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EFFECT OF WELDING PARAMETERS ON WELDING TEMPERATURE FIELD OF FRICTION STIR WELDING OF CURVED STRUCTURE'S OVERLAP JOINT

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Abstract. The loading of welding heat resource model on the curved structure's friction stir welding process is realized by means of the method of node-to-node connection. As an example, the temperature field of the stringer and skin structure's overlap joint during friction stir welding process is researched while the structure material is 7A04 Al alloy. The results of numerical simulation show that the resting time of rotational tool at the insertion position after the inserting process of the tool is finished greatly influences the welding temperature field. With the decrease of welding velocity, the increase of rotational speed and the increase of rotational tool's press, the peak temperature in the welding process increases and the high temperature region in weld enlarges. According to the best range of peak temperature and the less high temperature region, the optimization scheme of welding parameters of friction stir welding is put forward.

1. INTRODUCTION

In the field of aviation, there are many curved structures to be connected by riveting. However, the riveting can add the total mass of aircraft and decrease the dynamic or static strength. In order to meet the need of the development of aviation, the new connecting technologies need to be adopted to make the aircraft's weight lighter and the aircraft's reliability higher.

Friction stir welding (FSW) is a new technology, which is invented at the end of twentieth century. Friction stir welding is favored in the field of aerospace, because FSW owns many advantages, such as low stress, small distortion, high strength, no pollution, *etc.* [1-5]. Many international industries of aerospace use the FSW technology to connect the typical structures of aircraft. These companies include Boeing Aircraft Company, Fokker BV, GIE Airbus Industry, *etc*. By using friction stir welding instead of riveting, the total mass of aircraft is lighter, the strength of joint is higher, the working efficiency is higher and the product cost is lower.

The peak value and distribution of welding temperature are key factors to affect the property of welding joint. Therefore, the temperature field is always the research emphasis in the field of welding. As one of welding technologies, the temperature field of friction stir welding is more important because there is a close relation between the material flow and the temperature field. And the welding quality of FSW is mainly related to the material flow [6-8]. In this paper, as one of the typical structures in aircraft, the stringer and skin structure's temperature field is studied by the commercial software Msc.Marc and then the optimized method of welding parameters is put forward. The research results about FSW brought forward in this paper have significant theoretic and practical engineering meaning because those results can be considered as theoretical basis for FSW application in the field of aerospace.

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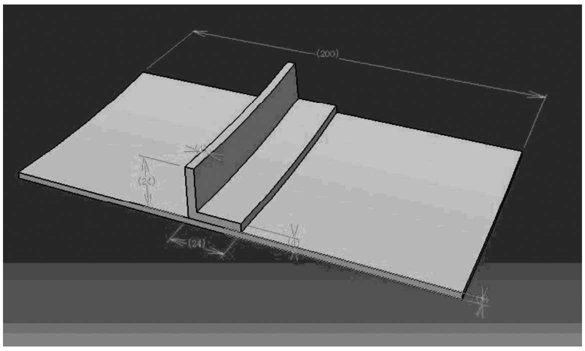

Fig. 1. Schematic of the stringer and skin structure.

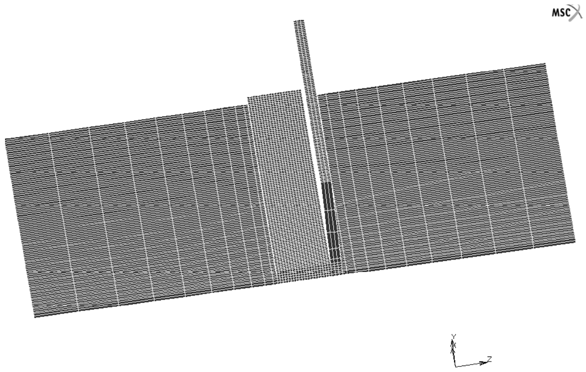

Fig. 2. Mesh generation of the stringer and skin structure.

2. FEM OF FRICTION STIR WELDING

2.1. Mesh generation

The stringer and skin structure is one of the typical structures in aircraft. In general, the stringer and the skin are single curved, double curved or more complicated. Moreover, the stringer and the skin often use the riveting to connect together. In this paper, the friction stir welding technology is used to connect the stringer and the skin and then the temperature field in FSW is discussed. The dimensions of stringer and skin structure are shown in Fig. 1. Thereinto, the number of skin is one in order to make the discussion simple. And the mesh generation is shown as Fig. 2. Moreover, the joint of the stringer and skin structure is the overlap joint.

