G Model
JMST-1090; No. of Pages 5
ARTICLE IN PRESS
Journal of Materials Science & Technology xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Journal of Materials Science & Technology
journal homepage: www.jmst.org

Improving weld formability by a novel dual-rotation bobbin tool friction stir welding

F.F. Wang[a,b,c], W.Y. Li[a,*], J. Shen[b,*], Q. Wen[a], J.F. dos Santos[b]

[a] State Key Laboratory of Solidification Processing, Shaanxi Key Laboratory of Friction Welding Technologies, Northwestern Polytechnical University, Xi'an 710072, China
[b] Helmholtz-Zentrum Geesthacht, Institute of Materials Research, Materials Mechanics, Geesthacht 21502, Germany
[c] China Academy of Launch Vehicle Technology, Beijing Institute of Astronautical Systems Engineering, Beijing 100076, China

ARTICLE INFO

Article history:
Received 5 March 2017
Received in revised form 10 April 2017
Accepted 6 May 2017
Available online xxx

Keywords:
Bobbin tool friction stir welding
Dual rotation
Material flow
Microstructure
Microhardness

ABSTRACT

A novel dual-rotation bobbin tool friction stir welding (DBT-FSW) was developed, in which the upper shoulder (US) and lower shoulder (LS) have different rotational speeds. This process was tried to weld 3.2 mm thick aluminum-lithium alloy sheets. The metallographic analysis and torque measurement were carried out to characterize the weld formability. Experimental results show that compared to conventional bobbin tool friction stir welding, the DBT-FSW has an excellent process stability, and can produce the defect-free joints in a wider range of welding parameters. These can be attributed to the significant improvement of material flow caused by the formation of a staggered layer structure and the unbalanced force between the US and LS during the DBT-FSW process.

1. Introduction

As has been well described in numerous publications, friction stir welding (FSW) can produce welds that are free of defects associated with local melting and solidification, which are characteristics of the traditional fusion welding processes [1–3]. Since FSW is a solid state process, weldability can be significantly improved in some materials, such as high strength aluminum alloys, steels and metal matrix composites [4–6]. However, owing to the typically high down forces needed in the process, FSW is usually practiced as a fully mechanized process, and a rigid anvil support from the bottom surface of the workpiece is generally inevitable, which reduces the application of FSW in complex structures [7,8].

Bobbin tool friction stir welding (BT-FSW) is an enhancement and another good variant of FSW, using a welding tool with a upper shoulder (US) and lower shoulder (LS) connected by a probe [9,10]. It has been declared that BT-FSW has high potential in welding of closed profiles [11]. However, there are many scientific questions for this young technology [12]. Among them the most common problem reported is the void and tunnel defects [12,13]. Although defect-free joints can be obtained by the well-designed probe feature and optimized welding parameters [12], some investigations proved that unexpected void and tunnel defects do present in a regular welding parameter [14,15]. These defects are often considered as a consequence of inappropriate material flow and insufficient mixing during welding [16,17].

An effective methodology for enhancing the material flow in BT-FSW is therefore in demand. It has been proven that the dual-rotation setup can effectively improve the material flow in FSW [3,18,19]. Inspired by that finding, therefore, a novel dual-rotation BT-FSW (DBT-FSW) was developed, in which the US and LS have different rotational speeds, to obtain Al-Li alloy AA2198-T851 sheets. Preliminary experiments show that the DBT-FSW process greatly improves material flow and effectively avoids the void defect. Therefore, the present work is aimed at revealing the essential reason for the improved weld formability during DBT-FSW.

2. Experimental procedure

Aluminum-lithium alloy (AA2198-T851) sheets with dimensions of 250 mm × 100 mm × 3.2 mm were butt-welded by both BT-FSW and DBT-FSW along the rolling direction at a welding speed (v) of 42 mm/min and the rotational speeds (ω) from 400 to 1200 rpm. The welding tool was characterized by a cylinder featureless probe (Ø4 mm) and a concave shoulder (Ø11 mm) as shown in Fig. 1a. The LS was attached to the probe and driven by a motor

* Corresponding authors.
E-mail addresses: liwy@nwpu.edu.cn (W.Y. Li), junjun.shen@hzg.de (J. Shen).

https://doi.org/10.1016/j.jmst.2017.11.001
1005-0302/

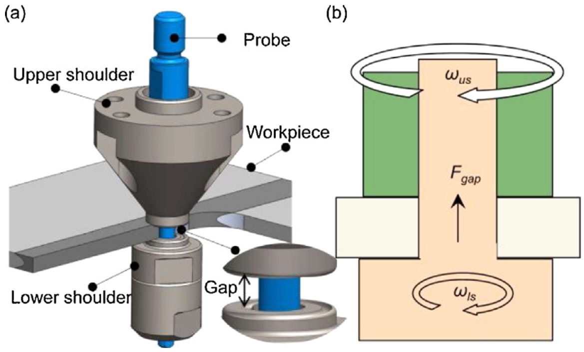

Fig. 1. (a) Details of the welding tool and (b) schematic of DBT-FSW.

shaft, while the US was rotated by another independent motor, therefore making the US and LS can have the same (i.e., BT-FSW) and different (i.e., DBT-FSW) rotational speeds. The welding system can adjust both the gap and gap force F_{gap} (i.e. distance and force between the US and LS) induced on the workpiece. Also, the reacting torque/force was measured by an embedded torque/force measuring system in the custom designed FSW (Flexi Stir) machine. At the beginning of the welding process, the plunge depth was set as 0.1 mm for both US and LS. After the controlling model shifted to force control model, the plunge depth various with the gap force, and all joints showed good surface appearance for both BT-FSW and DBT-FSW.

