

## Short communication

### Numerical analysis of welding heat source temperature field

**Abstract:** This article studies the numerical simulation analysis of the temperature field of welding heat sources. During the welding process, the rapid input of local heat and subsequent rapid cooling can cause permanent plastic deformation of the weld seam and its surrounding area, resulting in residual stress and deformation. In order to accurately grasp the variation law of the welding temperature field, this article uses ANSYS software for numerical simulation, and uses birth and death element technology and volume heating rate to simulate the welding temperature field. In the simulation, convection and heat conduction are mainly considered, and the heat source is simulated by applying the heat generation rate at the nodes of the welded components. Taking Q235 thick plate T-joint as the research object, a double-sided weld model is established, and thermal analysis is carried out using ANSYS software. The results indicate that during the welding process, the temperature at the weld seam rises sharply and then diffuses to the surrounding area, forming a trend of diffusion from the centerline of the weld seam to the surrounding area. After a period of welding, due to the influence of welding sequence, the welded part will form a quasi steady state temperature field with a steeper temperature gradient behind the heat source.

**Keywords:** Welding heat source; Temperature field; Numerical simulation; ANSYS; Finite element analysis

#### 1. Introduction

Welding is a complex physical and chemical process. In industry, the distortion, residual stress and tensile strength of weld and heat affected zone are directly related to the thermal cycle of welding heat melting process, which makes the simulation of welding temperature field become a hot topic for welding workers at home and abroad.

In the process of welding, a large amount of heat is input in a short time, which leads to uneven heat transfer and heat dissipation. The temperature in some parts of the workpiece rises rapidly, resulting in different thermal expansion and strain and deformation, resulting in serious residual stress and welding deformation after the assembly of a large number of welded components<sup>[1]</sup>, which leads to the reduction of the ultimate bearing capacity of the component and the fatigue strength of the structure. Therefore, it is extremely important to accurately grasp the numerical simulation and variation law of the welding temperature field to ensure the welding quality<sup>[2]</sup>.

In the welding process, due to the short-term application of a large amount of local heat and subsequent rapid cooling, permanent plastic deformation occurs in the weld and its surrounding areas,

resulting in residual stress and distortion, and additional time is required to correct the deformation during the structural assembly process<sup>[3]</sup>. From the 1960s to the 1970s, finite difference method ( FDM ) and finite element method ( FEM ) were successively introduced into welding numerical calculation, and two new methods were used to solve various complex problems of welding. At present, a lot of research has been carried out on the numerical simulation of welding process at home and abroad. In recent years, many scholars have carried out a large number of numerical simulation studies on welded components. Ronda et al. calculated and analyzed the temperature field change law of multi-pass butt welding of thick plates with TMM model<sup>[4]</sup>. Wang Jianhua et al. of Shanghai Jiao Tong University and Osaka University of Japan jointly studied the three-dimensional welding temperature field and explored its characteristics and methods to improve the accuracy<sup>[5-7]</sup>.

In order to further understand the change law of temperature field in the welding process, ANSYS software is used to simulate the welding process of the connecting weld. In this paper, the welding temperature field is simulated by the birth and death unit and the body heat generation rate.

## 2. Basic finite element theory of welding temperature field

During welding, the heat source heats the local part of the weldment with a very high energy density, so that the temperature in the region rises rapidly, and then as the heat source moves away, the weldment cools rapidly. This process of heating and cooling is not a simple linear change, but involves complex heat transfer, material properties and dynamic evolution of temperature field with time. It belongs to a typical nonlinear transient heat conduction problem. The governing equation of thermal analysis is :

$$\frac{\partial}{\partial x} \left( \lambda_{xx} \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( \lambda_{yy} \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( \lambda_{zz} \frac{\partial T}{\partial z} \right) + q = \rho c \frac{dT}{dt}$$

$$\frac{dT}{dt} = \frac{\partial V}{\partial t} + V_x \frac{\partial T}{\partial x} + V_y \frac{\partial T}{\partial y} + V_z \frac{\partial T}{\partial z}$$

In the formula : material density ; c is the specific heat capacity of the material ; t is the temperature field distribution function ; t is time ; the thermal conductivity of the material ; q is the intensity of internal heat source ;  $\lambda_{xx}, \lambda_{yy}, \lambda_{zz}$  change with the change of temperature.

In the actual simulation process, there are three main boundary conditions commonly used for welding heat conduction analysis: the initial temperature of the known component, the heat flux density distribution on the boundary of the known component during the welding process, and the heat exchange between the known component and surrounding objects.

In the analysis process, the focus is on two factors: convection and heat conduction. As for heat radiation, the appropriate approach is to increase the convection coefficient and heat conduction coefficient to roughly simulate the effects of radiation. The simulation work for welding heat sources is achieved by

applying heat generation rates at the corresponding unit nodes of the weld seam.

