

Numerical simulation of temperature fields for T-joint during TIG welding of titanium alloy *

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Abstract Three-dimensional finite element model was established to simulate temperature fields of T-joint titanium sheets during TIG welding with finite element method (FEM) software. Temperature dependent material properties and the effect of latent heat were considered. A technique of element birth and death was used to simulate the process of welded metal filling. Dynamic variation process of temperature fields during TIG welding was achieved. The simulated results agreed well with the measured results.

Key words TIG welding, titanium, T-joint, temperature field, finite element method

0 Introduction

Titanium alloy has been widely used in aerospace industry from 1950 s because of its excellent performance. As one of machining methods, welding plays an important role in titanium alloy processing. With the development of computer technology, numerical simulation for welding process can be performed using FEM software, such as ANSYS, MARC, SYSWELD and ABAQUS.

Nowadays, a lot of analytical and FEM models have been proposed to simulate the welding temperature field during TIG welding for butt joint^[1-3]. However, only very limited literatures describe temperature fields of titanium alloys^[4], especially for T-joint fillet welds. It is necessary to perform further research to study the characteristic of temperature fields of T-joint titanium sheets. At the same time, it is the foundation of simulating residual stresses and the distortion attributed to welding.

In this study, a 3-D thermal elastic-plastic finite element model is developed to simulate temperature fields during TIG welding using FEM software. Experimental tests are carried out to obtain the welding thermal circles and the simulated results agree well with the measurements.

1 Analysis model

The length of the fillet weld, the width of the base sheet and the height of the reinforced web are assumed to be 112 mm, 86 mm and 30 mm, respectively. The plate thickness is 2.5 mm for the flange and 2 mm for the reinforcing ribs. The base material is TA15 titanium alloy and its thermal physical parameters which are dependent on the temperature history can be obtained in literature [5].

The welding parameters chosen for this analysis were as follows. Welding method is single pass gas tungsten arc welding. Welding current is 380 A. Welding voltage is 10.4 V and welding speed is 1.4 mm/s.

The finite element mesh is shown in Fig. 1. A thermal analysis hexahedron element of 8 nodes is adopted in this study. Because of the big temperature gradient in the weld zone, fine meshes are used. The minimum element is 1 mm × 1 mm × 2 mm.

2 Thermal analysis of T-joint fillet weld

2.1 Heat source

Calculation of the temperature field history during welding needs a transient thermal analysis. The thermal analysis is based on the formulation of heat conduction

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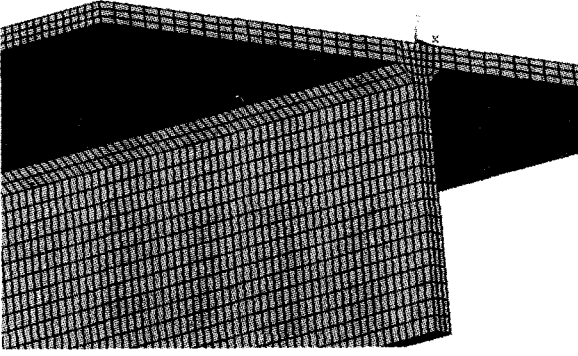


Fig. 1 Finite element meshes

using temperature dependent thermo-physical properties and a moving heat source. The model in this study adopts the technique of element birth and death to simulate the weld filler variation with time in T-joint fillet welds. All elements must be created, including those weld fillers to be 'born' in later stages of the analysis. All elements in the weld zone must be 'killed' before calculating. When beginning to calculate, the 'killed' elements should be reactivated in turn. Meanwhile, a heat generation is loaded on the reactivated elements.

$$HGEN = \eta UI / (A_{\text{weld}} \times v \times dt) \quad (1)$$

Where $HGEN$ is the heat generation during time dt , W/mm^3 . η is heat input coefficient. The arc efficiency is assumed to be 0.67 for GTAW in this study. A_{weld} is the cross-sectional area of the weld, mm^2 . v is the welding speed, mm/s and dt is the time of every load step, s .

