Acta Technica 62 (2017), No. 6B, 1029–1036

Process parameter setting and optimization based on computer simulation

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Abstract. Welding speed is one of most important process parameters in friction stir welding process, in this paper, in the case of rotation speed is constant, the different welding speed is used for friction stir welding experiment, and studied on the impact of welding speed on the joint quality with thermal analysis model established. Experimental results show that the smaller welding speed, the joint surface appeared a burnt, with the increase of welding speed, the weld surface glabrous, continue to increase the welding speed, joint surface tiny crack. Analysis results show that the increase of welding speed, smaller effect of the welding heat input, but material involved in the formation of weld increased, liquidity becoming poor, and forward resistance increased, making the joint quality becomes poor.

Key words. Friction stir welding, Rotating speed, Welding speed.

1. Introduction

Friction stir welding (FSW) is a kind of new technology of solid-phase jointing; compared with traditional welding method, it boasts many advantages and can be used to weld the metal which is used to be hard to be welded [1-7]. However, if the traditional process parameter is unreasonably selected, and the quality of joint is poor, it will have an influence on its use. The welding speed, as an important process parameter of the welding process, is often increased to improve production efficiency in the process of production. However, it needs to be analyzed that whether the increase on welding speed in FSW will affect the quality of joint. In the Thesis, FSW welding test is conducted in different speed, and then the reason that change on welding speed affects quality of joint is analyzed by using the established heat-fluid model.

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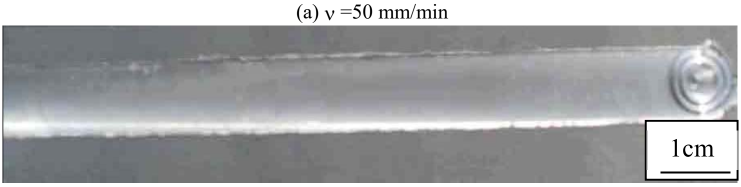
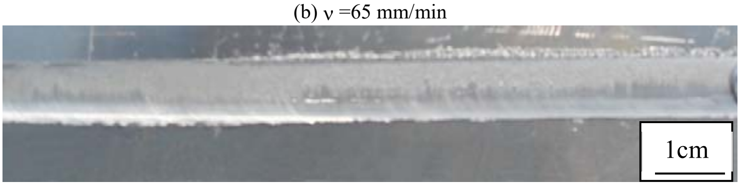
2. FSW process test

6061 aluminum alloy is used for test and the size of test panel is 150×50×6.3 mm. The stir-welding head is in the shape of cone+ concave concentric surface, and the surface is provided with thread with screw pitch of 1mm. The rotation speed of the head should be kept in 600r/min; the welding test should be conducted at the welding speed of 50mm/min, 65mm/min and 80mm/min; the picture of appearance of weld is shown in Fig.1. It can be seen from Fig. 1 (a) that when the welding speed is 50 mm/min, the quality of weld appearance is poor and the welding surface is uneven and of many burrs, which causes overburning. It can be seen from Fig. 1 (b) that when the welding speed is 65 mm/min, the welding surface is even and smooth. It can be seen from Fig. 1 (c) that when the welding speed is 80 mm/min, the surface of weld is rough and of larger flash.

(a) ν =50 mm/min



(b) ν =65 mm/min



(c) ν =80 mm/min

Fig. 1. Effect of different welding speed on joint quality

3. Heat-flow analysis model

In traditional welding method, the unit thermal input will reduce with the increase on the welding speed; whether there is the same law in FSW process; in order to analyze the influence mechanism of welding speed on the joint quality, heat-flow analysis model based on fluid dynamics has been established; the materials serve as the laminar flow, stickiness and non-Newtonian fluid around rotation cylinder [8]. The heat-flow coupling on quasi-stable state is analyzed by solving equation of continuity, momentum equation and energy equation of fluid.

The heat input in the welding process comes from friction heat produced in the contact area between stir-welding head and work piece and heat produced from plastic deformation; when it reaches quasi-stable state, the friction shearing stress at any point in the contact area is equal to the shear stress when the materials is in plastic deformation [9]. The heat produced in the contract area between shaft shoulder, side and bottom surface of stirring needle and work piece should be considered.