### 3. Finite element model of structure

The establishment of geometric model is an important step in the process of numerical analysis. The quality of the model is not only reflected in the speed of calculation, but also affects the results of calculation. Taking the T-joint of Q235 thick plate as the research object, the double-sided welding seam model is established. It is assumed that the physical performance parameters of wood and welding material are the same. As shown in Fig.1, the two thick plates are both 20mm. In order to improve the calculation efficiency and accuracy, the mesh size is 5mm, and the mesh is adaptively divided. The thermal analysis function of the large general finite element software ANSYS is used to simulate the welding process. Thermal analysis of the structure is performed using the Solid70 unit.

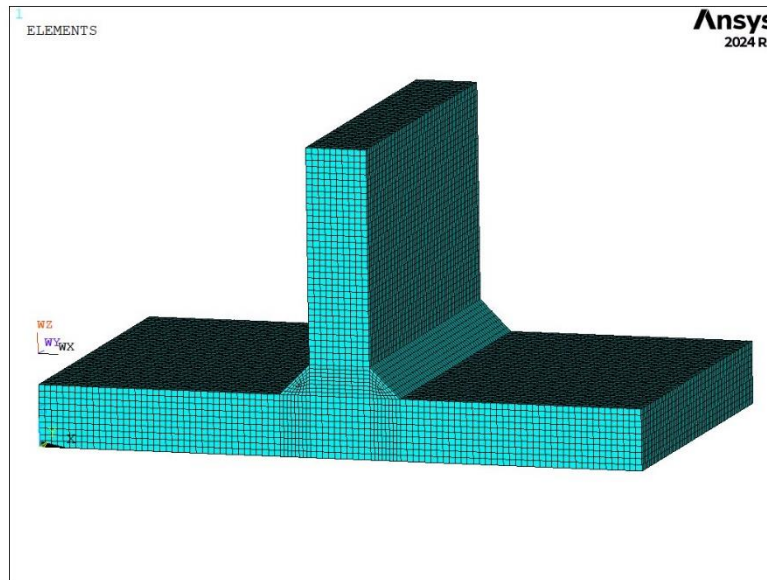


Fig. 1. T-shaped finite element model

During the implementation of welding operations, precise control of the entire welding process is achieved through the loop control function of APDL language. At the same time, according to relevant professional standards, carefully review the data and accurately input the corresponding key parameters of the welding heat source, which cover multiple aspects such as welding voltage, welding current, welding heat power, and welding speed. The detailed welding heat source parameters are listed in Table 1

Table 1 Heat source parameter table

| weld seam | fillet weld | voltage | electric current | speed | Welding thermal efficiency |
|-----------|-------------|---------|------------------|-------|----------------------------|
|-----------|-------------|---------|------------------|-------|----------------------------|

Using the birth and death element technology to simulate the welding heat input process by simulating the weld filling method, the temperature load is applied in the form of heat generation rate. The calculation formula for heat generation rate is shown as follows:

$$HGEN = Q/(A_{weld} \times v) = \eta UI/(A_{weld} \times v)$$

In this simulation process, the birth death unit technique was used to carry out relevant operations. In the initial calculation stage, all units within the weld seam are first set to a "dead" state. As the calculation progresses, these units are gradually activated in a predetermined order to accurately simulate the filling process of weld metal. Among them, each time step is set to 1 second, and the first weld seam undergoes a total of 12 time steps in the heating process, completing the welding process smoothly in 12 seconds. After the first weld seam cools to a specific temperature, the welding process for the second weld seam is immediately started, which also takes 12 seconds to complete the welding operation. Finally, the welded component enters the comprehensive cooling stage. Until the welding is completely completed, the welded component is cooled to the preset temperature, and the resulting temperature stress cloud map is shown in Figure 2. As can be clearly seen from the figure, the difference between the highest and lowest temperatures is controlled within 2°C, which fully indicates that the weldment has been sufficiently cooled and fully meets the requirements for subsequent analysis.

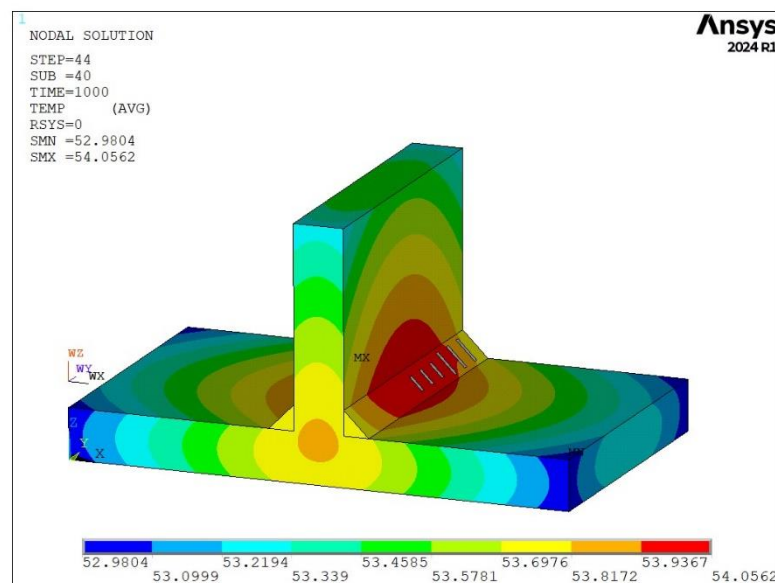


Fig. 2. Finite element model analysis results

## 4. Discussion and analysis

During the continuous progress of welding, the temperature field in which the weldment is located is in a dynamically changing state and will continue to change over time. Due to the constant movement of the welding heat source, there is a close and highly correlated temperature field and time in various parts of the welded component. In order to accurately and intuitively grasp this changing trend, we can observe the evolution of the temperature field of the welded joint over time in detail by selecting the method of generating temperature time curves.