2.2 Initial condition and boundary condition

The initial condition is as follows: when time is equal to 0, weldment has uniform primary temperature. The environmental temperature is commonly chosen as 20°C .

To consider heat transfer due to fluid flow in the weld pool, an artificially increased thermal conductivity is assumed for temperatures above the melting point. In welding process, weldment exchanges heat in the pattern of convection and radiation. Owing to the different calculative methods between thermal radiation and thermal convection, the radiant exchange heat and convection relating

to the difference of temperature on the surface of the region next to the weld bead are considered with the total exchange heat coefficient in the calculation for convenience^[6].

For the region of weld bead surface under the nozzle, forced convection due to the shielding gas is considered, and the convection coefficient is assumed as $7 \times 10^{-4} \text{ J}/\text{mm}^2 \cdot \text{s} \cdot \text{K}$ ^[7].

2.3 Latent heat of fusion

Some researches have indicated that the latent heat of fusion highly influences the shape and size of the weld pool, as well as the temperature distributions in the vicinity of the weld pool. In this paper, the solidification temperature range (1660°C to 1720°C) of titanium is evenly divided into many intervals as shown in Fig. 2.

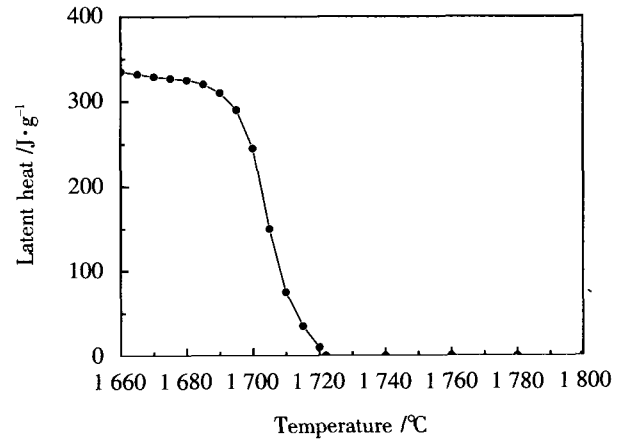


Fig. 2 Latent heat of TA15 titanium alloy

3 Simulated results of temperature field and experimental verification

A typical path $A-A'$ ($y = 56 \text{ mm}$) is shown in Fig. 3. The thermal cycles of four points on the path are shown in Fig. 4, and they are node 1 ($0, 56, 0$), node 2 ($2, 56, 0$), node 3 ($5, 56, 0$), node 4 ($8, 56, 0$).

As shown in Fig. 4, the curves ascend rapidly because of the high speed of heating-up during welding and each point gets its peak temperature in a short time. The further the distance is away from the center of the weld, the lower the maximal temperature is. In the cooling stage, the temperature of each point falls down slowly.

The inflexion in the curves between solidus temperature and liquidus temperature is evident, which results from the latent heat.

