Influence of Mesh Size on Welding Deformation and Residual Stress of Lap Joints

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Abstract. To explore the influence of mesh size on the accuracy of welding simulation, the weld seam and heat affected zone are treated with different mesh sizes. The finite element models are established to obtain the welding deformation and residual stress distribution of the lap joint. The results are verified by the test. The results show that, from the trend of deformation and residual stress distribution, results from different weld mesh sizes coincide with the distribution trend of test results, which proves the validity of the finite element models. Welding deformation of the starting arc position is less than that of the ending arc welding position, and the maximum deformation position occurs on the free side along the longitudinal end of weld seam. The change of mesh size has a certain effect on the residual stress distribution. By comparing with the test results, the errors of mesh size of 0.5mm, 1mm, 2mm and 3mm are 2.4%, 5.1%, 16.6% and 12% respectively. The research results have important guiding significance for the pre-processing of welding simulation.

1. Introduction
With the continuous development and maturity of welding simulation technology, engineering application puts forward higher requirements for high precision and high efficiency calculation. The freedom degree of the finite element model is directly related to the computational efficiency, and the discretization of the geometry is closely related to the accuracy of the calculation. Mesh size is a key factor in the computation. At present, grid partitioning technology is mainly divided into static mesh generation and dynamic mesh generation that are preset cell filling and adaptive grid technology. The grid adaptive technology takes much time for grid conversion in large model calculation. Although it can improve the calculation precision, in the process of optimizing the process, the period is long. The preposition unit is filled. It is necessary to analyze the grid size. The reasonable mesh size helps to promote the efficiency and the accuracy of calculation. The mesh size calculation of joint is the basis of engineering structural research.

At present, many experts and scholars have done many researches on mesh generation technology to effectively improve the accuracy and efficiency of calculation. On the dual ellipsoid power density distribution body heat source model, Wang W. et al. [1] established the finite element model of the butt joint. The numerical integration calculation was used to analyze and compare the difference between the theoretical heat input and the actual heat input under different mesh sizes. The suitable mesh
size was proposed. Wang J. C. et al. [2] studied the method to improve the accuracy of calculation. Reasonable mesh size could effectively improve the accuracy and efficiency of calculation. Zhang S. R. et al. [3] studied the influence of grid size on the numerical simulation accuracy of underwater explosion shock wave propagation. Therefore, how to get reasonable mesh size for static mesh generation is very important to the accuracy and efficiency of calculation.

In this research, based on the theory of thermo elastic plasticity, the welding deformation and residual stress results are obtained by different mesh treatment on the weld seam and heat affected zone of the lap joint, and the results are compared with the test results.

2. Methodology

2.1. The relationship of stress and strain [4].

The stress-strain relationship of materials in elastic or plastic state is as in equation (1).

$$\{d\sigma\} = [D]\{d\varepsilon\} - \{C\}dT$$

(1)

In the formula: $[D]$ is elastic or elastic plastic matrix; $\{C\}$ is temperature dependent vector.

In the elastic zone, the stress-strain relation is as in equation (2), (3).

$$[D] = [D]_e$$

(2)

$$\{C\} = \{C\}_e = [D]_e \left( \{\alpha\} + \frac{\partial[D]^{-1}}{\partial T} \{\sigma\} \right)$$

(3)

In the formula: $\alpha$ is the coefficient of linear expansion; $T$ is temperature.

In the plastic zone, the yield conditions of the material are as in equation (4).

$$f(\sigma) = f_0(\varepsilon_p, T)$$

(4)

In the formula: $f$ is yield function; $f_0$ is a function of yield stress related to temperature and plastic strain.

2.2. Equilibrium equations [4].

For a unit of the structure, there is the following equilibrium equation as in equation (5).

$$\{dF\}^e + \{dR\}^e = [K]^e \{d\delta\}^e$$

(5)

In the formula: $\{dF\}^e$ is the increment of element node; $\{dR\}^e$ is the increment of the initial strain of the element equivalent to the node caused by the temperature; $\{d\delta\}^e$ is the increment of displacement for the node; $[K]^e$ is the element stiffness matrix.

