) respectively, and then they are taken as initial strains and were used in elastic FEM analysis for welding deformation’s prediction. The analysis results of welding deformation in X-Y plane and in X, Y, Z directions were showed as Figure 5.

For comparison, the variation in distances between of the centers of A, B, C, D four roles in Figure 4 are taken as judges: (the value after welding subtract the value before welding)

\[ \Delta \Delta_{AB} = U_{AX} - U_{BX} \] : the variation of the center distance between the role A and role B in X direction;
\[ \Delta \Delta_{CA} = U_{CY} - U_{AY} \] : the variation of the center distance between the role C and role A in Y direction;
\[ \Delta \Delta_{CD} = U_{CX} - U_{DX} \] : the variation of the center distance between the role C and role D in X direction;
\[ \Delta \Delta_{DB} = U_{DY} - U_{BY} \] : the variation of the center distance between the role D and role B in Y direction;
\[ \Delta \Delta Z \] : the maximum of the center difference of A, B, C, D in Z direction. The deformation results in the analysis (\( \Delta \Delta_{AB} \), \( \Delta \Delta_{CA} \), \( \Delta \Delta_{CD} \), \( \Delta \Delta_{DB} \) and \( \Delta \Delta Z \)) are listed in Table 2.
Figure 4 - Structure of Buick’s Chassis Underframe

- a) Welding deformation in X-Y plane
- b) Welding deformation in X direction
- c) Welding deformation in Y direction
- d) Welding deformation in Z direction

Figure 5 - Welding Deformation of Buick’s Chassis Underframe

- a) Welding deformation in X-Y plane
- b) Welding deformation in X direction
- c) Welding deformation in Y direction
- d) Welding deformation in Z direction
The Effect of Mesh Size on Prediction Precision

Previous investigations showed that mesh size has a significant influence on the accuracy of the solution. The more mesh’s number is, the longer the solution time is. However, too coarse mesh will cause the bigger solution error. To assure the accuracy of the numerical solution, the mesh of Figure 4 is refined as Figure 6, where the mesh size near the weld is about 5mm. The numbers of nodes and elements are 20441 and 20412 respectively. The deformation results in X-Y plane and in X, Y, Z directions are similar to the Figure 5.

For comparison with the results obtained from mesh size 1, the simulation results of mesh size 2 are also listed in Table 2. From Table 2, it can be shown that the calculation error in two cases is no more than 11%. For the welding deformation prediction of underframe, the error is permitted, and so the mesh size 15mm near the welds is enough for this analysis.

Table 2 - Comparison Of Welding Deformation Results

<table>
<thead>
<tr>
<th>deformation (mm)</th>
<th>$\Delta_{AB}$</th>
<th>$\Delta_{BD}$</th>
<th>$\Delta_{CD}$</th>
<th>$\Delta_{AC}$</th>
<th>$\Delta_{Z}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>mesh1</td>
<td>0.30</td>
<td>-0.33</td>
<td>-0.38</td>
<td>-0.26</td>
<td>0.06</td>
</tr>
<tr>
<td>mesh2</td>
<td>0.33</td>
<td>-0.34</td>
<td>-0.41</td>
<td>-0.29</td>
<td>0.065</td>
</tr>
<tr>
<td>error $\delta$</td>
<td>10%</td>
<td>3%</td>
<td>3%</td>
<td>11%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Take an examples with $\Delta_{AB}$, error $\delta = \frac{\Delta_{AB_2} - \Delta_{AB_1}}{\Delta_{AB_1}} \times 100\%$. 

Figure 6 - Underframe Plane of Refine Meshes
**Conclusion**

1. The inherent strain can be introduced with ANSYS code and ANSYS code can be used to predict welding deformation with the inherent strain method.

2. Inherent strain method is also applied to the welding deformation prediction of the large structure – GM’s Buick’s chassis underframe assembly which is make of four bridges with 21 welds.

3. The mesh size 15mm near the welds is enough for underframe’ welding deformation analysis.

4. It can be concluded Inherent strain method is a promising simple method in predicting the welding deformation of large complex structures. Further investigation is suggested for the instruction of practical production.

**References**


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