Tool forces and deformations in friction stir welding

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Summary The welding tool can be heated in the friction stir welding process and the temperature on tool can be increased with the increase of the angular velocity and decreased with the increase of the translational speed. Analysis on tool forces show that the tool force is increased with the increase of the transverse speed in certain angular speed. But the tool force is decreased with the increase of the angular speed in certain transverse speed. At the end of the pre-heating period, the tool force reaches its maximum. Based on the calculated results, the fatigue life of the welding tool can be evaluated and designed.

Friction Stir Welding (FSW) was a solid state joining technology invented by Thomas et al. at TWI [1]. In FSW, a rotating tool which consists of a shoulder and a pin is inserted into the butt of the two welding plates. With several seconds for pre-heating [2], the welding tool starts to move along the butt of the joint with rotations. Then the materials in the nugget zone can be mixed due to the stirring caused by the welding tool and the generated heat. The schematic of FSW is shown in Fig.1.

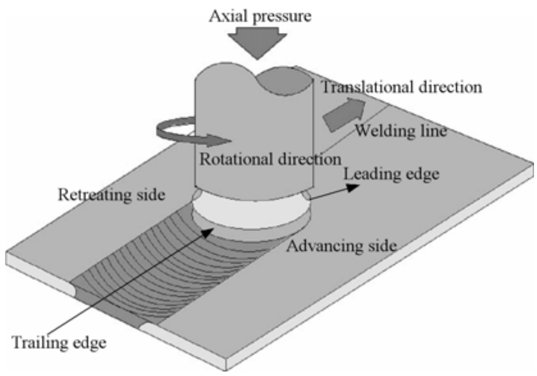


Fig.1 Schematic of FSW [3]

The forces on the tool are very important for the determination of the fatigue life of the welding tool. So, an adaptive re-meshing technique based model was used to study the forces in the FSW of AZ91 magnesium alloy. Arrhenius equation was used for the description of the flow stress,

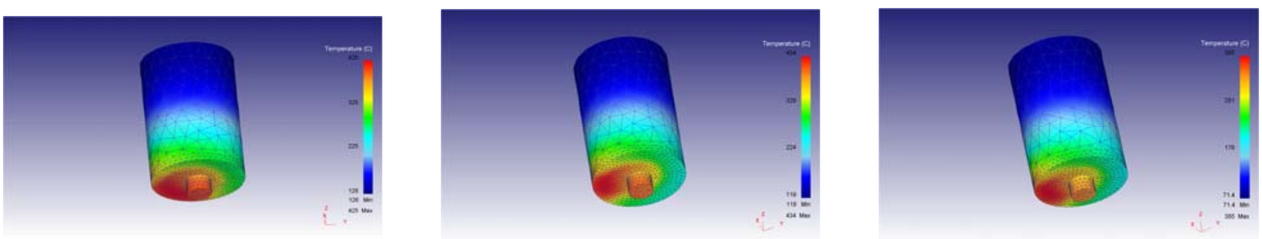
$$\dot{\bar{\varepsilon}} = A\left[\sinh\left(\alpha\bar{\sigma}\right)\right]^{n} e^{\left(-\Delta H / RT_{\mathrm{abs}}\right)} \quad (1)$$

where $\bar{\sigma}$ is the equivalent stress. $\dot{\bar{\varepsilon}}$ is equivalent strain rate. T_{abs} is the absolute temperature. ΔH is the activity energy. R is the gas constant. n is the strain rate exponent. A and α are constants.
Levy-Mises flow rule is used to relate stress and strain tensor,

$$\sigma_{ij} = \frac{1}{\dot{\lambda}}\dot{\varepsilon}_{ij} \quad (2)$$

where the coefficient λ is a function of state variables and the material.
Shear model is used for the definition of the contact between the welding tool and the plates,

$$f = mk \quad (3)$$



900rpm, 40mm/min　　1200rpm, 40mm/min　　900rpm, 60mm/min

Fig.2 Temperature distributions on the welding tool

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In FSW, the tool can be heated due to the friction between the welding tool and the welding plates. The temperature distributions on the welding tool in different welding parameters are shown in Fig.2. The maximum temperature on the welding tool is increased with the increase of the angular velocity and is decreased with the increase of the transverse speed of the welding tool. The maximum temperature on the welding plates can be also increased with the increase of the angular velocity of the welding tool [4].
The axial load on the welding tool reaches its maximum at the end of the pre-heating period as shown in Fig.3. In 900rpm and 40mm/min, the maximum axial force in FSW is 22kN. It is increased to 23kN when the transverse speed is increased to 60mm/min and can be decreased to 16kN when the angular velocity of the welding tool is increased to 1200rpm. The decrease of the axial force means the decrease of the friction force between the tool shoulder and the welding plates. Although this is beneficial to the protection of the welding tool, the temperature on the welding tool is increased. This means that both the temperatures on the welding tool and the calculated tool force should be simultaneously considered in the prediction of the fatigue life and the design of the welding tool.

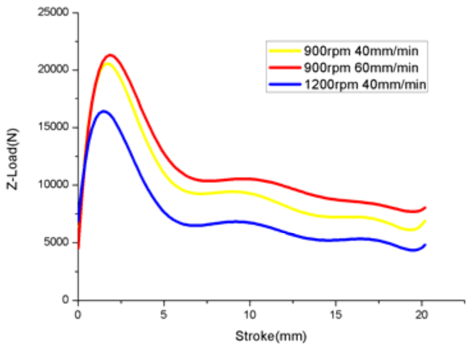

Fig.3 Axial tool forces on the welding tool

The transverse force on the welding pin can be decomposed as two parts: the friction force between the pin tip and the welding plates and the hydraulic pressure applied on the pin in the FSW process,

$$F_{\text{long}} = \oint_{S_1} p\cos\theta dS + \oint_{S_2} \tau_f dS \tag{4}$$

$$F_{\text{trans}} = \oint_{S_1} p\sin\theta dS \tag{5}$$

With consideration of the adaptive re-meshing model, the tool forces in the other two directions are shown in Fig.4.

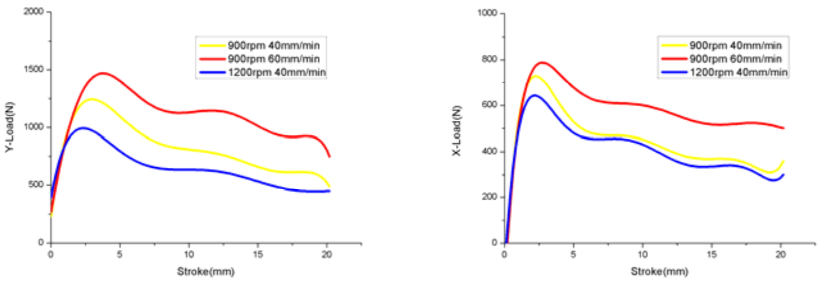

Fig.4 Tool forces in the other two directions

Acknowledgements

This work was supported by the National Natural Science Foundation of China (No. 11172057) and the National Key Basic Research Special Foundation of China (2011CB013401).

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