Samples for microstructure analysis were cut perpendicular to the welding direction, mechanically ground and polished, etched using the Keller's Reagent (2 ml HF, 3 ml HCl, 5 ml HNO_3, and 190 ml H_2O), and examined by optical microscopy (OM). A suitable surface finish for electron backscatter diffraction (EBSD) was achieved by applying mechanical polishing in a similar fashion followed by vibration polishing. The hardness maps of the cross sections were obtained using an UTS100 hardness tester with a load of 0.2 kg for 10 s. The 2D hardness map was consisting of 11 lines on the cross sections with point space of 0.25 mm and line space of 0.25 mm.

3. Results and discussion

3.1. Formation mechanism

Fig. 2(a, b) shows the transverse cross-section of the BT-FSW joint produced at a rotational speed of 600 rpm, and the DBT-FSW joint produced at the US rotational speed of 400 rpm and LS rotational speed of 600 rpm, respectively. Both of them have an hourglass shaped stirred zone (SZ), composing of the US dominated zone (USDZ) and LS dominated zone (LSDZ) [10]. The distinct microstructures lead to an obvious triple junction of thermo-mechanically affected zone (TMAZ), USDZ and LSDZ on the advancing side (AS) of the joint [20]. Moreover, compared to BT-FSW, DBT-FSW has a much wider TMAZ with waved structure as shown in Fig. 2(d, e). However, similar to other reports [14,15], the unexpected void defect sometimes happens even using the same welding parameters in BT-FSW at the triple junction as shown in Fig. 2(c). A series of welding experiments are repeated with increasing rotational speeds from 400 to 1200 rpm. Unfortunately, the void defect is found at all rotational speeds and is very difficult to eliminate as shown in Fig. 3(a), indicating a poor stability of BT-FSW. By contrast, no void defect is found in the DBT-FSW joint at rotational speeds from 400 to1200 rpm as shown in Fig. 3(b). These facts reveal a good weld formability and stability of DBT-FSW. This improvement of the weld quality by DBT-FSW should be attributed to the following reasons.

On one hand, DBT-FSW generates an asymmetrical material flow with staggered layer structure in the weld, which makes the voids can be easily filled during welding. As can be observed from the material flow pattern at the run-out of DBT-FSW, two parts of periodical layer structures emerge on the cross section in the USDZ and LSDZ, respectively, as shown in Fig. 4(a). The layer structure comes from a cyclic material deposition in the wake of the weld, causing by a dynamic contact condition between the tool and the matrix [21,22]. The periodic distance (λ) between each layer corresponds with the ratio of v/ω [23,24]. In BT-FSW, the layer structures of the USDZ and LSDZ have the same λ value and their crests and troughs collide synchronously at the triple junction region (see Fig. 4(c)).

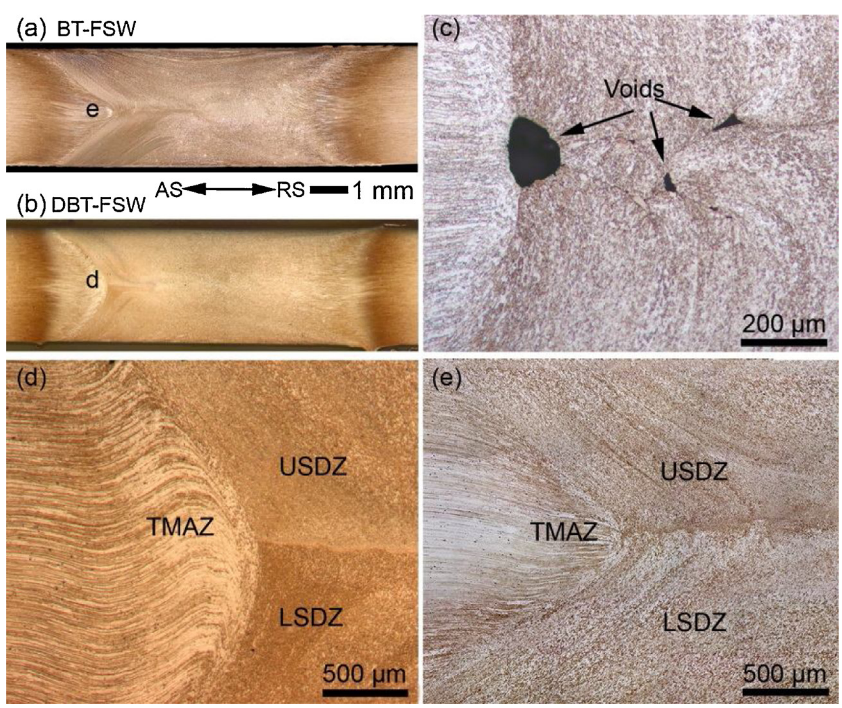

Fig. 2. OM images of: (a) BT-FSW joint; (b) DBT-FSW joint; (c) typical void defect exhibited in BT-FSW; and typical microstructure on the AS of (d) DBT-FSW and (e) BT-FSW.

Please cite this article in press as: F.F. Wang, et al., J. Mater. Sci. Technol. (2017), https://doi.org/10.1016/j.jmst.2017.11.001