Research on welding deformation of side beam of freight train bogie

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Abstract. The welding deformation directly affects the production quality and service life of the bogie, so controlling welding deformation is an important engineering problem in the production process of the bogie. In this paper, the side beam of freight train bogie is taken as the research object, the heat source of the local joint mode is checked based on the thermal elastic-plastic theory and the plastic strains are extracted to establish the inherent strain database with the welding simulation software. Then, the welding deformation of the whole side beam is carried out by using the inherent strain method based on thermal elastic-plastic theory. By quantitative analysis of the displacement deformation, the results show that simulation numerical results are similar to factory experimental data. At the same time the rationality and reliability of the established inherent strain database are verified. It is also proved that the inherent strain method based on thermal elastic-plastic theory is a fast and effective way to predict the welding deformation, which provides technical support for the prediction and control of the welding deformation of the whole frame of the fast freight train.

1. Introduction

Welding is commonly used in mechanical processing and it is an extremely important processing method in the manufacturing process of railway vehicle bogie. Because the residual deformation will inevitably occur in the welding process, the residual deformation will directly affect the production quality and service life of the bogie. Therefore, at the present stage of railway development in China, the research on welding deformation of bogie has extremely important practical engineering significance[1].

With the rapid development of computer technology in recent years, numerical simulation of welding deformation has also played a great role in deformation research. A lot of research results have been obtained in welding deformation simulation of locomotive and vehicle. The thermal elastic-plastic finite element method is used to simulate the welding process by recording every moment of the welding process, so as to obtain the results of the temperature field, stress field and strain field at every moment. For example, Sun chuanzheng from southwest jiaotong university simulated the whole welding process of the bogie frame with this method and obtained the welding deformation of the bogie under the actual production conditions[2]. Due to the influence of computer capacity, the application of three-dimensional thermal elastic-plastic finite element method to simulate welding deformation of large components will be limited, but the inherent strain method can solve this problem well. When the size and distribution of the inherent strain are known, it is applied to the action area as
an initial value. The welding deformation of large components can be calculated by elastic calculation. For example, Zhu Ping from Tianjin University used this method to predict the welding deformation of Bogie of Mumbai Metro[3].

In this paper, under the actual production process conditions, a three-dimensional geometric model of the bogie side beam is built and the typical local models are extracted according to the joint form, geometric parameters and process parameters. Then based on thermal elastic-plastic theory, the inherent strain database is established by extracting the local plastic strains on joints. At last, the deformation of the whole model is calculated with the mapped joint database, which provide some references for actual welding of bogie side beam of express freight train.

2. Introduction of Bogie Side Beam Model

2.1 Bogie Side Beam

Bogie is an important load-bearing component of locomotive and vehicle, which plays the role of supporting the body. The welding deformation of side beam directly affects the overall production quality of bogie, so the welding variation of side beam is controlled.

Side beam is composed of upper (16 mm) and lower cover plate (20 mm), web plate (14 mm), spring seat and sleeve. The base material of side beam is Q345A. The geometric model of side beam is shown in Fig.1.

2.2 Local Joint Model

According to the different types of joints, thickness of plates and process parameters, two joints are adopted: double-sided and single-sided welded T-joint, shown in Table 1 and Fig.2.

Table 1. Description of Joints

| No | Type                     | Location                              | Dimension                     | Layers |
|----|--------------------------|---------------------------------------|-------------------------------|--------|
| 1  | double-sided             | the middle of the lower cover plate and the web | 200 mm × 94 mm × 116 mm       | 7      |
| 2  | single-sided             | the middle of the upper cover plate and the web | 200 mm × 80 mm × 120 mm       | 5      |

Figure 1. Side Beam Geometry Model

(a) Double-sided welded T-joint

(b) Single-sided welded T-joint

Figure 2. Finite element model of T-joint

2.3 Welding Scheme

The welding deformation caused by six main welds of side beam between webs and upper, lower cover plates is mainly considered. The distribution of six main welds is shown in Fig.3, and the number of layers per weld is shown in Fig.4. The detailed welding process description is shown in Table 2.
3. Calculation of heat source and plastic strain for Local Model

The accuracy of heat source checking directly affects the accuracy of inherent strain database. The welding parameters of local model heat source checking are shown in Table 3.

Table 3. Welding parameters

| Groove form | Groove angle | Groove depth | Blunt edge | welding method | Welding wire |
|-------------|--------------|--------------|------------|----------------|--------------|
| V-groove    | Slope angle 50 degrees | 14mm | 0.5mm-11mm | gmaw | SM-70(ER50-6)Ø1.2 |
| Protective gas | Weld material | Base material | Thermal convection coefficient | ambient temperature | Interlayer temperature |
| 20%CO2+80%Ar | Q345A | Q345A | 20W/(m²·k) | 20℃ | <100℃ |

Fig.5 and Fig.6 are respectively the strain results of local plastic strain of welded T-joints.