Although the temperature in FSW is lower than the melting point, the temperature distribution is much uneven and the change of temperature is very serious. Therefore, the elements in the weld and nearby are very fine in order to enhance the computational accuracy while the elements far away from the overlap weld are relatively big in order to save the computational time. The model discussed in this paper is made up of 19300 hexahedron elements and 25048 nodes.

2.2. Confirmation of material parameters

7A04 Al alloy owns many advantages, such as excellent corrosion resistance, good workability, high yield strength, *etc*. Therefore, 7A04 Al alloy can be used to manufacture the stringers and the skins in aircraft. The physical parameters of 7A04 Al alloy is shown in Table 1. Moreover, the density of 7A04 is 2850 kg/m^3 and the melting point is about 532 °C.

Table 1. Material parameters of 7A04 Al alloy.

Temperature (°C)	25	100	200	300	400
Specific heat (W/m · °C)	875	921	1005	1047	1089
Thermal conductivity (J/kg · °C)	155	159	163	163	159

2.3. Boundary condition of heat input

In this model, the plastic deformation of material is assumed to result from only the tool pin. Therefore, the heat in FSW mainly include two part: heat generated by the tool shoulder and heat generated by the tool pin [9].

a) heat generated by the tool shoulder

The heat between the workpiece and the tool shoulder is considered as the friction heat, whose expression can be written as follows

$$Q_{shoulder} = 2\pi\mu F_n R\omega, \quad (1)$$

where μ is the friction coefficient. F_n is the normal force applied to the workpiece, ω is the rotational speed and R is the distance of some calculated point from the rotational tool axis.

b) heat generated by tool pin

The heat generated by tool pin includes three parts: heat generated by shearing of the material; heat generated by friction on the threaded surface of the pin; heat generated by friction on the vertical surface of the pin. The expression of total heat by the tool pin can be written as follows:

$$Q_{pin} = 2\pi r_p hk\bar{Y}\frac{V_m}{\sqrt{3}} + \frac{2\mu k\bar{Y}\pi r_p hV_{rp}}{\sqrt{3\left(1+\mu^2\right)}} + \frac{4F_p\mu V_m\cos\theta}{\pi}, \quad (2)$$

where $\theta = 90° \times \lambda \times \tan^{-1}(\mu)$,

$$V_m = \frac{\sin\lambda}{\sin\left(180 \cdot \theta \cdot \lambda\right)} \nu_p,$$

$$V_{rp} = \frac{\sin\theta}{\sin\left(180 \cdot \theta \cdot \lambda\right)} \nu_p,$$

$$\nu_p = r_p \omega,$$

where r_p is the radius of the tool pin, h is the thickness of workpiece, $\overline{Y}$ is the average shear stress of the material, F_p is the translation force during the welding and λ is the helix angle of the thread.

In the process of numerical simulation, the above-mentioned heat model can be loaded to the stringer and skin model by the subroutine Flux in Msc.Marc.

To any joint with the complicated curved surface, the heat source of FSW is difficult to load. In this paper, the method of node-to-node connection is put forward to realize the load of heat source. Thereinto, it is assumed that the heat source linearly moves between two adjacent nodes in the welding direction. Because the elements in the weld are very fine, the distance between two adjacent nodes is very little and this loading method is feasible. The welding velocity expression of a certain direction is as follows:

$$\nu(m) = \nu \frac{m(i+1) - m(i)}{\sqrt{\sum\left[m(i+1) - m(i)\right]^2}}, \tag{3}$$

where *v* is the welding velocity and *m* represent one of three coordinates, namely *x, y* or *z*. ν(m) is component of the welding velocity in *x* direction(or *y* direction or *z* direction). $\sum\left[m(i+1) - m(i)\right]^2$ represents the distance between two adjacent nodes of weld and *i* is the node number.

3. TEMPERATURE FIELD IN WELDING PROCESS

In this paper, the insertion process of rotational tool isn't discussed and the numerical simulation begins at the time of completion of rotational tool's insertion. In general, the rotational tool rests on the insertion position for several seconds before this tool moves along the overlap weld, which makes the temperature near the tool insertion region so high that the plastic flow of material is excellent. In this paper, the resting time is chosen as 3 s. The results of numerical simulation during the resting time are shown in Fig. 3. Thereinto, the welding parameters are as follows: the welding velocity is 2 mm/s, the rotational speed is 15 r/s and the normal press of rotational tool is 7500 N.

