Numerical Simulation of Welding Deformation and Flame Straightening of Ear Plate Structure

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Abstract: In this thesis, the simulation model of welding and flame straightening process based on the Thermal elastic-plastic method is developed by taking the ear plate structure as object of study. The primary and secondary relations of straightening effect influenced by heating temperature, heating width and heating time are analyzed through DOE procedure. The results show that: The parameters of flame straightening are dependent on each other, and the heating width has the greatest influence on deformation straightening; When the heating temperature is 750℃, the heating time is 20±2 s and the heating width is 30 mm, the distance between two ear plates is 130.5 mm, which satisfies the design requirement reasonably.

1 INTRODUCTION

Due to the advantages of simple production process, short manufacturing cycle and high flexibility of structure design, welding has become found amental processing method of complex construction. Nevertheless, welding residual strain resulting from uneven temperature field should not be ignored on account of the extremely complex special characteristics of high temperature, dynamicity and transience in welding process. Hence deformation straightening process should be added after welding procedure so as to avoid structural geometrical imperfection and instability of product quality caused by welding deformation[1,2].

As a distortion rectification method used widely at home and abroad, flame straightening is utilized to rectify the welding deformation through heating plate locally based on the thermal expansion theory of metallic materials using a simple equipment, which is suitable to the straightening of large welding products typically. However, the straightening effect is affected by the operator's experience including various factors such as heating temperature, heating time, heating area and heating position, which increase the uncertainty of the straightening effect. The process of flame straightening has been studied in detail by a lot of researchers[3,4]. Zhang Yujuananalyzed the microstructure and mechanical properties of S355J2 structure steel after the correction process[5]. Zhu Zhaohua expounded the factors to be taken into consideration in flame straightening and welding deformation[6]. ZengXiaopeng discussed the usage of inherent strain method in simulation of flame correction[7]. K B Jayananalyzed the flame straightening process of Corrosion Resistant Structural Steel. Based on the experimental results, the study revealed the consequences of flame straightening on microstructure and mechanical properties of the work material influenced by oxy acetylene pressure, torch nozzle diameter and the holding time[8]. Zhao Dongsheng proposed a formula for selection of gas flow based on ‘straightening energy input = welding energy input’, which was verified reasonable by test results[9]. Juan Blandon compared three different gas heating methods commonly employed in actual practice and judged which was more efficient in terms of correcting welding distortion while reducing energy and time consumption[10].

In this paper, welding deformation and flame straightening process of ear plate are simulated in FE software and DOE method is provided to analyze the main factor of straightening effect in order to supply effective guidance to the actual flame straightening operation of ear plate structure.

2 PHYSICAL MODEL OF EAR PLATE STRUCTURE

The overall geometrical model of the ear plate structure is shown in Fig1, including base plate, beam and two ear plates. The material of plates is Q345 and the fillet joint is achieved in carbon dioxide gas shielded welding with the Fronius TPS5000 welding power. There is no welding groove on the plate and the surface of specimen would be cleaned before welding. The welding process parameters are shown in Tab 1. The gap D between two ear plates shall not meet the assembly requirements of 131mm after welding, and the welding deformation of the first ear plate should be rectified by means of flame straightening.

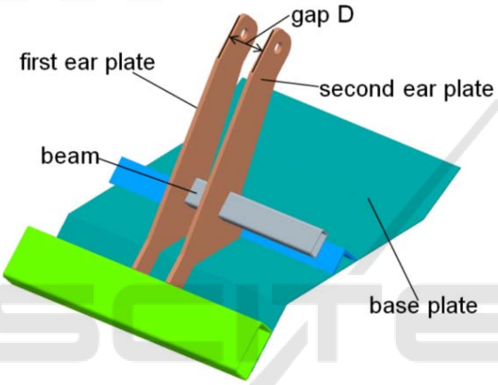

Fig1:Geometrical model of ear plate.

Tab1:Welding process parameters.

name	I /A	U/V	v/(mm·s^{-1})
value	260~280	26~28	6

3 WELDING SIMULATION MODEL OF EAR PLATE

3.1 Generation of Grid Model

The geometrical model of ear plate is partitioned into solid grid model. The base mental is divided into 2~3 layers in order to ensure the accuracy of calculation and the size of grid around weld and HAZ is set as 2mm so as to improve the calculation speed, while the size of grid remote from the welding zone is 6mm. Two element transitions are adopted in the width direction among the above-mentioned regions to ensure the accuracy of calculation and reduce the number of elements. As shown in Fig2, the element number of ear plate grid model is 144956.