The heat produced in the contract area between shaft shoulder and work piece due to friction and plastic deformation can be expressed as Equation (1):

$$q_{zj} = C_f(\frac{\pi n R}{30} - U \sin\theta)\tau_{yield}\,. \tag{1}$$

The heat input produced in the contract area between side of stirring needle and work piece due to friction and plastic deformation can be expressed as Equation (2):

$$q_{zc} = C_f(\frac{\pi n r}{30} - U \sin\theta)\tau_{yield}\,. \tag{2}$$

The heat input produced in the contract area between bottom of stirring needle and work piece due to friction and plastic deformation is the same as Equation (1).

In Equation (1) and (2), Cf refers to the proportion of heat input workpiece produced in the contact area between stir-welding head and workpiece, and it is 0.85 in the Thesis; n refers to rotation speed of the stir-welding head; U refers to movement speed of workpiece (the welding speed is equal to its size in the opposite direction); R refers to the distance from any point on the contact area between shaft shoulder and workpiece to spin axis of stir-welding head; r refer to radius of stirring needle; θ refers to the included angle between connection of any point on the contact area between stir-welding head and workpiece and spin axis and movement direction of workpiece. τ_{yield} refers to shear stress when the materials are in yield, and its relationship with yield strength is shown in Equation (3); the yield strength of materials decreases with the increase on temperature [5]; when the temperature reaches a certain value, the yield strength decreases to 0; the heat in the contact area between stir-welding head and work piece will not be produced, and the temperature will not rise.

$$\tau_{yield} = \sigma_s \big/ \sqrt{3}\,. \tag{3}$$

6061 aluminium alloy is used in the analysis; the melting point is 855 K; the density is smaller with change on temperature and its value is 2700 kg/m3; the heat conductivity coefficient λ, specific heat Cp and yield strength σ_s are fitted into Equation (4), (5) and (6) with variation of data with temperature [14]:

$$\lambda = 25.22 \ + \ 0.3978\mathrm{T} \ . \tag{4}$$

$$\mathrm{C}_p = 929.3 - 0.627\mathrm{T}\,. \tag{5}$$

$$\sigma_s = \begin{cases} 182.16 + 0.71544T - 0.00134T^2 & T \le 477 \\ 3671.57 - 14.29T + 0.0187T^2 & \mathrm{T} \le 855 \end{cases} \tag{6}$$

The stir-welding head rotates counterclockwise in computational model, and the rotation speed is 600r/min; the workpiece moves in constant speed from the left to right along the x positive direction. In order to save computation time, a part of the workpiece is taken for computation; the computational zone is in cylindrical shape; x direction is 52mm in length, namely twice diameter of shaft shoulder; z direction is 500mm in length and y direction is 6.3mm of thickness of plate, as shown in Fig. 2.

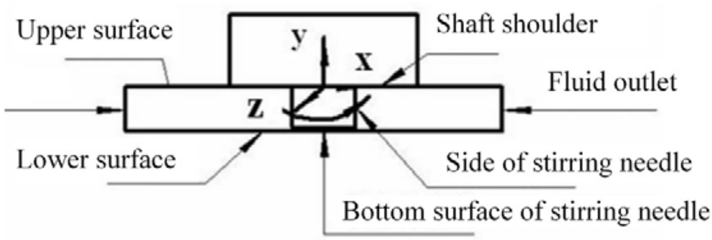


Fig. 2. Schematic of computational zone

The shaft shoulder, side and bottom surface of stirring needle serve as the boundary of heat input, and it heat flow is shown in Equation (1) and (2). The boundaries of upper surface, bottom surface, forward side and backward side are set as moving wall; the speed is the same with that of movement of work piece. The boundary of fluid inlet is set as the boundary condition of speed inlet, and the speed is equal to the movement speed of work piece; the boundary of fluid outlet is set as boundary conditions of pressure outlet. The upper is exposed to the air and it is a kind of heat convection boundary; the heat convection coefficient is 50 W/ (m2·K); the bottom surface contacts with base plate; the coefficient of heat conduction is 500 W/ (m2·K); the portion of forward side and backward side contacts with air; part of them contacts with fixture; the convection coefficient of heat conduction is set as 200 W/(m2·K); initial temperature is set as 300K.