As the unit in the elastic or plastic zone, $[D]_e$ and $\{C\}_e$ are used to replace the $[D]$ and $\{C\}$. The element stiffness matrix and the equivalent node load are formed. Then the total stiffness matrix $[K]$ and the total load vector $\{dF\}$ are integrated, and the equilibrium equations of the whole component are obtained as in equation (6).

$$[K][d\delta] = \{dF\}$$

(6)

In the formula: $[K] = \sum [K]^e$; $\{dF\} = \sum \left( \{dF\}^e + \{dR\}^e \right)$

Considering that welding process generally has no external force, the corresponding node force around each node is a self-balancing force system.
When \( \sum \{dF\}^e = 0 \), \( \{dF\} = \sum \{dR\}^e \).

2.3. Welding process parameters and detection methods.
The size of the lap joint is 200mm x 150mm x 10mm and 200mm x 200mm x 10mm, and the plate material is Q345 steel. The welding method uses CO2 gas protection welding, and the wire is ER50-6 \( \Phi 1.2 \). It uses single channel welding, and the speed is 40mm/s.

Three coordinates are used to measure the deformation, and the position of the larger deformation is selected as the measuring point. Therefore, the two free boundary of the lap joint floor is taken as the measuring position. The 9 points between the 25mm distance of the starting and ending arc are selected in the direction of the longitudinal weld seam.

The HK21A type residual stress tester is used to measure the stress. The measuring position is close to welding toe. The device can distinguish two holes with 30mm, so the measuring point is chosen at the 50mm distance from the starting and ending arc position, as shown in Figure 1.

![Figure 1. The residual stress measurement of the lap joint](image)

3. The establishment of finite element model for the lap joint

3.1. The establishment of material parameters.
With the literature [5], the relevant parameters of Q345 for simulated materials are obtained, as shown in Figure 2.

![Figure 2. The relationship between thermal-mechanical parameters and temperature in Q345](image)

3.2. The heat source model.
The most reasonable heat source model of carbon dioxide gas shielded arc welding is considered to be the double ellipsoid heat source model. The specific heat source distribution of the model is as in equation (7), (8).
3.3. The establishment of grid model and mechanical boundary.

To effectively reduce the freedom degree, the transition model is applied to the lap joint model. The mesh is encrypted at the weld seam and welding height. The weld height is 6mm. Mesh size of weld seam is treated as follows: The number of elements at the welding height is 2, that is, unit size of weld seam is 3mm. The total number is 12673, and the number of nodes is 13788. The number at the welding height is 3, that is, element size is 2mm. The total number is 12840, and the number of nodes is 15037. The number at the welding height is 6, that is, element size is 1mm. The total number is 57784, and the number of nodes is 63115. The number at the welding height is 12, that is, element size is 0.5mm. The total number is 394868, and the number of nodes is 426805. The finite element model is established respectively, as shown in Figure 3.

\[
q(x, y, z,t) = \frac{6\sqrt{3}\beta f_o Q}{a b c \pi \sqrt{\pi}} e^{-3x^2/\alpha} e^{-3y^2/\beta} e^{-3z^2/\gamma}
\]

\[
q(x, y, z,t) = \frac{6\sqrt{3}\beta f_o Q}{a_2 b c \pi \sqrt{\pi}} e^{-3x^2/\alpha} e^{-3y^2/\beta} e^{-3z^2/\gamma}
\]

4. Result analysis and discussion

4.1. Effect of mesh size on welding deformation.

Under the same mechanical boundary condition and thermal loading mode, the effect of mesh size on the welding deformation of lap joints is predicted by calculation. To analyze the influence of mesh size on welding deformation, the free boundary deformation of the bottom plate in Z direction is compared with simulation and experimental measurement.

