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Effect of Process Parameters on Structure and Mechanical Properties of Friction Stir Welding Joint of 5052 Aluminum Alloy

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Abstract. 2.5 mm thick sheets of AA5052 were welded using friction stir welding technology. The effects of welding speed, rotational speed of pin, length of pin, single-side and double-side welding process on the morphology, microstructure and mechanical properties of welded joints were studied and analyzed. The failure mode was studied. The results show that the joints with good mechanical properties and without welding defects can be welded when the rotational speed of pin is 500-1200r/min and the welding speed is 100-480mm/min. The microstructure of weld nugget is mainly composed of α phase solid solution and β phase particles. The process parameters of friction stir welding have great influence on the static strength of welded joints. The static strength increases with the increasing of rotational speed of pin, however decreases with the increasing of welding speed. The peak load of the double-side welding increases by 30% compared with the single-side welding. The length of pin has little effect on the tensile strength. The tensile fracture of the single-side welding is located in the weld nugget zone, whereas the fracture of double-side welding is located in the base material zone.

1. Introduction

Aluminum alloy has been widely used in aerospace, machinery, automobile manufacturing and other fields because of its high strength-to-weight ratio and easy forming. However, due to its low melting point and high linear expansion coefficient, the weldability of traditional fusion welding techniques is poor. Friction stir welding (FSW) is a new solid-state bonding technology. In the bonding process, the base material does not melt, which can avoid traditional welding defects such as cracks and blowholes, and the welding deformation is not serious. FSW can effectively realize the connection of non-ferrous metals such as aluminum, magnesium and titanium alloys [1-5]. A large number of scholars are studying the technology, forming and principle of friction stir welding and so on.

In this paper, sheets of AA5052 were friction stir welded in order to reveal the effects of different process parameters on the structure and mechanical properties of welded joints.

2. Experimental Preparation

2.1. Experimental Materials

The equipment used in this test is FSW-LM-025-2540 friction stir welding machine produced by Jiangsu Ruicheng Machinery Co., Ltd. The test material is 250 mm \times 80 mm \times 2.5 mm thick sheet of AA5052. The chemical composition and mechanical properties of AA5052 are shown in Table 1.



Table 1. Chemical composition ($\omega\%$) and mechanical properties of AA5052

Mg	Cr	Fe	Cu	Zn	Mn	Si	Al	Tensile strength σ_b (MPa)	Conditional yield strength $\sigma_{0.2}$ (MPa)
2.4	0.28	0.33	0.05	0.05	0.09	0.08	Bal.	200	90

2.2. Experimental Method

AA5052 sheets were friction stir welded together using a tool with a 10mm diameter shoulder and a 3.2mm diameter pin. The tilt angle of the pin is set to 2.5° . The effects of welding speed, rotational speed of pin, length of pin, single-side and double-side welding process parameters on weld formation and properties were discussed. The welding parameters are shown in Table 2.

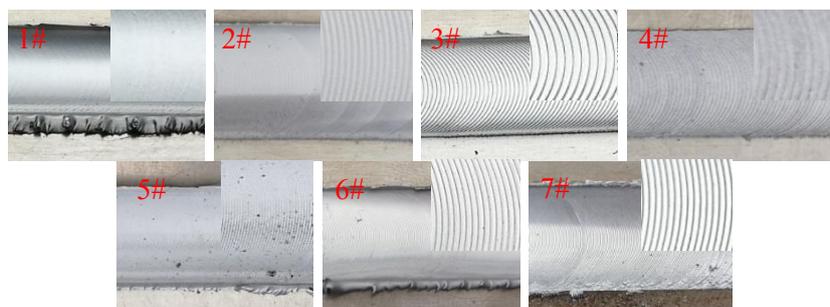
Table 2. Welding parameters

No.	Length of pin H(mm)	Rotational speed of pin R(r/min)	Welding speed V(mm/min)	Forming process
1#	3	1200	100	Single-side
2#	3	1200	200	Single-side
3#	3	1200	480	Single-side
4#	3	500	200	Single-side
5#	3	1500	200	Single-side
6#	2	1200	200	Single-side
7#	2	1200	200	Double-side

3. Results and Analysis

3.1. Surface of Welded Joints

Figure 1 shows the surface forming of the welded joints. The surface quality of the welds is good, but there are some burrs. Obvious arc stripe can also be observed from the joint surface, which are the scratches left when FSW tool shoulder rotates at a high speed. The stripe spacing is the distance that the tool moves along the welding direction during the tool rotates exactly one circle. It can be seen from the 1 #, 2 # and 3 # specimens in Figure 1 that the higher the welding speed is, the bigger the stripe spacing is, and the rougher the joint surface is. The burr of the 1 # specimen is serious, but the joint surface is beautiful and smooth. It can be seen that with the increase of speed of pin and the decrease of welding speed, the stripe spacing becomes denser. The small black particles in the joint surface increase obviously when the rotational speed of pin reaches 1500 r/min. The friction between FSW tool and metal sheets increases with the increase of rotational speed, so that the welding heat input increases, which is beneficial to weld formation. However, some weld metal may melt due to overheating when welding heat input is too much, resulting in the decrease of metal viscosity on the weld surface. So many small particles will remain on the joint surface. Because the rotational speed of pin and the welding speed are the same, the stripe spacing of the joint surface of 2 #, 6 # and 7 # specimens is the same.

