The Effect of Main Factors on Forces during FSJ Processing of AA2024 Aluminum

Dunwen Zuo, Yongfang Deng, Bo Song

***Abstract*—**An attempt is made here to measure the forces of three directions, under conditions of different feed speeds, different tilt angles of tool and without or with the pin on the tool, by using octagonal ring dynamometer in the AA2024 aluminum FSJ (Friction Stir Joining) process, and investigate how four main factors influence forces in the FSJ process. It is found that, high feed speed lead to small feed force and small lateral force, but high feed speed leads to large feed force in the stable joining stage of process. As the rotational speed increasing, the time of axial force drop from the maximum to the minimum required increased in the push-up process. In the stable joining stage, the rotational speed has little effect on the feed force; large rotational speed leads to small lateral force and axial force. The maximum axial force increases as the tilt angle of tool increases at the downward movement stage. At the moment of start feeding, as tilt angle of tool increases, the amplitudes of the axial force increasing become large. In the stable joining stage, with the increase of tilt angle of tool, the axial force is increased, the lateral force is decreased, and the feed force almost unchanged. The tool with pin will decrease axial force in the downward movement stage. The feed force and lateral force will increase, but the axial force will reduced in the stable joining stage by using the tool with pin compare to by using the tool without pin.

***Keywords*—**FSJ, force factor, AA2024, friction stir joining.

I. Introduction

FRICTION Stir Joining (FSJ, also called FSW, Friction Stir Welding) is a solid state joining process invented by The Welding Institute (TWI, UK) in 1991[1]. By the advent of this technology, it has been favored by aviation industry and become the best choice to aluminum connection [2]-[5]. 2024 aluminum alloy with high strength, low density, etc., has been widely used in the aviation industry, for example: in traditional, aircraft fuselage skin, stiffened plate, wing framework, etc., manufacture by 2024 aluminum alloy. So, FSJ technology for 2024 aluminum alloy requires in-depth study. The force which acts on the tool has a significant impact on the joint forming, microstructure and properties of joints in the FSJ processing. It is significance on studying the process force which act on tool.

Sorensen and Stahl [6] studied feed load in the FSJ process and find that the size of feed load change with the varying of needle size and radius on the tool. Kumar and Elangovan [7], [8] have investigated the relationship between axial force and joint organizations, mechanical properties. Crawford and Cook [9] studied feed load in the FSJ processing, and believe there is a certain relationship between the feed load and rotational speed of tool. Xijing Wang, Zhongke Zhang et al. [10] studied the varying of feed load in the FSJ processing and believed that, when joining the same material, feed load increasing along with the joining speed, amount of indentation or the thickness of the material increasing and, when joining the different materials, feed load of joining the high hardness material is greater than feed load of joining the low hardness material. Xijing Wang et al. [11], [12] studied it by measuring the output power of the motor, which driven horizontal table movement and installed on the FSJ machine, to calculate the force between the workpiece and the tool. Reference [13] simulates torque and power output in the FSJ process. Some researchers have studied the forces of some directions in the FSJ processing and discussed some influencing factors for some single direction forces, but study on factors for single direction force is not sufficient to characterize force states to the FSJ processing. However, practically no information is available in open literature about how the main factors for FSJ processing affect the forces of three directions. Therefore, an attempt is made here to investigate law about how four main factors of the FSJ processing influence forces in the FSJ processing.

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II. Experiment Procedure

Aluminum alloys AA2024-T3 which have the chemical composition listed in Table I, were used in this research work. The yield strength, ultimate tensile strength, uniform elongation and total elongation of the alloy are 205 and 337MPa and 13.2% and 13.7%, respectively. Plates of size 200mm×100mm×3.2mm were prepared from the rolled plates.

TABLE I
CHEMICAL COMPOSITION OF 2024 AL ALLOY (MASS FRACTION, %)

Si	Cu	Mn	Mg	Zn	Al
0.5	4.24	0.6	1.34	0.076	Balance

Friction stir welding was performed on the FSJ machine of FSW2-4CX-006C. Prior to FSJ processing, the surface oxides were removed and the surface was cleaned using ethanol and the plates were friction stir butt joined along the rolling direction. Force on the tool is measured by dislocation octagonal-ring dynamometer with the linearity of pressure sensor 0.03. Octagonal ring dynamometer placed on the table, plate placed on the octagonal ring dynamometer. The pressure sensor is connected to the signal acquisition, and its output is a pressure signal. Pressure signal acquisition use JW5200 data collection instrument. Through the digital-analog conversion, the voltage signal which the data acquisition instrument captured is converted into a digital signal, and the data displayed on the display device. Experiment scheme shown in Fig. 1.