Welding deformation of the Z direction between points AB and CD of the bottom plate is compared with the measured results. The comparison curves of 0.5mm, 1mm, 2mm and 3mm and the measured results are obtained, as shown in Figure 4.
From Figure 4(a), it is known that the deformation trend of different mesh sizes coincides with the measured results, and the deformation of point A is less than that of point B. The maximum deformation occurs on the free side of the longitudinal ending arc. It is obvious that the results of mesh size 0.5mm and 3mm are closer to the simulation results, which effectively verifies the correctness of the deformation prediction results. Through measurement, the range of deformation along the AB direction is 1.23mm–1.5mm. The mesh size is 0.5mm, and the range of deformation along AB direction is 1.3mm–1.48mm. The maximum error of simulation result and test result is 2.9%. The mesh size is 1mm, and the range of deformation is 1.45mm–1.74mm. The maximum error is 14.8%. The weld mesh size is 2mm, and deformation is 0.94mm–1.15mm. The maximum error is 29.3%. The mesh size is 3mm, and the range of deformation is 1.35mm–1.56mm. The maximum error is 3%. From the trend of deformation, deformation along the BA direction is gradually increased. The starting arc position is located at the point of A. As the starting arc position is first welded, the point B of the ending arc position is affected by the contraction of the position, which makes the gap of the ending arc increase. The welding deformation trend fluctuates with different mesh sizes.

From Figure 4(b), the welding deformation trend of different mesh sizes coincides with the measured results, and the deformation of point C is less than that of point D. The maximum deformation occurs on the free side of the longitudinal ending arc. It can be clearly seen that the mesh size is 0.5mm, and the result is closer to the simulation results, which effectively verifies the correctness of the prediction results. Through measurement, the range of deformation along the CD direction is 0.42mm–0.9mm. The mesh size is 0.5mm, and the range of deformation along CD direction is 0.46mm–0.93mm. The maximum error of simulation result and test result is 9.5%. The mesh size is 1mm, and the range of deformation is 0.34mm–0.85mm. The maximum error is 19%. The mesh size is 2mm, and the range of deformation is 0.49mm–1.05mm. The maximum error is 21.3%. The mesh size is 3mm, the range of deformation is 0.34mm–0.84mm, and the maximum error is 19%, and the maximum error of the simulation result and the test result is 9.1% in the removal of the starting arc point. From the deformation trend, the welding deformation trend has a certain fluctuation.

4.2. Effect of mesh size on residual stress.
The residual stress distribution of the lap joints with different mesh sizes is obtained by simulation, and the simulation results of different mesh sizes are compared, as shown in Figure 5.

From Figure 5, the change of mesh size has a certain effect on the residual stress distribution. When mesh size is 0.5mm and 1mm, the residual stress distribution is fluctuated in the range of 150mm–200mm from the starting arc, and the distribution trend is the same in the range of 0mm–150mm. The distribution trend is gradually decreasing in the position of stress wave peak. When mesh size is 0.5mm, the peak value appears at the 199mm position from the starting arc, and the value is 356.6MPa. When mesh size is 1mm, the peak value of residual stress appears at the location of the starting arc, and the value is 307.4MPa. When mesh size is 2mm and 3mm, the residual stress...
distribution fluctuates in the range of 30mm~150mm from the starting arc, and the distribution trend is the same. When mesh size is 2mm, the peak value of residual stress appears at the 82mm position from the starting arc, and the value is 314.3MPa. When mesh size is 3mm, the peak value of residual stress appears at the location of 65.7mm, the value is 313.7MPa. By comparing with the test results, the errors of mesh size of 0.5mm, 1mm, 2mm and 3mm are 2.4%, 5.1%, 16.6% and 12% respectively.

To sum up, mesh size affects the deformation and residual stress distribution of lap joints. Considering the accuracy of calculation, the smaller mesh size is, the smaller the error is. The mesh size can be selected by 3mm without considering the residual stress distribution and not focusing on the position of the starting arc. The simulation results are in good agreement with the calculated results. In the case of residual stress distribution, 1mm is recommended for mesh size. Without considering the computational efficiency, the smaller mesh size is, the better the accuracy is.

![Figure 5. Comparison residual stress of the lap joints](image)

5. Conclusions
In this paper, the finite element models of lap joints in different mesh sizes of 0.5mm, 1mm, 2mm and 3mm, respectively, are established. The results of deformation and stress are analyzed, and the deformation and residual stress of the lap joints are measured and compared. The following conclusions are drawn. The mesh size affects the deformation and residual stress distribution of lap joints. Considering the accuracy of calculation, the smaller mesh size is, the smaller the error is. In this study, the measurement points of residual stress are less, and at the same time, the establishment of mesh size model is less, so it is necessary to further compare and analyze in the next step.

Acknowledgments
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