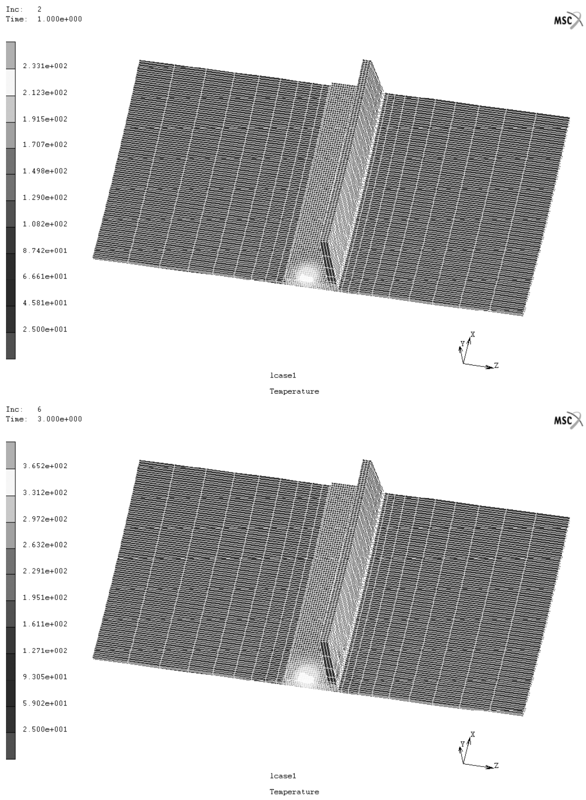

Fig. 3. Temperature field during the resting time of rotational tool. a) 1 s; b) 3 s.

It is known from the Fig. 3 that the peak temperature of material increases with the increase of the rotational tool's resting time. When the resting time reaches 3 s, the peak temperature is about 70% of melting point of 7A04. Moreover, the resting time greatly influence the temperature field. If the resting time is very short, the temperature value near the insertion position region is so low that the plastic flow of material is not enough, which influences the quality of joint. If the resting time is so long that the peak temperature may be higher than the melting point, the advantages of friction stir welding are lost.

Fig. 4 and Fig. 5 are the distribution of temperature field at different time when the rotational tool moves along the welding direction. Integrating with Fig. 3, it is seen that the temperature near weld is higher than that far from the weld. Moreover, the temperature of material near the heat source ascends very faster than that far from the weld.

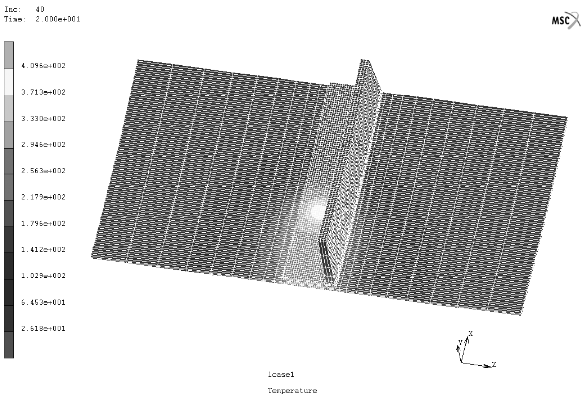

Fig. 4. Temperature field at the welding time of 20 s.

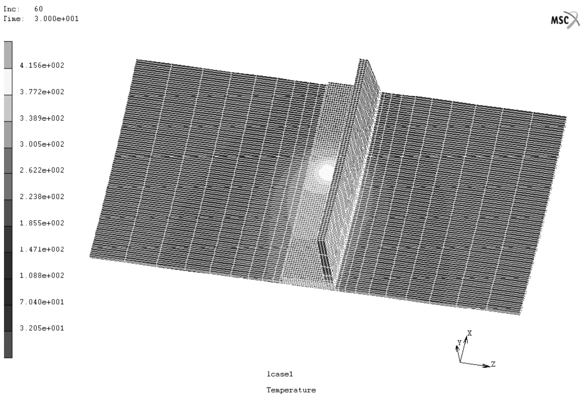

Fig. 4. Temperature field at the welding time of 30 s.