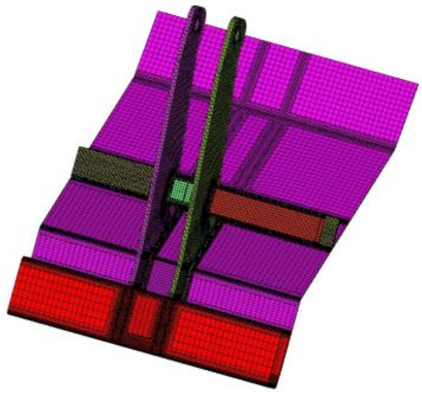

Fig2: Grid model of ear plate structure.

3.2 Relevant Parameters Setting of Finite Element Model

Double ellipsoid thermal source is used as the boundary condition of welding heat source due to the temperature change of welding process is totally involved during the welding process. The material of ear plate grid model is set as Q345 and it is assumed that the whole model has the same thermal physical property parameters with the change of temperature. The base metal and welding wire are set equipped with isotropic properties: poisson's ratio is 0.33, mass density is 7870 kg/m3, and the other parameters such as thermal conductivity, specific heat, elastic modulus, thermal expansion coefficient with the temperature change are shown in Fig 3.

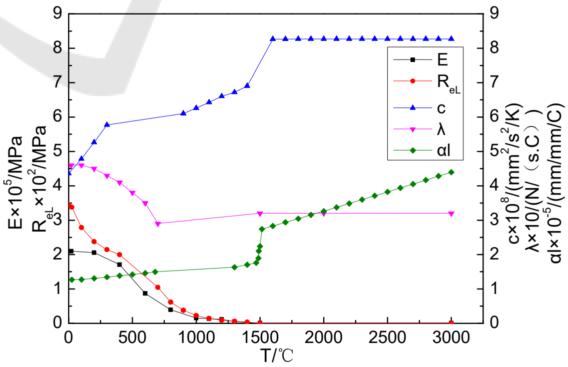

Fig3: The relationship between heat-force parameters and temperature of Q345.

3.3 Welding Deformation Analysis of Ear Plate Structure

The welding deformation of ear plate structure as shown in Fig 4 is extracted after the calculation is completed when the ear plate structure has been cooled to room temperature.The main reason for the structure deformation of ear plate is that the base material's expansion during the welding process results in some plastic distortion around welding zone which would retain after welding. The deformation of the second ear plate along the Y direction is only 0.1mm due to heat input on both sides while the deformation of the first ear plate is up to -5.5mm as a result of only one side heat input.The gap D is altered to 126.25mm on account of welding deformation, which is consistent with the actual situation.The VONMISES stress nephogram of ear plate structure after the completion of welding is shown in Fig5, from which some results can be achieved that the maximum of VONMISES stress is 340 MPa and the welding residual stress of weld and HAZ is much higher than that remote from the welding zone which even close to zero.

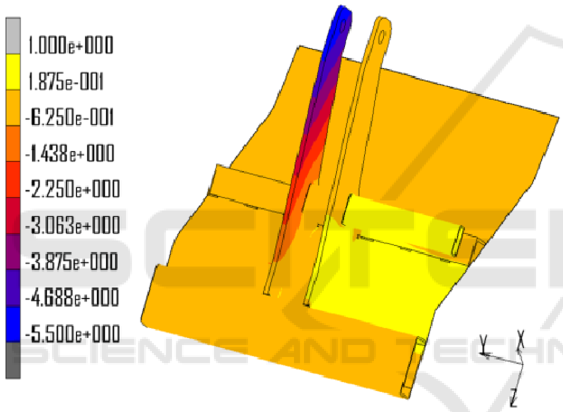

Fig4:Welding deformation nephogram of ear plate structure.

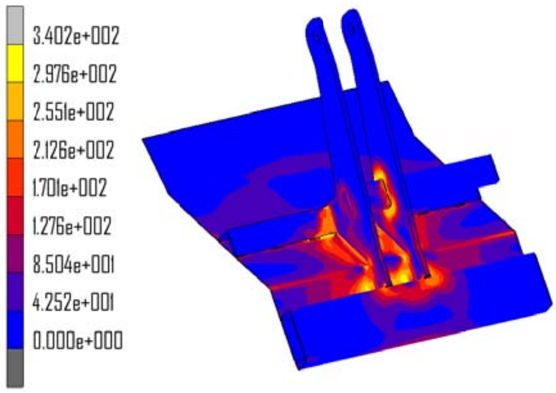

Fig5:Welding residual stress nephogram of ear plate structure.