Fig. 1 Experiment scheme

Before the test, calibrate octagonal ring dynamometer is need here. Octagonal ring dynamometer fixed on the workbench by meeting requirement of force direction. Checking and adjusting the level of the workbench of the octagonal ring dynamometer before the test start. workpiece placed on the plate, joining line located in the middle of the octagonal ring dynamometer. The joining starts after the workpiece clamping tight. The threaded taper tool with 3.0mm in top diameter and 3.0mm long were used in the process. The scrolled shoulder had 12mm in diameter. In order to investigate the main factors for FSJ processing affect the forces of three directions, the following tests were carried out:

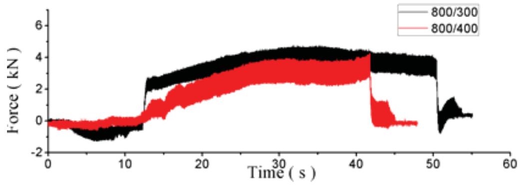
1. While the joining were performed at 2° tilt angle, 0.05mm downward distance of tool, and under moving the tool at 800rpm rotational speeds, 300mm/min and 400mm/min feed speed are used in the forces test.
2. While the joining were performed at 2° tilt angle, 0.05mm downward distance of tool, and under moving the tool at 400mm/min feed speed, 600rpm and 800rpm rotational speeds are used in the forces test.
3. While the joining were performed at 0.2mm downward distance of tool, and under position control by moving the tool at 950mm/min feed speed and 300rpm rotational speed, 0° tilt angle and 2° tilt angle are used in the forces test.
4. While the joining were performed at 2° tilt angle, 0.05mm downward distance of tool , and under position control by moving the tool at 600mm/min feed speed and 100rpm rotational speed, tools with or without pin are used in the forces test.

III. Results and Discussion

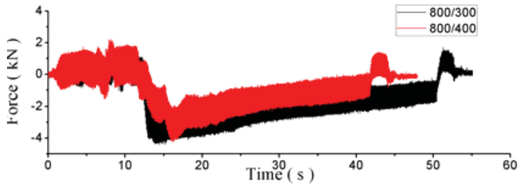
A. The Effect of Feed Speed

While the joining was performed at 2° tilt angle, 0.05mm downward distance of tool, and under moving the tool at 800rpm rotational speed. 300mm/min and 400mm/min feed speeds are used in the forces test. Tool force curves can be obtained as shown in Fig. 2.

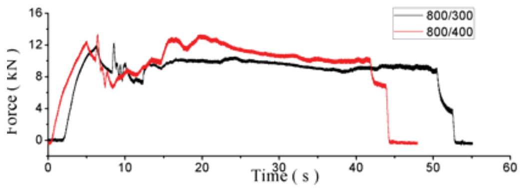
Comparing force curves in Fig. 2, in the 0-15s, the tool under the stage of push-up with the tool rotation, but the tool has no feed motion. At this stage, all of feed force, lateral force and axial force of the different feed speed substantially the same. This is because, with the same speed, the joining process is basically the same under the downward stage. The outputs of feed force and lateral force in the tool are small, almost zero, while the value of the axial force in the tool increases with time, reaching a maximum value 12.5kN at 8s. After 8s, the axial force starts to decrease, and in the final stage of push-up, the minimum value of push-up, 5kN, is reached. When the 12s, the tool start to feed, feed force, lateral force and axial force are suddenly increased. Some minutes later, the process will reach a stable joining stage, and the forces acting on the tool become stabilize. In the stable joining stage, high feed speed lead to small feed force in the stable join process, and large feed speed also lead to small lateral force of tool in the join process. But the same trend cannot get in the axial force that high feed speed leads to large feed force in the stable join process.



(a) Feed force



(b) Lateral force



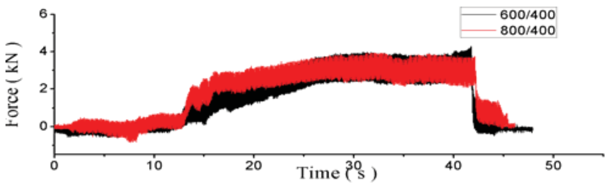
(c) Axial force

Fig. 2 Force curves under different feed speeds of tool

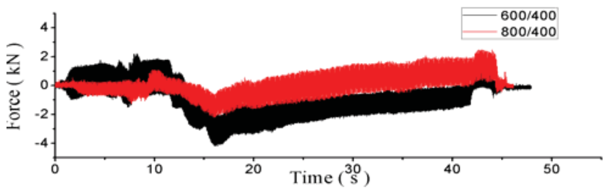
B. The Effect of Rotational Speed

While the joining were performed at 2° tilt angle, 0.05mm downward distance of tool, and under moving the tool at 400mm/min feed speed, 600rpm and 800rpm rotational speeds are used in the forces test. Tool force curves can be obtained as shown in Fig. 3.

