

Mechanical Properties of Al/Steel Composite Plates Fabricated via Friction Stir Processing

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Abstract. The mechanical properties of Al/steel composite plates fabricated by friction stir processing were investigated through micro-hardness and shear test. The tool rotational speed is in the range of 800-1500 r/min. The welding speed is in the range of 40-80 mm/min. The plunge depth is in the range of 0-0.7 mm. The effects of friction stir process parameters to the mechanical properties are analyzed.

1. Introduction

Friction stir processing is a solid state metal joining technology. In this process, a solid body is used to join the two metals by excessive localized plastic deformation. The mechanical properties of composite plates fabricated via friction stir processing mainly depend on the plasticity and fluidity of composite metal during the process. In the past, some researchers investigated the mechanical properties of different alloys.

Han et al. [1] studied the mechanical properties, microstructure evolution and subsequent aging performance in both as cast and as quenched conditions of Mg-14 wt% Gd alloys subjected to friction stir processing. Kumar et al. [2] studied the microstructure and mechanical properties of AISI 316L austenitic stainless steel welded by friction stir processing. The results show that the discontinuous dynamic recrystallization was the main recrystallization mechanism in the stir zone. Devaraju et al. [3] studied the effect of cryogenic cooling on the mechanical properties of 2014 aluminum alloy joint produced by friction stir welding. The results indicate that the tool pin profile and welding parameters play a major role to the weld quality. Sashank et al. [4] made an attempt to investigate the microstructure evolution and mechanical properties of friction stir welding of 6063 aluminum alloy. The mechanical properties were optimized by adjusting the welding speed and rotational speed. Das et al. [5] compared the mechanical properties and microstructure of friction stir welding of complex phase and ultrahigh strength dual phase steels based on the experimental results. Naveen et al. [6] investigated the influence of tool pin profiles on the mechanical properties and temperature rise of friction stir welded AZ31 alloy. Nagabharam et al. [7] made an attempt to study the effect of tool pin profiles, rotational speed and traversing speed on friction stir processing zone transformation in copper. The optimum mechanical properties of the friction stir welding of copper were found out.

In this paper, the mechanical properties of Al/steel composite plates fabricated using the friction stir processing were investigated. The effects of different parameters on the mechanical properties were analyzed.



2. Material and Experimental

The thicknesses of 5A06 aluminum alloy and 316L stainless steel used in this investigation are 4mm and 2mm, respectively. The chemical compositions of the test materials are shown in Table 1 and Table 2, respectively. The schematic representation of process test is shown in Fig. 1. The tool rotational speed is in the range of 800-1500 r/min. The welding speed is in the range of 40-80 mm/min.

Table 1. Chemical composition of 5A06 aluminum alloy (wt.%).

Si	Cu	Mn	Mg	Ti	Zn	Al
0.40	0.10	0.68	6.30	0.07	0.20	Bal

Table 2. Chemical composition of 316L stainless steel (wt.%).

C	Cr	Ni	Mo	Mn	Si	P	S	Fe
0.03	17.20	13.65	2.40	2.00	1.00	0.035	0.03	bal

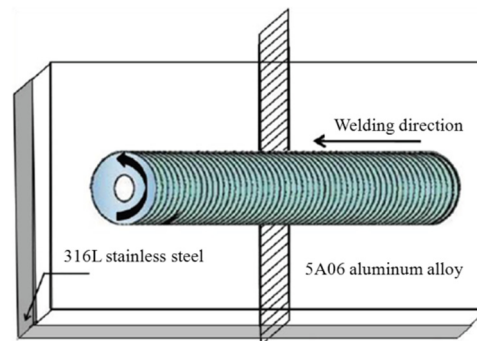


Figure 1. Schematic representation of process test.

3. Results and Discussions

3.1. Micro-hardness of Al/steel composite structure

The micro-hardness distribution of Al/steel composite structure fabricated by friction stir processing is shown in Fig. 2. The tool rotational speed is 1200 r/min and the traverse speed is 60 mm/min. The plunge depth is 0.1 mm. The hardness can be divided into four zones: shoulder affected zone, middle part of welding zone, bottom of welding zone and thermo-mechanically affected zone. It can be seen that the micro-hardness of composite structure shows an inhomogeneous trend. The middle part of welding zone hardness is relatively uniform and below the hardness value of aluminum alloy. The hardness is relatively high in the bottom of welding zone and the maximum value is about 370HV. The zone close to the interface of stainless steel is affected by both thermal and mechanical effects. Due to microstructure refinement, the micro-hardness is relatively high in this area.

