Simulation of temperature field and stress field of v-groove butt joint

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Abstract. The APDL language of ANSYS software is used to write program to realize the moving load of weld heat source. The thermal-elastic-plastic finite element method for multi-layer and multi-pass welding process was used to simulate the temperature and stress fields of the V-groove Q235 steel plate butt joint with a thickness of 12 mm. It is concluded that in the welding process, the maximum temperature field does not appear at the center of the heat source, but around the heat source. The farther the free end is from the weld zone after welding, the larger the deformation is. After welding, the overall stress on the upper surface of the weld is larger than that on the middle and lower surface of the weld. Post-weld stress mainly concentrates at the bottom of the weld, i.e. the bottom of the V-shaped opening, and tends to increase from small to large in the direction of thickness.

1. Introduction
Although welding parameters are also important factors affecting weld performance, the effect is relatively small compared with the residual stress caused by the cooling of a large number of filler metals from melting state to solid state in thick plate butt joint [1-6]. Therefore, this paper focuses on the distribution of welding stress field under V-groove, which provides a scientific theoretical basis for optimizing welding process and reducing residual stress.

2. Establishing geometric model
The model size is two Q235 steel plates with 12mm *90mm *300mm, V-groove is 60 degrees and Z direction is weld direction. In this study, SOLID90 is used to analyze the temperature field. In this heat source model, the body heat generation rate heat source is used. Heat generation rate=(K*U*I)/(A*V*DT). The welding process is protected by CO2 gas, and the welding thermal efficiency is lower than that of argon arc welding, so the K value is 0.55. U, I and V represent welding voltage, welding current and welding speed respectively (see Table 1 below). A represents the cross-sectional area of the weld. The plate butt model is shown in Figure 1 and the V-groove shape is shown in Figure 2.

It is concluded that the cross-sectional area of V-shaped welding seam is in turn:

A1=3.14*4*4/6
A2=3.14*(8*8-4*4)/6
A3=3.14*(12*12-8*8)/12
A4=3.14*(12*12-8*8)/12
**Fig 1.** Establishment of 3d graphics

**Fig 2.** Shape of v-shaped groove.

**Tab 1.** Welding Parameters of V - Groove

| Groove form | Layer number | Electric current(A) | Voltage(V) | welding speed(mm/s) |
|-------------|--------------|---------------------|------------|---------------------|
| V-groove    | 1            | 150.00              | 21.20      | 3.95                |
|             | 2            | 254.00              | 28.51      | 4.62                |
|             | 3            | 250.00              | 28.40      | 5.26                |
|             | 4            | 252.00              | 28.50      | 6                   |

3. **Analysis of temperature field**

The temperature distribution of the second and third welds is shown in Fig. 3-4.

**Figure 3.** Temperature field distribution of the second weld
At this time, the second heat source continues to load, and the maximum temperature around the heat source is 2150°C. This is because the welding parameters of the second weld are larger than that of the first weld. At the same time, it is impossible to have enough time to cool the welded plate to room temperature before processing the next weld. The heat energy of the former weld is transmitted to the second weld.

At the later stage of the third heat source loading, the motion temperature field no longer increases and changes, but with the heat source moving, the temperature field distribution is elliptical, showing a quasi-steady state. The appearance of quasi-steady state indicates that the mesh generation and time step division have met the requirements, and the numerical simulation of temperature field is accurate.

In this experiment, four heat sources were loaded one after another. The temperature of the spot on the former weld will rise again with the loading of the heat source on the latter weld. The temperature curves of the third weld at different time were compared and analyzed by selecting the path (named R1) consisting of five points (0, 75, 150, 225 and 300) along the direction of the weld (i.e. the Z-axis positive direction) from the coordinate origin. The path is shown in Figure 5.

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**Figure 4.** Temperature field distribution of the third weld

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**Figure 5.** Path diagram on the third weld.
In the figure, RITMP represents the last step (when the heat source is loaded at the end of the fourth weld), RITEMP2 represents step 81 (when the heat source is loaded at 3/10 of the third weld), RITMP3 represents step 101 (when the heat source is loaded at the end of the third weld), and RITEM4 represents step 121 (when the heat source is loaded in the middle of the fourth weld).