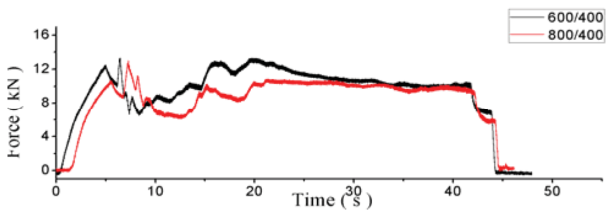
Comparing force curves in Fig. 3, in the 0-15s, the tool under the stage of push-up with the tool rotation, but the tool has no feed motion. At this stage, the outputs of feed force and lateral force in the tool are small, almost zero, while the value of the axial force in the tool increases with time, reaching a maximum value 12.5kN at 8s. After 8s, as the material soften, the axial force starts to decrease. After the axial force decrease to the minimum, the axial force began increase until the tool start feed. As the rotational speed increasing, the time of axial force drop from the maximum to the minimum required increased. When about 15s, the tool start to feed, feed force, lateral force and axial force are suddenly increased. Some minutes later, the process will reach a stable joining stage, and the forces acting on the tool become stabilize. In the stable joining stage, the feed forces of tools at different rotational speeds show almost the same value. This means that the rotational speed has little effect on the feed force. Large rotational speed leads to small lateral force of tool in the stable joining process. And the same trend can get in the axial force that high rotational speed leads to small feed force in the stable joining process.



(a) Feed force



(b) Lateral force



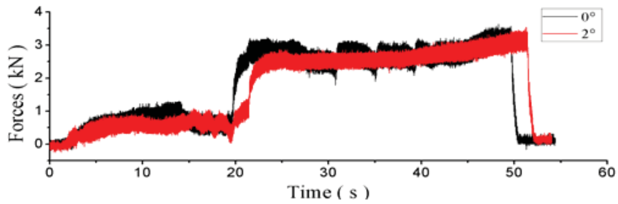
(c) Axial force

Fig. 3 Force curves under different rotational speed of tool

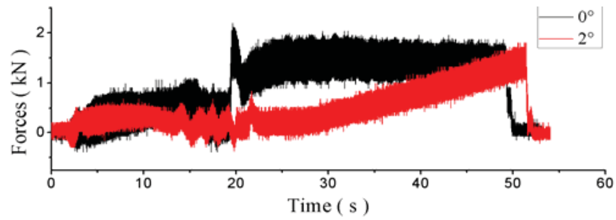
C. The Effect of Tilt Angle of Tool

While the joining were performed at a 0.2mm downward distance of tool, and under position control by moving the tool at 950mm/min travelling speed and 300rpm rotational speed, tool with 0° tilt angle and 2° tilt angle are used in the forces test. Tool force curves in the three directions can be obtained as shown in Fig. 4.

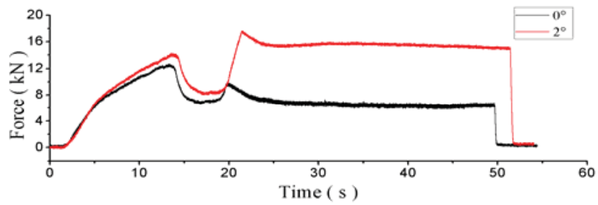
Comparing three force curves in Fig. 4, in the 0-20s, the tool under the stage of push-up with the tool rotation, but the tool has no feed motion. At this stage, the outputs of feed force and lateral force in the tool are small, almost zero, while the value of the axial force in the tool increases with time, reaching a maximum value at about 12s. Corresponding to the value of tilt angles 0°and 2°, respectively, maximum axial force is 12.5kN, and 14.5kN. It is clear that the maximum axial force increases as the tilt angle increases at the downward movement stage. After reach the maximum value, the axial force starts to decrease, and in the final stage of push-up, the minimum value of axial force is reached. When the 20s, the tool start to feed, feed force, lateral force, and axial force suddenly increased. At the moment of start feeding, as tilt angle of tool increases, the amplitudes of the axial force increasing become large. In the stable joining stage, with the increase of tilt angle of tool, the axial force is increased, the lateral force is decreased, and the feed force almost unchanged.