4 FLAME STRAIGHTENING ANALYSIS OF EAR PLATE STRUCTURE

4.1 Finite Element Model Setting of Flame Straightening of Ear Plate Structure

The physical process of flame straightening is the same as that of welding, both including the coupling of thermal, structure and phase transition. In this paper, the method of direct coupling is utilized to the simulation of flame straightening, and the relevant parameters of finite element such as mesh and material are set in the same way as the welding process. With the result of welding numerical simulation as the initial boundary condition, the influence of welding on flame straightening is analyzed during which the "Previous Analysis State" function would be used to read the welding deformation and residual stress results. According to the welding deformation analysis results, the position of flame straightening is located at the top area above the beam in the first ear plate and the heating method adopts the linear heating method. The parameters of flame heating are shown in Tab2.

Tab 2. Parameters of flame heating.

name	Oxygenpressure /MPa	acetylene pressure(low) /MPa	acetylene pressure(high) /MPa	acetylene gasflow /$m^3 \cdot h^{-1}$	nozzle diameter /mm
value	0.7	0.07	1.1	2.25	2.5

4.2 Design of Simulation Scheme

The effects of heating temperature, heating time and heating width on the deformation were mainly taken into consideration during the design of simulation scheme and the three factors as well as corresponding three levels are shown in Tab 3. The experimental design of above-mentioned parameters is carried out by the Latin hypercube method. As shown in Tab 4, the experiment scheme is composed of 10 samples and all of them are distributed evenly in the sample place.

Tab 3: Distribution of heating factors and levels.

	Temperature/℃	Time/s	Width/mm
Level1	650	10±2	10
Level2	700	15±2	20
Level3	750	20±2	30

Tab 4:Test scheme and final results.

NO.	Temperature /℃	Time /s	Width /mm	D /mm
1	650	20±2	10	127.94
2	750	15±2	20	129.17
3	650	10±2	30	129.77
4	750	20±2	20	129.43
5	650	10±2	20	128.55
6	750	10±2	30	130.37
7	700	10±2	10	127.69
8	700	15±2	20	128.89
9	750	15±2	30	130.71
10	750	20±2	30	131.13

4.3 Thermal Deformation Analysis of Flame Straightening of Ear Plate Structure

The simulation results of DOE are analyzed by the main effect diagram and Plato after the calculation completed so as to determine the effect of parameters such as heating temperature, heating time and heating width on the distance between two ear plates.

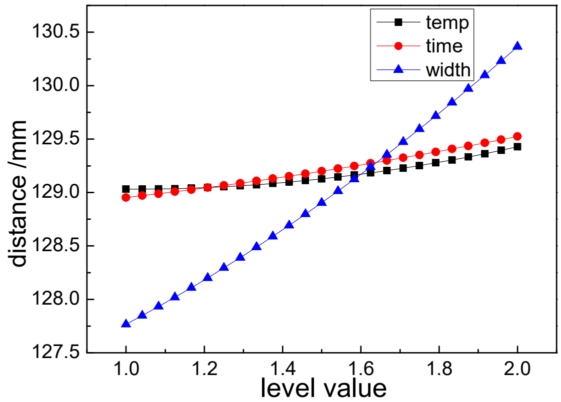

Fig6:The main effect diagram of straightening parameters.

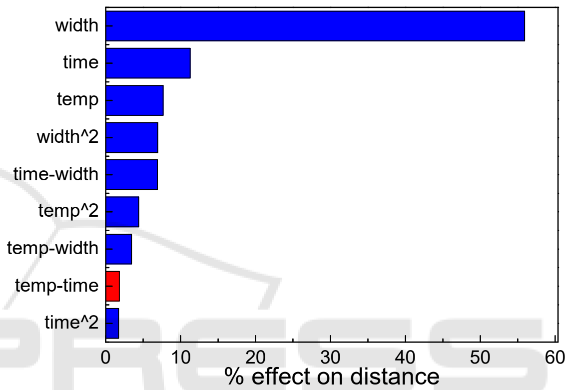

Fig7:The Plato of straightening parameters.