**Figure 1.** Surface of the welded joints

3.2. Microstructure of Welded Joints

Figure 2 shows the microstructure of the welded joint. Figure 2(a) shows that the base metal was hot rolled. During hot rolling, the grains, the second phases and segregation in the metal were elongated with the deformation of the structure so that it is typical fibrous rheological structure along the direction of deformation. Because of the strong stirring and friction under the combined action of the stirring force and friction heat of the FSW tool, the initial fibrous rheological structure was distorted and broken up, and eventually disappeared. At the same time, with the influence of the welding thermal cycle, dynamic recrystallization occurred to form fine and uniform β phase and α phase solid solution in the weld nugget zone (WNZ), as shown in Figure 2(b). The thermo-mechanically affected zone (TMAZ) was both stirred by FSW tool and heated by thermal cycle, which resulted in the deformation of fibrous structure. At the same time, some of the second phases dissolved and regrouped, as shown in Figure 2(c). The heat affected zone (HAZ) was only affected by the welding thermal cycle and was not affected by the stirring action, so it remained fibrous structure, as shown in Figure 2(d).

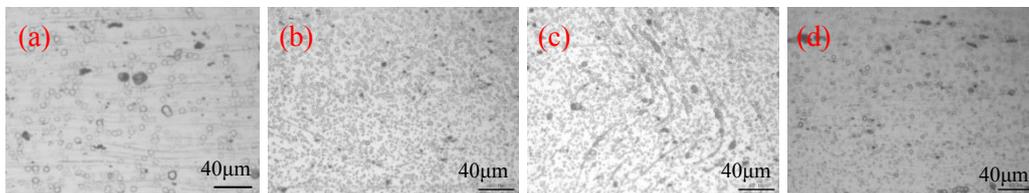


Figure 2. Microstructure of (a) base material, (b) WNZ, (c) TMAZ and (d) HAZ

3.3. Mechanical Properties of Welded Joints

Figure 3 shows the effect of single-side and double-side welding forming process on the tensile properties of welded joints. In the test, the peak load when FSW joint destroyed acts as static strength index. The peak load is 9.20KN in single-side welding and 11.97KN in double-side welding, respectively. The peak load of double-side welding was increased by about 30% compared with the single-side welding process. This is because two sides in double-side forming were welded well, whereas the back side of the FSW joint in single-side forming was not welded well.

Figure 4 shows the effect of length of pin on the tensile properties of welded joints. The pin length has little effect on the tensile strength. The peak load at 3mm was 9.53KN, which was slightly higher than that at 2mm. This is because the increase of the length of pin has little effect on the contact area between the cylindrical surface of pin and the sheet metals so that the stirring degree and heat input change little in the welding process, resulting in little difference in joint strength.

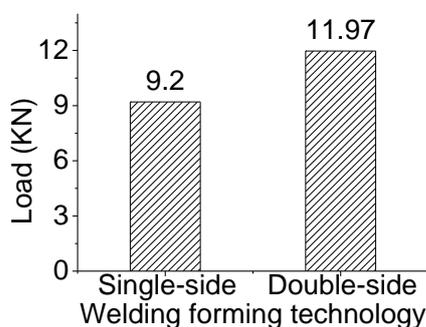


Figure 3. Effect of welding forming technology

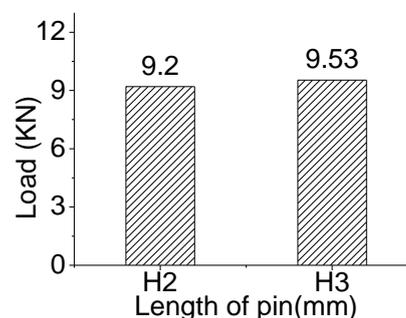


Figure 4. Effect of length of pin

Figure 5 shows the effect of welding speed on the tensile properties of welded joints. The peak load of FSW joints with welding speed of 100 mm/min, 200 mm/min and 480 mm/min were 12.03 KN, 9.53 KN and 7.53 KN, respectively. It can be seen with the increase of welding speed, the peak load

decreased. With the increase of welding speed, the stirring degree and heat input per unit length of weld seam decrease, which leads to the decrease of connection quality of FSW joint.

Figure 6 shows the effect of rotational speed of pin on the tensile properties of welded joints. With the increase of welding speed and rotational speed of pin, the tensile strength increased. The peak load of FSW joints with rotational speed of 500 mm/min, 1200 mm/min and 1500 r/min were 7.28 KN, 9.53 KN and 11.45 KN, respectively. With the increase of rotational speed of pin, friction heat increases, plastic flow is more sufficient and joint quality is better.