(a) Feed force



(b) Lateral force



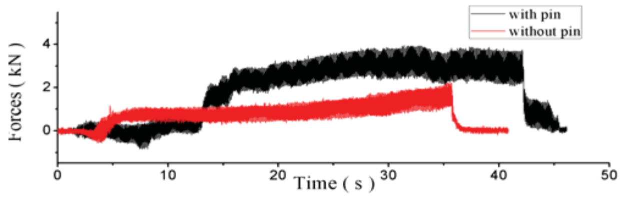
(c) Axial force

Fig. 4 Force curves under different tilt angles

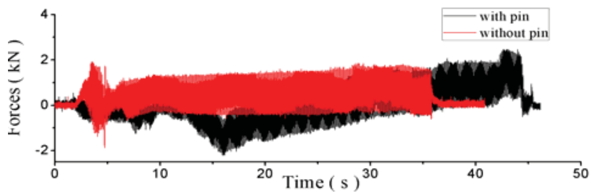
D. The Effect of Tool with or without Pin

While the joining were performed using tool with 2° tilt angle, a 0.05mm downward distance of tool, and under position control by moving the tool at 600mm/min travelling speed and 100rpm rotational speed, tools with or without pin are used in the forces test. Three tool force curves can be obtained as shown in Fig. 5.

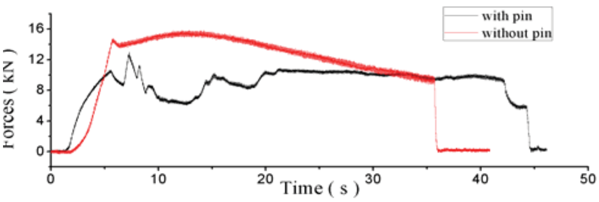
Form Fig. 5, it is clear that, in the stage of push-up with the tool rotation and the tool has no feed motion, the outputs of feed force and lateral force in the tool are small, almost zero and the axial force is increased with time. The tool with pin, the value of the axial force reaches a maximum 12.5kN at 8s. But the tool without pin, the value of the axial force reaches a maximum 14kN at 8s. After 8s, the axial force starts to decrease. It is because, after a certain time, accumulating frictional heat caused material softens. In the final stage of push-up, the minimum value of axial force, 3.5kN, is reached. For the process using the tool without pin, after reaching the maximum value, the axial force is only slightly reduced. This is because without pin, most of the material does not reach the softened state. At downward movement stage, the joining process using tool without pin needs more axial force than joining process using tool with pin. When the tool start to feed, feed force, lateral force, and axial force all suddenly increased in the process using tool with the pin. But for the process using tool without pin, feed force, lateral force, and axial force have no significant change. In the stable joining stage, feed force and lateral force is small, the value is 2kN, 2kN, respectively in the joining process using tool with pin. While the value of feed force and lateral force is 1kN, 0.5kN, respectively in the joining process using tool without pin. In the stable joining stage, axial force is 7.5kN for the joining process using tool with pin, while the mean value is 10kN for the process using tool without pin. It is clear that feed force need less for the joining process using tool with pin than for the joining process using tool without pin. The feed force and lateral force will increase, but the axial force will reduced in the stable joining stage by using the tool with pin compare to by using the tool without pin.



(a) Feed force



(b) Lateral force



(c) Axial force

Fig. 5 The effect of pin for forces

IV. Conclusion

1. In the stable joining stage, high feed speed lead to small feed force and small lateral force, but high feed speed leads to large feed force in the stable join process.
2. As the rotational speed increasing, the time of axial force drop from the maximum to the minimum required increased in the push-up process. In the stable joining stage, the rotational speed has little effect on the feed force. Large rotational speed leads to small lateral force and axial force.
3. The maximum axial force increases as the tilt angle of tool increases at the downward movement stage. At the moment of start feeding, as tilt angle of tool increases, the amplitudes of the axial force increasing become large. In the stable joining stage, with the increase of tilt angle of tool, the axial force is increased, the lateral force is decreased, and the feed force almost unchanged.
4. The tool with pin will decrease axial force in the downward movement stage. The feed force and lateral force will increase, but the axial force will reduced in the stable joining stage by using the tool with pin compare to by using the tool without pin.

Acknowledgment

The work was supported by Funding of Jiangsu Innovation Program for Graduate Education (CXZZ13_0152), Funding for the National Natural Science Foundation of China (51175255) and the Fundamental Research Funds for the Central Universities in P.R. China.

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