The Influence of Process Parameters in Friction Stir Processed Al/Steel Composite Plates

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Abstract. The macroscopic morphology of Al/steel composite plates processed by friction stir welding was investigated through micro-hardness and shear test. The welding speed is in the range of 20-80 mm/min. The tool rotational speed is in the range of 800-1200 r/min. The plunge depth is in the range of 0-0.7 mm. The effects of different friction stir process parameters to the quality of Al/steel composite plate are analyzed.

1. Introduction

Friction stir welding technology is widely used to join the two similar/dissimilar metals by excessive localized plastic deformation. The process parameters, such as tool rotational speed, welding speed and plunge depth have significant influence on the joint quality. In the past, some researchers investigated the influence of different friction stir welding process parameters on the quality of friction stir welding joints.

Fei et al. [1] investigated the effects of different pin offset on mechanical properties and microstructure evolution of joints between pure copper and 6061T6 aluminum alloy fabricated by friction stir butt welding. The results show that the mechanical properties of Cu/Al dissimilar joint are significantly influenced by the pin offset distance and the additional heat source of laser beam. Caetano et al. [2] studied the effects of friction stir welding process parameters on the quality of product. The results show that the friction stir welding joints without root flaws can be achieved through a correct balance between the axial force and rotation speed. Zhang et al. [3] investigated three effects of tool tilt angle on the heat and mass transfer in friction stir welding using a geometrical model and an incomplete contact boundary condition. Boukraa et al. [4] optimized the friction stir welding process parameters using an optimization strategy coupled with 3D transient heat transfer computation. Choi et al. [5] investigated the power and energy consumption of friction stir welding and provided a welding parameter map. Ahmad et al. [6] used the coupled Eulerian Lagrangian approach to model the friction stir welding of grade DH36 steel. Sadeghian et al. [7] performed a morphological simulation of the weld joint fabricated by friction stir welding to predict dissimilar materials flow behavior.

In this study, the influence of friction stir welding process parameters on the quality of Al/steel composite plates was investigated. The friction stir welding process parameters were optimized.
2. Material and Experimental
The chemical compositions of 316L stainless steel and 5A06 aluminum alloy are shown in Table 1 and Table 2, respectively. The schematic representation of process test is shown in Fig. 1. The thicknesses of 316L stainless steel used in this investigation is 2mm. The thicknesses of 5A06 aluminum alloy is 4mm. The tool rotational speed is in the range of 800-1200 r/min. The welding speed is in the range of 20-80 mm/min. The plunge depth is in the range of 0-0.5 mm.

| 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 |

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

Table 1. Chemical composition of 316L stainless steel (wt.%).

Table 2. Chemical composition of 5A06 aluminum alloy (wt.%).

3. Results and Discussions
3.1. The effect of tool rotational speed
The macroscopic morphology of the Al/steel composite plate processed by different tool rotational speed is shown in Fig. 2. The welding speed is 60 mm/min. The plunge depth is 0.3 mm. The tool rotational speed is in the range of 800-1200 r/min. It can be seen that the composite plate surface is relatively rough when the tool rotational speed is 800 r/min (Fig. 2(a)). There are surface grooves at the advancing side of the composite plate. When the tool rotational speed is 1000 r/min (Fig. 2(b)), the composite plate surface is relatively bright and the surface grooves at the advancing side are relatively small. When the tool rotational speed is 1200 r/min (Fig. 2(c)), the quality of composite plate surface is relatively good. There is no groove on the composite plate surface. Flash number decreases significantly.
3.2. The effect of welding speed

The macroscopic morphology of the Al/steel composite plate processed by different welding speed is shown in Fig. 3. The tool rotational speed is 1200 r/min. The plunge depth is 0.3 mm. The welding speed is in the range of 20-80 mm/min. It can be seen that the composite plate surface is very rough when the welding speed is 20 mm/min (Fig. 3(a)). The main reason is that there is more heat input at relatively low welding speed. This causes the decrease of composite plate forming properties. When the welding speed is 40 mm/min (Fig. 3(b)), the composite plate surface is relatively smooth. Meanwhile, the advancing side of the composite plate surface appears insufficient metal supplement phenomenon. When the welding speed is 60 mm/min (Fig. 3(c)), the quality of composite plate surface is fine. There is no obvious flash or groove defects. When the welding speed is 80 mm/min (Fig. 3(d)), the quality of composite plate surface is poor. The ring pattern is a little rough. There are obvious grooves and insufficient metal supplement on the advancing side of the composite plate surface.

3.3. The effect of plunge depth

The macroscopic morphology of the Al/steel composite plate processed by different welding speed is shown in Fig. 4. The tool rotational speed is 1200 r/min. The welding speed is 60 mm/min. The plunge depth is in the range of 0.1-0.7 mm. There are pincer structures in the composite plate overlap region of aluminum alloy under different plunge depth conditions. There are also steel particles distributed on the bottom of processing region. When the plunge depth is small, there is no cavity defect. When the plunge depth is 0.7mm, there are obvious cavity defects on the bottom of processing region.
Figure 4. The macroscopic morphology of the Al/steel composite plate processed by different plunge depth.

4. Conclusion
The effects of different friction stir welding process parameters on the quality of Al/steel composite plate have been investigated in this paper. When the tool rotational speed is 1200 r/min, the welding speed is 60 mm/min and the plunge depth is 0.3 mm, the quality of composite plate surface is good.

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