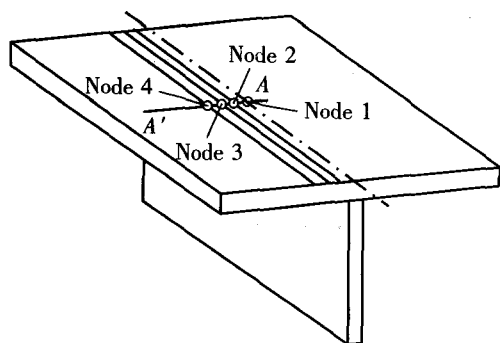


Fig. 3 Positions of the selected points

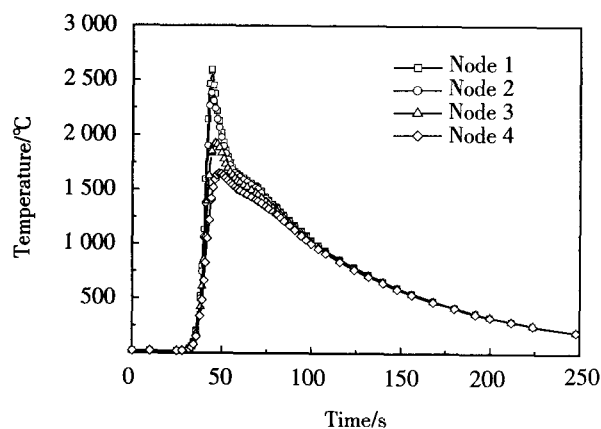


Fig. 4 Thermal cycles during TIG welding

NiCr-NiAl K-thermocouple is adopted in temperature field measurement. The dimension of the specimen for the experiment is the same as the simulated model. Two points are selected on the middle section of the weldment and they are point A (pA) (11, 56, 0), point B (pB) (14, 56, 0). The distribution of the two points is shown in Fig. 5. Thermal cycle curves of two points obtained by experiment and simulation are shown in Fig. 6.

As shown in Fig. 6, the thermal cycle curves obtained by simulations agree well with experimental results. The peak temperature obtained by experiment is lower than the one obtained by simulation. In the cooling stage, the simulated temperature descends faster than the measured one because the radiation coefficient is a constant in simula-

tion. However, in practice, the radiation coefficient is reduced as the temperature falls down. In addition, the method of fixing the thermocouple on the weldment can also affect the measured results.

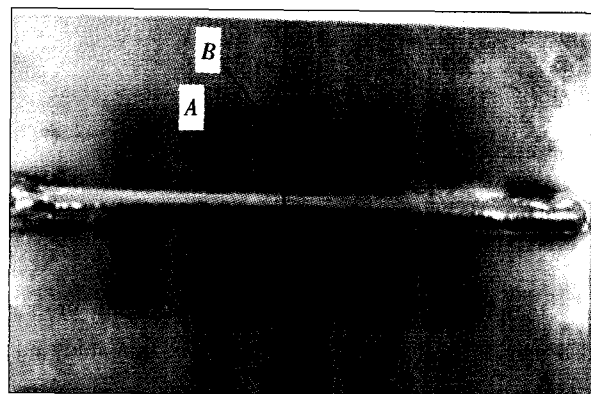


Fig. 5 Positions of the selected points

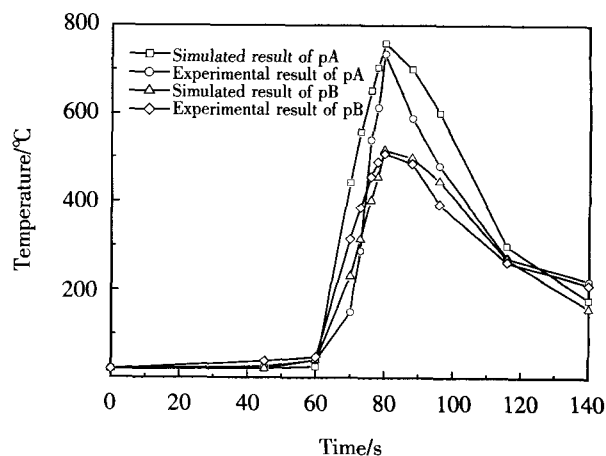


Fig. 6 Thermal cycle curves obtained by simulation and experiment

4 Conclusions

In this paper, the temperature distributions of T-joint titanium sheets during TIG welding are investigated by finite element method. The conclusions are as follows:

(1) The thermal physical parameters depended on the temperature are considered.

(2) A technique of element birth and death is used to simulate the process of welded metal filling and a heat generation is designed as the heat source. Latent heat is also considered during the simulation.

(3) The thermal cycle curves of selected points on the weldment are measured. The simulated results agree well with the measured results.

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