Finite element analysis of stress and distortion for welding reinforced structure of angular steel used for power tower under load

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Abstract. Based on thermal-elastic-plastic theory, a three-dimensional numerical model of residual stress and distortion in L-shaped welding reinforced structure of angle steel used for power transmission tower is developed. The characteristics of residual stress distribution and deformation are numerically investigated, which are compared with the stress and deformation under the action of lateral compressive load. The research results show that, a large stress is generated in and near the weld zone. With enhancing the weld bead length, both equivalent stress and residual distortion have a growth, and the equivalent stress peak reaches 329Mpa, slightly lower than the yield stress of base metal, meanwhile the longitudinal residual stress peak is 399Mpa, higher than the yield stress of base metal. Under the action of 15000Pa lateral compressive load, the stress has no obvious change in the near weld zone of reinforce structure compared with that without load, and the distortion peak reaches 11mm.

1. Introduction

With more and more power transmission tower reach their service life, the angle steel used for this tower require be reinforced so as to improve the safety performance, and welding technology is wildly used to reinforce the power transmission tower. Welding structures, welding stress and distortion are closely related to the quality of welded joint and their overall components, so it is of great academic and engineering application value to study the stress and distortion in welding reinforced structure of angle steel used for power transmission tower.

As for welding stress, the experimental method is mainly used to detect the stress at the specific position on the surface of welding parts, but it is difficult to measure the residual stress distribution in the whole three-dimensional. In order to make up for its deficiency, numerical simulation technology has been widely used to study the distribution characteristics of stress and distortion of welded components [1]. At present, researchers have carried out a large number of experiments [2,3] and numerical simulation [4] on welding reinforced structure of angle steel. In this paper, a suitable three-dimensional numerical analysis model of L-shaped welding reinforced structure of angle steel used for power
transmission tower is established to study the residual stress and distortion of welding reinforced structure and it's bearing capacity under the load condition.

2. Finite Element Modelling

In this paper, based on thermal-elastic-plastic theory, a three-dimensional numerical model of residual stress and distortion in welding reinforced structure of angle steel used for power transmission tower is developed, and the thermo-mechanical behavior of the weldment during is simulated using a sequentially coupled formulation. First, the temperature distribution and its history in the welding model is computed, and then the temperature history is employed as a thermal load in the subsequent mechanical elastic plastic calculation of the residual stress field [5]. In order to simplify the model and reduce the calculation time, in the process of thermal field analysis, the fluid flow in the molten pool is not considered, that is, only the solid heat conduction equation is used to calculate the welding temperature field. The influence of the liquid metal in the molten pool on the thermal field was indirectly considered by appropriately improving the thermal conductivity of materials.

2.1. The heat source

When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper. Due to the large size of the reinforced structure and a number of the welds, A homogeneous piecewise heat source is used to characterize the welding heat input, which assumes that welding heat is uniformly distributed in a certain heating volume, and the heat flux distribution function is shown as follows:

\[ q = \frac{\eta U I}{V} \]  

(1)

Where \( \eta \) is the thermal efficiency; \( U \) is the welding voltage; \( I \) is the welding current; \( V \) is the volume of the heat source; These parameters are set according to the weld length and the cross-sectional area.

2.2. Model and mesh

The original angle steel is L80×7mm, and the material is Q345. The reinforced angle steel is L100×8mm, and the material is Q345 too. The whole length of the structure is 3000 mm, including 2000mm for the reinforced part and 1000mm for the non-reinforced part. The specific grid of the model is shown in the Fig.1. To reduce the computing time in the case of enough numerical precision, an un-uniform mesh is employed in the calculation. A finer mesh is designed at the weld and its vicinity and a coarse mesh is applied at the region far away from the weld bead. in the mechanical simulation, the elastic stress-strain relationship of welded material is assumed to obey the isotropic Hooke’s law with temperature-dependent Young’s modulus. Thermal strain is taken into account through thermal expansion coefficient. Regarding the plastic behavior, a rate independent plastic model is applied. The yielding behavior of the welded material satisfies the von Mises principle, and a bi-linear hardening law is employed to simulate the strain hardening. Besides, similar to the thermal analysis, the temperature-dependent mechanical properties of materials are used in the mechanical model.
3. Results and discussion

3.1. Analysis of stress

Fig. 2 and Fig. 3 present the contour of residual stress distribution. From Fig. 2, it can be seen that the high residual stress is mainly generated in and near the weld zone, and the residual stress decreases rapidly in the area far away from the weld. The longitudinal stress peak of L-shaped welding reinforced structure is 399 MPa, slightly higher than the yield stress of base metal, and the equivalent stress peak reaches 329 MPa, slightly lower than the yield stress of base metal. Fig. 3 shows the distortion distribution of angle steel reinforced and unreinforced under the lateral compressive load. It is indicated that the residual stress peak is 359 MPa under the action of 15000Pa lateral compressive load, which is similar to that of without load.

3.2. Analysis of distortion
Fig. 4 gives the distortion distribution of L-shaped welding reinforced structure. It can be found that the deformations of the structure is zero on the restraint side, and the displacement increase gradually from the fixed end to the free end. The maximum welding residual distortion of the L-shaped reinforcement is 5.3mm. Under the lateral loading of 15000Pa, the maximum deformation of the reinforcement becomes 11mm, only having an increase of about 6 mm. This indicates that welding reinforcement is an effective way to increase the strength and stiffness of angular steel structure.

Besides, the above analysis also shows that simulated results can describe the distribution of stress and distortion of L-shaped welding reinforced structure reasonably, validating the effectiveness of the proposed model.

4. Conclusions
(1) A 3-D finite element model is developed to investigate the residual stress and distortion of L-shaped welding reinforced structure, in which an efficient heat source was used and improve the computational efficiency.

(2) The region of the high tensile stress constantly appears in the weld zone and its vicinity, and the peak of stress will decrease with the increase of the distance away from the weld area. Under the action of 15000Pa lateral compressive load, the peak and distribution of the stress are similar to that without load. Meanwhile, the distortion peak increases by about 6 mm.

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