According to Figure 6, we can conclude that:

From the RITEMP2 curve, we can see that the heat source is 90 mm away from the Z-axis origin (because the total length of the weld is 300 mm, RITEMP2 indicates that the heat source is 3/10 of the weld length), and the peak temperature occurs at about 93 mm away from the Z-axis origin. It proves that the highest temperature in the welding process does not occur at the center of the heat source, but around the heat source. At the same time, the higher the slope of the point closer to the peak temperature on RITEMP2, the more intense the temperature rises at the place where the heat source has been loaded, and the closer to the heat source in the heat affected zone. RITMP3 is a heat source loaded to the end of the weld, so the temperature curve rises. Finally, a small decrease is due to the existence of convective heat transfer at the edge. RITEM4 indicates that with the loading of heat source in the fourth heat source, the temperature of the third weld near the center of the heat source increases fastest, while the latter half of the sheet does not change because the heat source has not yet been loaded. RITMP represents that the temperature of each point on the weld is basically the same. After the welding process, the temperature tends to be the same.

4. Stress field analysis
In order to measure the free deformation of welding and prevent the non-convergence of finite element calculation caused by too little displacement constraints, the model is studied in this paper. The two constrained fixed points divide the edge length into three equal parts. The constrained position is shown by the red dot in Fig 7.
The von-miss stress diagram of the whole model and half of the model is drawn, as shown in Fig. 8 and Fig. 9.

**Fig 7.** Displacement constraint diagram

**Fig 8.** Overall von-miss should strive

**Fig 9.** The von-miss force diagram
As can be seen from Figure 3.2, the stress of the model is mainly concentrated at the weld and the end of the end. The large calculation results of the residual stresses at the end face with constraints are due to the fixed constraints of the corresponding finite element model set up in this paper to simulate the constraints in the actual welding process. The selection of constraints should take into account the actual situation of the welding process. In the welding process of V-groove butt plate, two plates need to be spot-welded first, with a gap of 1 mm between them. The existence of the gap can ensure one-sided welding and two-sided forming. Spot welding can effectively prevent the inconsistency of groove width caused by welding deformation. At the same time, the free deformation after welding should be measured, so one side should be fixed on the base plate worktable. Due to the existence of spot welding in the middle of the weld, there are two constraints in the actual plate deformation, one is in the middle of the weld and the other is at the end of the plate side, which results in a large residual stress at the end. However, we do not regard the results of the end face as the main analysis object of welding residual stress, but pay more attention to the distribution of residual stress around the weld and its surroundings. From the section stress diagram of the left butt plate in Fig. 3.3, we can see that the stress mainly concentrates on the bottom of the weld, i.e. the bottom of the V-shaped opening, around the weld, and tends from small to large in the direction of thickness.

In this paper, the residual stress curves of transverse and longitudinal welds are adjusted, as shown in Fig 10. and Fig 11.
From the transverse residual stress curve, it can be seen that the maximum stress in the weld zone is about 177 Mpa, the residual stress at the free end is only 58.2 Mpa, and the stress at the restrained end can reach 249 Mpa, which is consistent with the above analysis. From the curve of longitudinal residual stress, it can be seen that most of the residual stress at the longitudinal center of the weld is between 172 Mpa and 185 Mpa, and there is a large variation of residual stress at the beginning and end of the weld, which is due to the distance.

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From Figure 3.2, we can also see that the overall stress of the upper surface is larger than that of the middle surface and the lower surface.

From Figures 3.4 and 3.5, it can be seen that the maximum values of both transverse and longitudinal stresses occur at weld joints. The average and peak values of longitudinal residual stresses are larger than the average and peak values of transverse stresses. Therefore, the longitudinal residual stresses are the main consideration in the study of welding residual stresses.

5. Conclusion
1. During the welding process, the temperature field is distributed in quasi-steady state and moves dynamically with the heat source. The closer the spot on the weldment is to the heat source, the more intense the temperature rise is. In the welding process, the highest temperature field does not appear at the center of the heat source, but around the heat source.

2. The farther the free end is from the weld zone after welding, the larger the deformation is. The calculated values of residual stresses at both ends of the weld suddenly increase, which is due to the fact that the metal in the section is more easily deformed. After welding, the overall stress on the upper surface of the weld is larger than that on the middle and lower surface of the weld.

3. Because the peak value and average value of longitudinal residual stress are larger than that of transverse residual stress, the longitudinal residual stress is the main consideration when we study the welding residual stress. Post-weld stress mainly concentrates on the bottom of the weld, i.e. the bottom of the V-shaped opening, and tends to increase from small to large in the direction of thickness.

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