The main effect diagram of heating temperature, heating time and heating width is shown in Fig6, as can be seen from the figure, the heating width has the largest influence on the gap D and the distance changes dramatically with the change of heating width, while the influence of heating temperature and heating time are more gentle.

Fig7 shows the Plato of heating temperature, heating time and heating width, and from the graph it is evident that all of the parameters have a positive effect on the gap D, among which the heating width has the most positive effect on ear plate spacing, followed by heating temperature and heating time. Besides, the secondary and interaction terms have less influence on the gap D and the interactivity of temperature and time is negative for the ear plate spacing.

The result is shown in Tab 3 that the distance between two ear plates is 131.13 mm when the heating temperature is 750 ℃, the heating time is 20 s and the heated width is 30 mm. As shown in Fig 8, the Y direction deformation cloud diagram of the ear plate structure under the straightening parameter is obtained. It can be found that the deformation amount of the second ear plate along the Y direction remains 0.1mm because there is no heat input. However, as far as the first ear plate is concerned, the deformation at upper part is small while the deformation at the top area above the beam is a little larger due to the flame straightening.

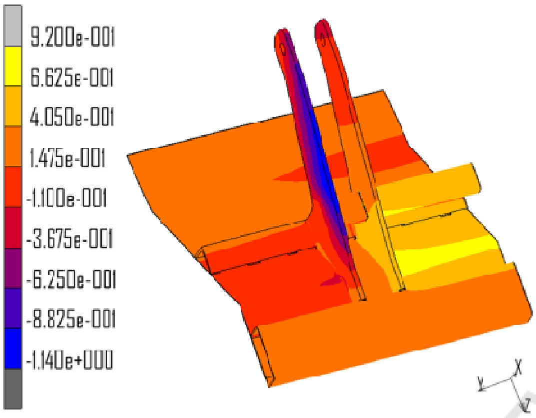

Fig 8: The welding deformation cloud diagram of the ear plate structure.

The VONMISES stress nephogram of ear plate structure after the completion of flame straightening is shown in Fig9, from which some results can be achieved that the maximum of VONMISES stress is 340 MPa and the welding residual stress of weld, straightening area and HAZ is still much higher than that of area remote from the above-mentioned zone. The VONMISES stress in the straightening area is higher than that of structure after welding in the same area from the comparison between two VONMISES stress nephogram.

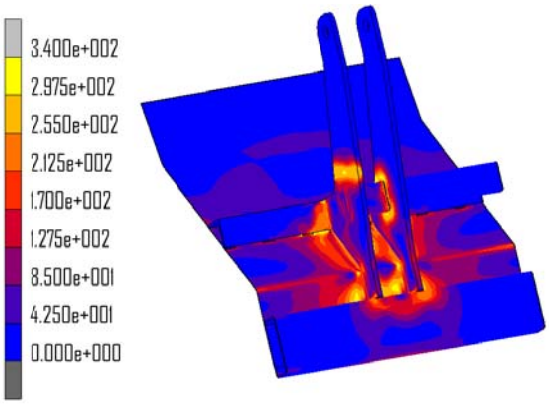

Fig 9:The VONMISES stress nephogram of ear plate structure.

According to the analysis of the DOE results, a straightening processing is utilized to rectify the welding deformation of ear plate which set as: the heating temperature is 750℃, the heating time is 20 sand the heating width is 30 mm. The rectified sample is shown in figure 10 and the gap D between two ear plates is measured. As shown in Tab 5, the measured gap D is 130.5 mm, which meets the design requirements.

Fig10:The rectified sample of ear plate.

Tab 5: Different results of gap D between two ear plates.

	Requirement	Weldingsi mulation	Weldinga ctuality	flame straightening simulation	flame straightening actuality
D	131±1mm	126.5mm	126.3mm	131.13mm	130.5mm

5 CONCLUSIONS

(1) The finite element model of the welding deformation prediction of the ear plate structure is established based on the thermal elastoplastic finite element method and the predicted results of welding deformation are consistent with the measured results.

(2)The flame straightening processing parameters are analyzed and optimized through DOE experimental analysis method. Parameters which have positive effect on deformation rectification are as follows: heating width, heating time and heating temperature while their quadratic terms have little influence on distances between two ear plates.

(3) According to the analysis of DOE results, the straightening processing is determined as: the heating temperature is 750℃, the heating time is 20 ±2s and the heating width is 30 mm. The verified test results show that the gap D meets the design requirements.

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