Gambit is used to building model, divide grid and lead in computational fluid mechanics software Fluent for the computational zone; implicit, linear and separate solver is used to compute and disperse the grid. In the solution procedure, the standard discrete equation is used to compute pressure; second-order upwind equation is used to compute momentum equation; first-order upwind equation is used to compute energy equation.

4. Calculation result and analysis

4.1. Influence of welding speed in peak temperature

The corresponding peak temperature at different welding speed when the rotation speed is 600r/ min is shown in Fig. 3. It can be seen from Fig. 3 that the welding speed has little influence on peak temperature, and there is no obvious laws. The reasons that the welding speed is too low compared with the line speed of stir-welding head in the FSW speed; the welding speed has little influence on the heat input of welding process. It is different with the traditional welding method. Therefore, the production efficiency can be improved by proper increase on welding speed in FSW process. However, from the aspect of result of process test, excessively fast welding speed will make the quality of joint poor. When the welding speed is slow, only little materials flow from the front of stirring needle to the rear of stir-welding head to form weld. Although heat input does not increase, the less materials cause overburning. With the increase on welding speed, the materials involving in forming weld will increase and the quality of joint is better. However, the welding speed increases con continuously; unit heat is relatively reduced; liquidity is poor; partial materials cannot be moved normally, so as to form crack or groove.

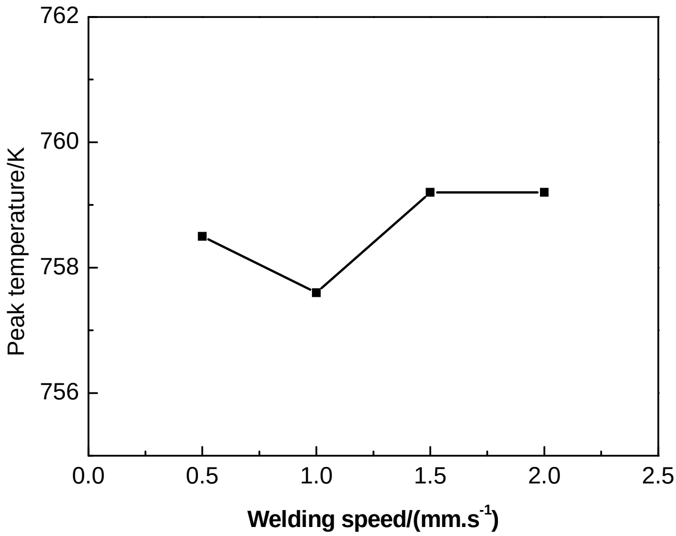


Fig. 3. Effect of different welding speed on peak temperature

4.2. Influence of welding speed on longitudinal force

Fig. 4. Effect of different welding speed on longitudinal force

The corresponding longitudinal force at different welding speed when the rotation speed is 600r/ min is shown in Fig. 4. It can be seen from the figure that the longitudinal force increases linearly with the increase on welding speed, larger and larger. The reason is that with the increase on welding speed, the material layer that the front of stir-welding head needs to be transferred to the rear is thickening, so that the forward resistance of stir-welding head increases, which may cause poor quality of joint. From the aspect of service life of tools, lower welding speed should be used, but the production efficiency will reduce. From the aspect of production, under the premise of ensuring quality, it hopes to improve production efficiency, reduce energy consumption and extend service life of tools. Therefore, comprehensive consideration should be taken to select weld process parameter; it is not allowed to blindly improve welding speed to enhance production efficiency.

5. Conclusion

1) Proper increase on welding speed will improve quality of joint, but excessively fast welding speed will make quality of joint poor.

2) Increase on welding speed will make materials involving in forming weld increase, make liquidity poor and forward resistance of stirring needle increase.

3) Comprehensive consideration should be taken to select welding speed to ensure quality of joint and improve production efficiency as far as possible.

Acknowledgement

The authors would like to thank the Shandong Province Key Projects of Research and Development (No. 2016GNC112006) and the Shandong Agriculture University Innovation Team for the financial support.

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Received May 7, 2017