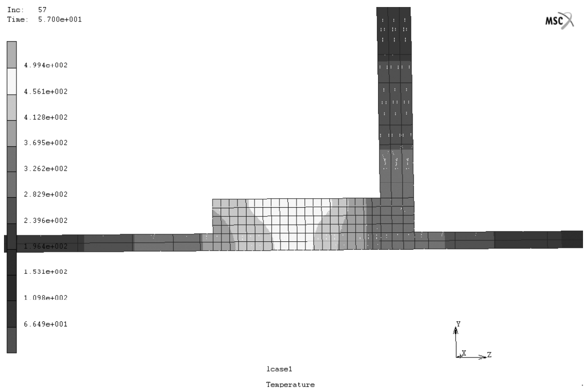

Fig. 6. Temperature field perpendicular to the weld by a welding velocity of 1 mm/s.

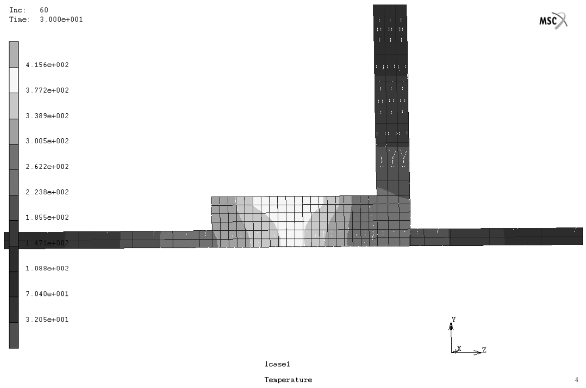

Fig. 7. Temperature field perpendicular to the weld by a welding velocity of 2 mm/s.

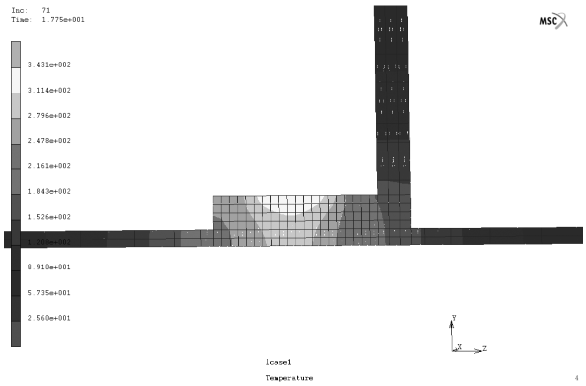

Fig. 8. Temperature field perpendicular to the weld by a welding velocity of 4 mm/s.

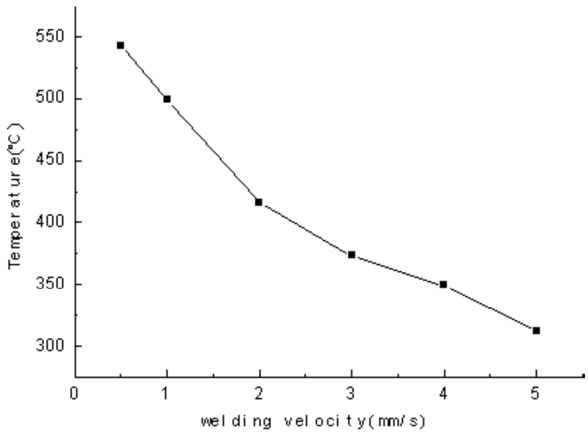

Fig. 9. Relation between the peak value of temperature field and the welding velocity.

4. OPTIMIZATION OF WELDING PARAMETERS

Fig. 6, Fig. 7, and Fig. 8 are the temperature distribution by the welding velocity of 1, 2, and 4 mm/s respectively. The rotational speed is 15 r/min and the rotational tool's press is 7500 N. Fig. 9 illustrates the relation between the peak temperature and the welding velocity when the welding process lies in the stable state.

It is seen that the welding velocity influence the temperature field greatly. When the welding velocity is relatively high, the heat transferred to the workpiece in unit time decreases and then the temperature value is relatively low. So the material's plastic flow is not good, which may result in the bad weld formation or make the weld strength low. When the welding velocity is relatively low, the temperature peak value may excel the material's melting point, which makes the advantages of friction stir welding lost.

When the welding velocity is 2 mm/s and the rotational tool's press is 7500 N, the relation be-

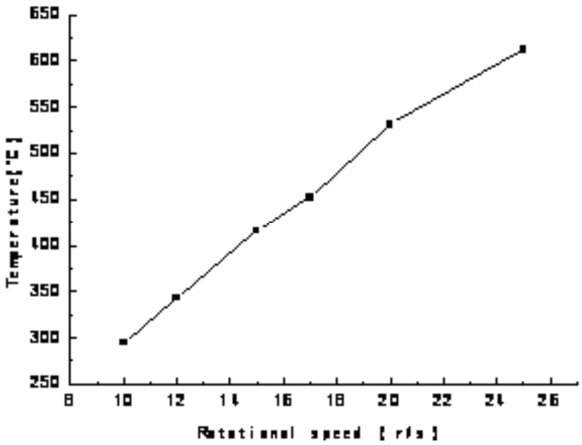

Fig. 10. Relation between the peak value of temperature field and the rotational speed.