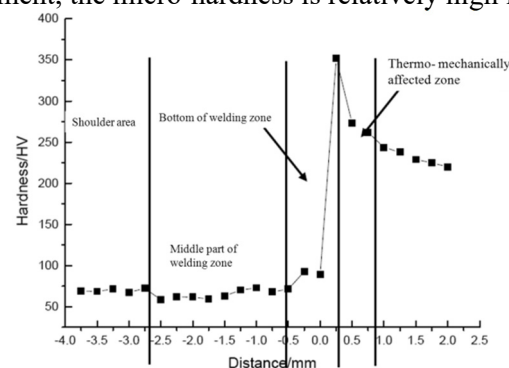


Figure 2. The micro-hardness distribution of Al/steel composite structure.

3.2. Tensile mechanical properties of Al/steel composite structure

The strain-load curve of shear test is shown in Fig. 3. The tool rotational speed is 1200 r/min and the traverse speed is 60 mm/min. The plunge depth is 0.1 mm. It can be seen that the composite structure has no obvious yield behavior during the shear test.

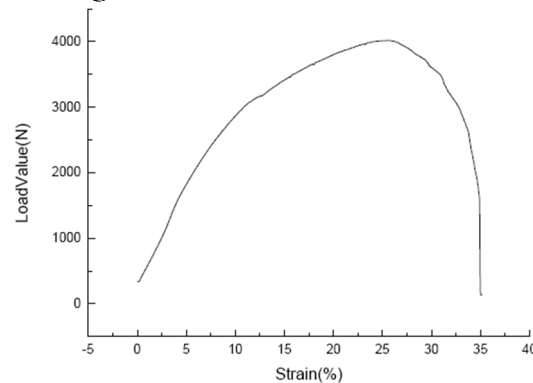


Figure 3. The typical strain-load curve of composite structure.

The specimens before and after shear test are shown in Fig. 4. Most of the shear fracture locations of composite structure are at the heat affected zone close to the aluminum alloy. The fracture morphology is irregular. The fractures of shear test in this investigation take place in the interface, because the strength of 5A06 aluminum alloy with 4 mm depth is higher.



Figure 4. The specimens before and after test.

The failure loads of different process parameters are shown in Table 3. It can be seen that the failure loads change greatly. The minimum failure load is 2.39 KN when the tool rotational speed is 1500 r/min and the traverse speed is 80 mm/min. The maximum failure load is 5.67 KN when the tool rotational speed is 1200 r/min and the traverse speed is 60 mm/min.

Table 3. The failure load of different shear test process parameters.

Test number	Rotational speed (r/min)	Traverse speed (mm/min)	Average failure load (KN)
1	800	40	3.11
2	800	60	3.26
3	800	80	2.41
4	1000	40	4.87
5	1000	60	4.33
6	1000	80	2.95
7	1200	40	4.87
8	1200	60	5.67
9	1200	80	2.95
10	1500	40	3.23
11	1500	60	3.96
12	1500	80	2.39

The failure loads of different plunge depth are shown in Table 4. The traverse speed is 60 mm/min. When the plunge depth is 0 mm, little combination happened between aluminum alloy and steel and the failure load is relatively small. The maximum failure load is 6.71 KN when the tool rotational speed is 1200 r/min and the plunge depth is 0.3 mm.

Table 4. The relationship between failure load and plunge depth.

Test number	Rotational speed (r/min)	Plunge depth (mm)	Average failure load (KN)
1	1000	0	1.93
2	1200	0	1.02
3	1000	0.1	4.33
4	1200	0.1	5.67
5	1000	0.3	4.91
6	1200	0.3	6.71
7	1000	0.5	5.82
8	1200	0.5	5.26
9	1000	0.7	2.15
10	1200	0.7	1.19

4. Conclusion

The mechanical properties of 5A06 aluminum alloy/3016L stainless steel composite plates fabricated by friction stir processing have been studied by micro-hardness analysis and shear test. The results show that the maximum failure load is 6.71 KN when the tool rotational speed is 1200 r/min, the traverse speed is 60 mm/min and the plunge depth is 0.3 mm.

Acknowledgments

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