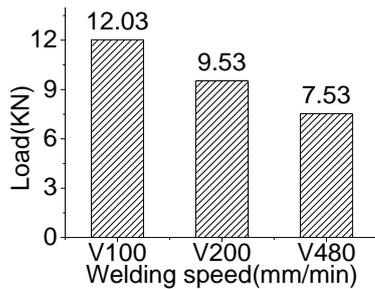


Figure 5. Effect of welding speed

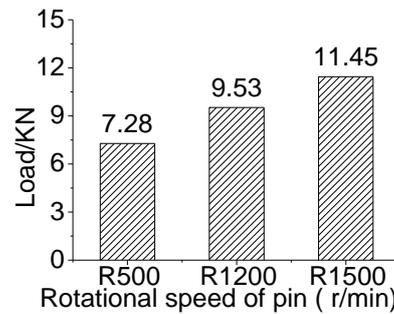


Figure 6. Effect of rotational speed of pin

3.4. Analysis of Failure Forms

The failure modes of welded joints are shown in Figure 7. In single-side welding, the fracture mainly occurred in the weld nugget zone, whereas in double-side welding, the fracture occurred in the base material zone. The reason is that the forming of back side in single-side welding is not as good as the double-side welding.

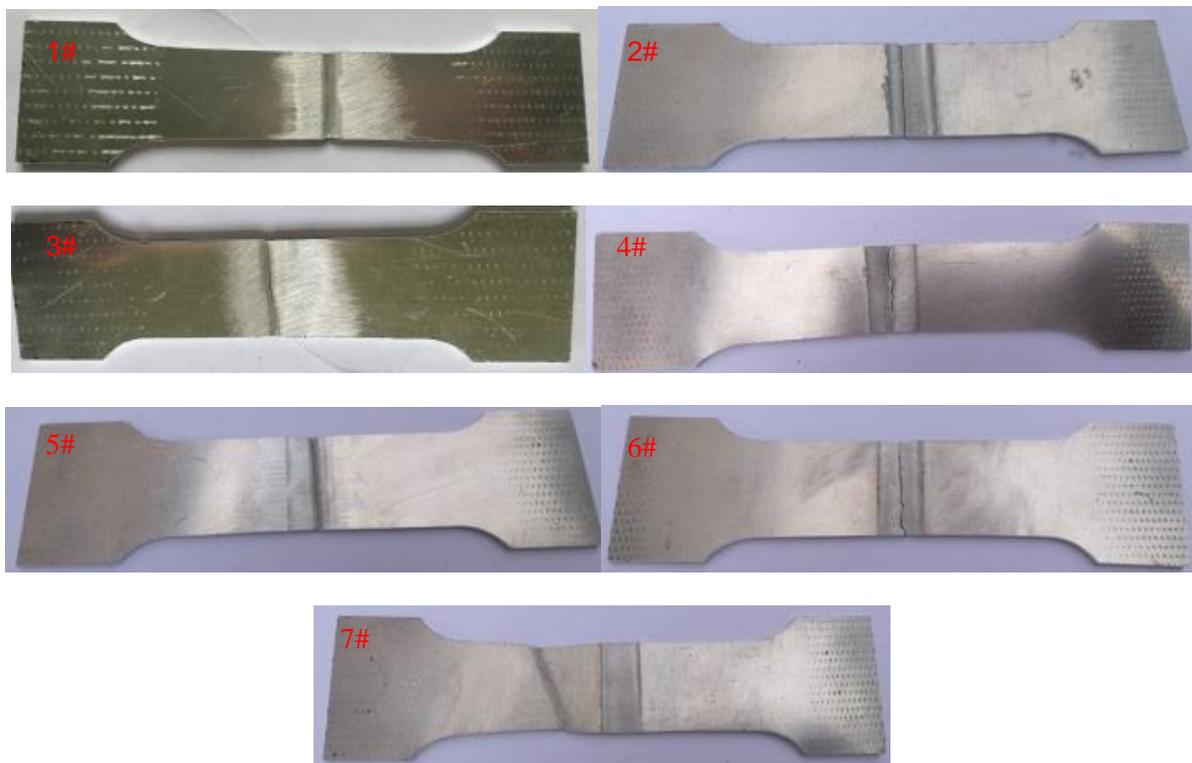


Figure 7. Failure forms

4. Conclusions

(1) FSW joints without welding defects can be welded when the rotational speed of pin is 500-1200r/min and the welding speed is 100-480mm/min.

(2) FSW joint consists of several distinct microstructural zones such as WNZ, TMAZ and HAZ. The microstructure of the WNZ is small and uniform particles of β phase distributed on the α phase solid solution.

(3) The peak load of double-side welding process is about 30% higher than the single-side welding process. The length of pin has little effect on the tensile strength. With the increase of rotational speed of pin, the static strength increases. However with the increase of welding speed, the static strength decreases.

5. Acknowledgement

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6. References

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