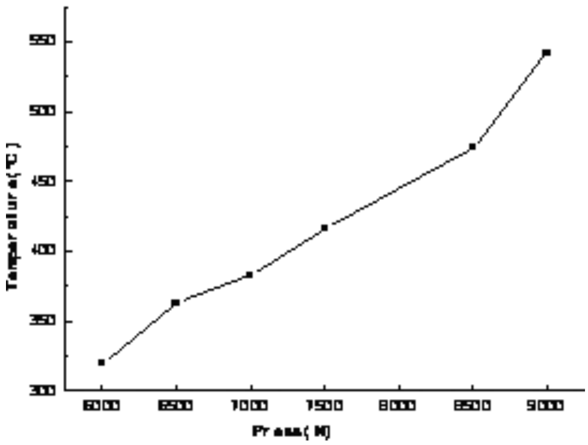

Fig. 11. Relation between the peak value of temperature field and the press of rotational tool.

tween the peak temperature and the rotational speed is researched, as is shown in Fig. 10. When the welding velocity is 2 mm/s and the rotational speed is 15 r/s, the relation between the peak temperature and the rotational tool's press is studied, as is shown in Fig. 11. It is seen from those two figures that the peak values of welding temperature increase with the increase of the rotational speed or the press of rotational tool. Therefore, it is not good for the rotational speed or the tool's press to be relatively low or high.

The research results show that the best temperature of FSW ranges from 75% of material's melting point to 80% of melting point [10-12]. Moreover, the distribution of welding temperature field influences not only the stress of structure, but also the strength of welding structure. Therefore, the less the high temperature region and the temperature gradient are, the best the quality of FSW joint is. Integrating with the above-mentioned results, the optimization welding parameters of FSW for the overlap joint of 7A04 Al alloy can be concluded as follows: the welding velocity is 2 mm/s, the rotational speed is 15 r/s and the press of rotational tool is 7500 N.

5. CONCLUSIONS

1) In process of friction stir welding, the resting time of rotational tool at the insertion position greatly influences the welding temperature field. It is not good for the resting time to be relatively long or short.
2) The welding velocity, the rotational speed ad the press of rotational tool all greatly influences the distribution of welding temperature field. With the decrease of welding velocity, the increase of rotational speed and the increase of rotational tool's press, the peak temperature during welding increases and the high temperature region enlarges.
3) From the view of the best range of peak temperature and the less high temperature region, the optimization method for the welding parameters of friction stir welding is introduced.

REFERENCES

[1] A. Heinz, A. Haszler, C. Keidel and S. Moldenhauer // *Mater. Sci. Eng. A* **280** (2000) 102.
[2] S.R. Ren and Z.Y. Ma // *Scripta Mater.* **56** (2007) 69.
[3] B.P. Michael and John A. Baumann David // *Acta Mater.* **54** (2006) 4013.
[4] W.B. Lee, Y.M. Yeon and S.B. Jung // *Mater. Sci. Eng. A* **355** (2003) 154.
[5] A.P. Reynolds // *Scripta Mater.* **58** (2008) 338.
[6] R. Nandan, G.G. Roy and T.J. Lienert // *Sci. Technol. Weld. Joining* **11** (2008) 526.
[7] M. Guerra, C. Schmidt and J.C. McClure // *Mater. Charact.* **49** (2003) 95.
[8] H.N.B. Schmidt, T.L. Dickerson and J.H. Hattel // *Acta Mater.* **54** (2006) 1199.
[9] M. Song and R. Kovacevic // *Proc. Instn Mech. Engrs Part B: J. Eng. Manufacture* **217** (2003) 63.
[10] R. Nandan and G.G. Roy // *Acta Mater.* **55** (2007) 883.
[11] H.B. Schmidt and J.H. Hattel // *Scripta Mater.* **58** (2008) 332.
[12] H.J. Liu, H. Fujii and M. Maeda // *J. Mater. Process. Technol.* **143** (2003) 692.