The previous presentation was the temperature field condition of the welded component at the moment of welding completion. If we want to clearly show the dynamic changes in temperature at different positions around the weld seam in the time dimension, we selected nodes at 1/2 section of the template weldment to further explore the temperature changes around the weld seam. Correspondingly, we obtained the temperature variation curves of each point in Figure 3 over time (see Figure 3). Upon careful observation of Figure 3, it can be observed that the temperature evolution at each monitoring point exhibits significant non-uniformity throughout the entire welding thermal cycle. For measuring points located inside the weld seam, once the welding heat source moves above that point, its temperature will rise at an extremely fast rate, and when the heat source moves away, the temperature will quickly fall back and then stabilize. When the second weld seam is welded, the temperature at the measuring point rises rapidly again and gradually cools down to room temperature. Moreover, the higher the peak temperature of the measuring point, the more significant the degree of temperature change. On the other hand, at locations relatively far from the heat source, when the heat source acts on the section, the temperature peak is significantly lower, and the entire temperature change process is relatively smooth, without the sharp rise and fall like the measuring points inside the weld seam.

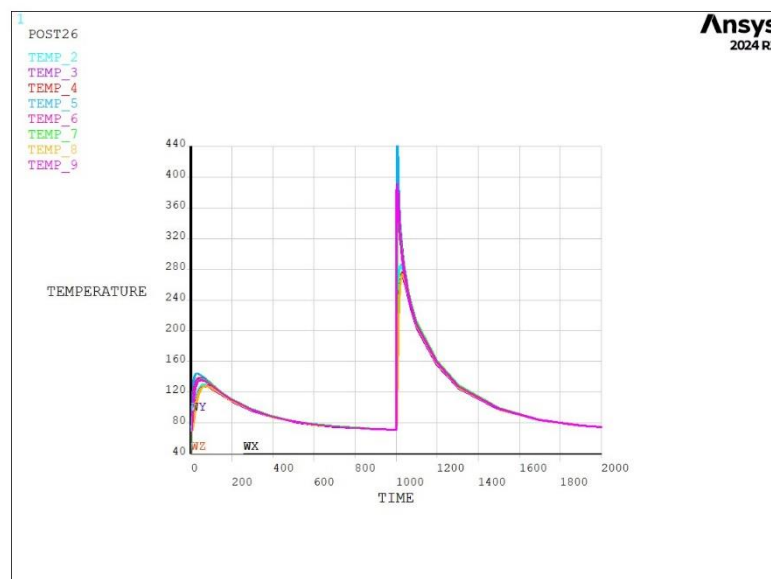


Fig.3. Temperature Time Curve during Welding Process

## 5. Conclusion

- 1、 When the welding is carried out, the temperature at the weld seam rises sharply, and then passes to the surrounding area, forming a trend of diffusion from the weld center line to the surrounding area.
- 2、 During the welding process, due to the influence of the welding sequence, a quasi-steady-state temperature field with a steeper temperature gradient behind the heat source than in front will be formed on the weldment.
- 3、 The welding process of the structure is simulated by ANSYS, and the welding is realized by APDL cycle, which can simulate the welding process more accurately.

## References

- [1] Cui Chuang, Bu Yizhi, Li Jun, et al. Distribution characteristics of welding residual stress between steel box girder panel and U-rib [ J ]. Journal of Southwest Jiaotong University, 2018, 53 ( 02 ) : 260-265.
- [2] Zhao Qiu, Wu Chong. Numerical simulation analysis of welding residual stress of U-rib stiffened plate [ J ]. Engineering Mechanics, 2012, 29 ( 08 ) : 262-268.
- [3] Numerical simulation of multi-layer and multi-pass welding of Q420 steel plate butt joint [ J ]. Metal processing ( hot processing ), 2024, ( 09 ) : 25-31 + 35.
- [4] Deng D. FEM prediction of welding residual stress and distortion in carbon steel considering phase transformation effects [J]. Materials and Design, 2009, 30(2): 359—366.
- [5] Ronda J. Oliver G J. Consistent Thermo-Mechano-Metallurgical Model of Welded steel with Unified Approach to Derivation of Phase Evolution Laws and Transformation-Induced Plasticity [J]. Computer Methods in Applied Mechanics and Engineering, 2000, 189(2):361-417
- [6] Wang J. et al. An FEM Model of Buckling Distortion During Welding of Thin plate [J]. Journal of Shanghai Jiao tong University, 1999.E-4(2):69-72
- [7] Wang Jianhua. et al. Improvement in Numerical Accuracy and Stability of 3-D FEM Analysis in Welding[J]. Welding Journal, 1996, 75(4):129-134