The Influence of Thread Form on Refilling Friction Stir Welding of 2219 Aluminum Alloy Sheets

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1. Introduction

The material flow around welding tool during friction stir welding (FSW) is critical to determine the thermomechanical conditions during the process[1-3]. The refilling friction stir welding is a new solid-state joining technique which can provide a close track welded seam to many applications[4]. In refilling FSW process, the welding tool should meet the requirements of both normal welding process stage and pulling back stage. It is useful to be able to perform the simulation of the effect of thread form and welding parameters on the material flow fields of refilling FSW. Few work now has presented to demonstrate a sufficient level of complexity of achieve this goal. In this paper, a force analytical model was applied to analyze the motion characteristics of the thread form in the FSW process. A fluid analysis model using FLOW3D was developed to simulate the material flow in refilling FSW process. The material flow fields were analyzed in different welding speed, rotational speed, especially in three types of thread form. The material flow in different pulling back speed was also discussed. The method of volume of fluid (VOF) was also adopted to trace the voids in the welding process. The simulation is helpful to optimize welding process parameters to reduce the voids in the FSW.

2. Force analysis

The previous researches showed that the void can be reduced by the forced downward convection at the welding node zone and the heat mechanical affected zone[5, 6]. In the RF-FSW, the threaded stir-pin can provide the convection force. The diagram of force analysis is shown in Fig.1. where V is the welding speed, ω is the rotation speed of the stir head, F_ω is the friction force, FP is the pressure induced by the thread, F_B is the pulling-back force, F is the resultant force of F_ω and F_P, and the base metal will be in convection under the resultant force F. Since the base metal around the stir-pin is plastic, the pressure force FP is much less than the friction force F_ω. In addition, the depth of the thread is less than 0.5mm, and the metal far from the stir-pin is slightly influenced by the thread. Thus, there is a small downward convection of the plastic base metal and the motion of the metal is mostly along the circumferential direction of the stir-pin.

The stir-shoulder presses at the top surface of the base metal during the pulling-back stage to ensure the downward flow. The point A, point B and point C in Fig.2 are influenced by the next three forces: the extrusion force F_{AS}, the downward pressure F_Y and the friction force Fω, while the point D is influenced by only F_Y and F_ω. The drag force at the point D is weak, and it can be neglected. The point A is the start point that the metal begins to plasticizing, and then the metal flows by the stir-shoulder to the point D. Because of the downward pressure by the stir-shoulder, the metal will flow to the back of the stir-head and fill the void left by the motion of the stir-pin. As the fluidity of the metal is not able to fill all the voids, the defects are formed. The stir-head plays two roles in the welding process, namely rotation and translation, the pin move forward one unit length after the stir-head rotates one round.

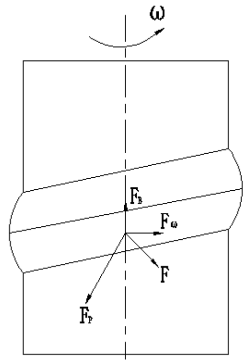


Fig.1 Diagram of force analysis on the thread

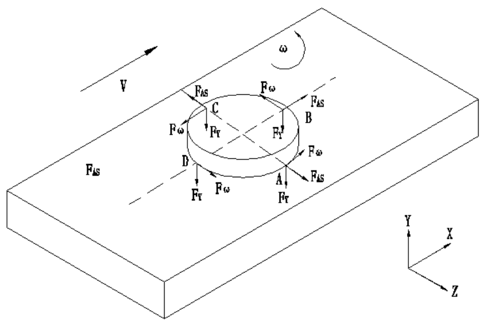


Fig.2 Diagram of the force at the stir-shoulder

The distance *l* of the motion can be described as,

$$l = \frac{2\pi V}{\omega} \tag{1}$$

In the RF-FSW, the pulling-back distance of the stir-pin can be described as,

$$h = \frac{2\pi V_P}{\omega} \tag{2}$$

where, V is the welding speed, V_P is the pulling-back speed of the stir-pin, ω is the angular velocity of the stir-head. The ratio of the pulling-back distance and the translation distance is:

$$C = \frac{h}{l} = \frac{V}{V_P} \tag{3}$$

In this experiment, the stir-head will move 0.25 mm when it rotates one round. The translation of the stir-head and the pulling back of the stir-pin will form the negative pressure behind the stir-head and the bottom of the stir-pin. Because of the negative pressure, the voids may be formed.