4. Calculation and Result Analysis

4.1 Extraction and Establishment of Inherent Strain
The extraction radius of local plastic strain for each layer of weld can be determined by the range of strain results for each layer of local joint. According to the law of strain distribution, the maximum linear distance which can include the inherent strain region is selected. Inherent strain database is shown in Table 4.

| Weld Sequence Number | Strain direction | XX (X Direction) | YY (Y Direction) | ZZ (Z Direction) |
|----------------------|------------------|------------------|------------------|------------------|
|                      | MIN | MAX | MIN | MAX | MIN | MAX |
| 1-1                  | -0.00666696 | 0.024652 | -0.0425451 | 0.0209707 | -0.0174792 | 0.0447186 |
| 1-2                  | -0.00999595 | 0.0340229 | -0.0593649 | 0.032815 | -0.0277338 | 0.064911 |
| 3-1                  | -0.00790944 | 0.0296367 | -0.0724171 | 0.0217609 | -0.0173627 | 0.0691026 |
| 3-2                  | -0.00832088 | 0.028951 | -0.071391 | 0.0231193 | -0.0189444 | 0.0679748 |
| 3-3                  | -0.00974087 | 0.02933 | -0.0730706 | 0.0234046 | -0.0194767 | 0.0685246 |
| 3-4                  | -0.0130494 | 0.0304866 | -0.0493287 | 0.0221104 | -0.0207003 | 0.0345855 |
| 3-5                  | -0.016489 | 0.0359886 | -0.0332113 | 0.032365 | -0.0249184 | 0.0291924 |
| 4-1                  | -0.0105564 | 0.0340391 | -0.0745641 | 0.0271177 | -0.0220328 | 0.0814115 |
| 4-2                  | -0.0120663 | 0.0255148 | -0.0725146 | 0.011822 | -0.0127627 | 0.0807358 |
| 4-3                  | -0.0108391 | 0.0213225 | -0.043764 | 0.010728 | -0.0106305 | 0.0436322 |
| 4-4                  | -0.0103737 | 0.0207295 | -0.0346696 | 0.0075113 | -0.00752363 | 0.0213824 |
| 4-5                  | -0.0106442 | 0.0213972 | -0.0323672 | 0.0114897 | -0.0142981 | 0.0235924 |

4.2 Analysis of the calculation results
Using the plastic strain database value of each layer of local welded joint as the mapping source, map each layer of weld corresponding to the overall model, and an elastic calculation is carried out.

The central points of the two webs along the X direction of 800mm, 680mm, 480mm, 380mm, 180mm, -180mm, -380mm, -480mm, -680mm, -800mm are selected as the measuring points (as shown in Fig. 7). The comprehensive displacement and other deformations in three directions of the 11points are quantitatively analyzed, as shown in Fig. 8.

![Figure 7. The location of Measuring Points](image)
According to the analysis of the figure, the maximum deformation position of the side beam web in the longitudinal direction (X) is at the position of the slope of the curved surface at both ends, and the maximum value is 0.22 mm. The deformation trend of the vertical (Y) is convex, which means the deformation of both ends is small and the deformation of the middle is large, and the maximum value is 1.16 mm. The maximum deformation position in the transverse direction (Z) is in the middle position, and the maximum deformation amount is 0.49 mm. The comprehensive deformation trend is the same as the vertical deformation, and the maximum deformation is 1.24 mm. The vertical deformation of the side beam web obtained from the factory statistics is about 1.10 mm-1.30 mm, and the longitudinal and lateral deformations are very small. The experimental data are similar to the calculated simulation values.

5. Conclusion

Based on thermal elastic-plastic theory, the heat source of the local joint is checked and the plastic strain is extracted to establish the inherent strain database. Then using the inherent strain method, the elastic deformation of the whole model is calculated. The results of welding deformation are compared with the statistical data of the factory. It is found that the simulation results are similar to the statistical data and the error is within a reasonable range. The following conclusions can be given:

(1) Reasonable checking of heat source for local joints of side beams. The 5 layers of welds (21607 elements) for single-side welded T-joints need 8 hours for thermal elastic-plastic calculation. And the 7 layers of welds (27504 elements) for double-side welded T-joints need 12 hours for calculation. But it only takes 20 minutes to calculate the elastic deformation for the 24 layers of welds (718501 elements) of the overall side beam model. So it can be seen that the inherent strain method based on thermal elastic-plastic theory is an economical and applicable method, which can be used to calculate the welding deformation of large structures.

(2) According to the analysis of welding deformation data, the vertical deformation of the side beam is the largest and the deformation trend is convex. The maximum deformation is 1.16 mm, and the error between simulation and experiment is 5.45% - 10.76%.

(3) The rationality and validity of the inherent strain database established by extracting three main directions of plastic strain are verified by comparing simulation results with experiments.

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