3. Simulation model

In order to analysis the flow behaviors in the RF-FSW process, a simulation model was established. The simulation was based on the equations of fluid flow, which contains the mass continuity equation, the momentum equations and the energy equation. The volume of fluid model was also considered to trace the void. In this model, the diameter of the stir-shoulder and the stir-pin were 24 mm and 8 mm, respectively. The press-in depth was 0.5 mm. As shown in Fig.3, the simulation model used the following three kind of the stir-pin: smooth, 1.2 mm thread pitch and 0.6 mm thread pitch.

(a) smooth (b) 1.2 mm (c) 0.6 mm

Fig.3 The model of fluid flow simulation and stir-pin

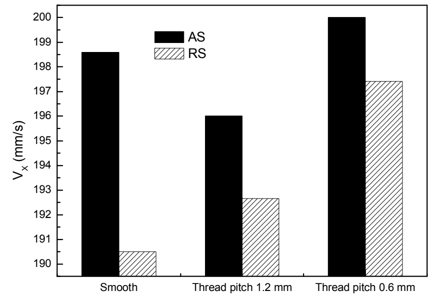
In the simulation, the stir-head stayed at the start point for 0.4 second to simulate the heating stage of the welding, and then the stir-head started the welding process. The convection coefficient of the bottom boundary and other boundaries are 1000 W/m^2°C and 10 W/m^2°C, respectively. The reference process parameters of the welding process are shown in Table 1.

Table 1 The welding process of the RF-FSW

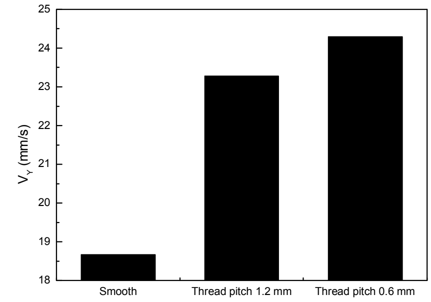
Welding speed (mm/s)	Angular velocity (rad/s)	Pulling-back speed (mm/s)	Thread pitch (mm)
3.33	83.8	0.2	varied

4. Result and Discussion

The thread of the stir-pin will strongly influence the flow in the thickness direction of the RF-FSW, especially in the pulling-back stage. Figure 4 shows the velocity of the metal as the V_P is 0.6 mm/s. Comparing with the smooth stir-pin, the downward speed of the metal is accelerated. As V_P = 0.4 mm/s, the V_Y increases 21.9% and 9.6% by using the thread pitch of 1.2 mm and 0.6 mm respectively, while the V_Y increases 24.7% and 30.2% as V_P = 0.6 mm/s. On other hand, the increase of the V_X is lower than 3.6%. Based on the above results, the thread on the stir-pin can accelerate the metal to flow downward, and the influence on the V_Y is much stronger than on the V_X. If the V_P is low, the large thread pitch can fill the void better, while the V_P is high, the small thread pitch is better.



(a) V_X



(b) V_Y

Fig.4 The influence of the thread pitch under the V_P of 0.6 mm/s

5. Conclusion

In this paper, the force analysis and the numerical simulation were applied to the study the material flow in the RF-FSW for 2219 aluminum alloy sheets. The following conclusions are derived.

(1) The stir-pin with threads can provide the force which can ensure the metal flows downward. If the velocity along the welding direction is so high to form the voids, the downward flow can fill the voids and reduce the defects.

(2) The stir-pin with 1.2 mm and 0.6 mm thread pitch can increase the downward velocity by 21.9% and 24.7%, and the downward flow will fill the voids below the stir-head.

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