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Effect of R-DSFSW on Mechanical and Metallurgical Properties of Commercial Pure Aluminum

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Abstract

Double shoulder Friction stir welding (DSFSW) is a relatively new solid state technique for welding of aluminium alloys. There was wastage of material during welding and material removed region will create notch effect which causes stress concentration. This problem was solved by the introduction of a refilling method and named as refilled double shoulder friction stir welding (R-DSRSW). In this method a 3 mm thick commercial pure aluminium plate was kept at the bottom of joint line. While the tool is traversed through the joint line as in DSFSW at constant feed rate of 25 mm/min, welding takes place without any material loss. The welds were made in butt joint configuration at three different tool rotational speeds namely 900 rpm, 1120 rpm and 1400 rpm. Macrostructure, microstructure and micro hardness studies have been carried out. Finally the results obtained from both DSFSW and R-DSFSW have been compared.

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Keywords: FSW,DSFSW, R-DSFSW, Advancing side(AS), Retreating side(RS);

1. Introduction

The technique of friction stir welding (FSW) has been developing fast since it was invented at The Welding Institute (TWI) in 1990s (Thomas et al. 1991). FSW has been widely utilized in welding aluminium alloys (Mishra et al. 2005).

The conventional FSW tool consists of a shoulder and pin. During welding forces are acting in x, y and z direction. And rigid backing plate is needed to offer reacting forces (Rajneesh Kumar et al. 2012; Razal Rose et al. 2011). However welding of pipes and complex shapes, designing of backing plate may not be feasible. In order to

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overcome the above limitation an attempt has made to weld aluminium plate without backing plate using refill double shoulder friction stir welding (R-DSFSW). The double shoulder friction stir welding (DSFSW) has two shoulders and one pin. By these two shoulders, the large pressure in welding progress could be balanced with its internal self–reacting mechanism, and thus the welding load is taken by the DSFSW effectively (Marie et al. 2007; Hilgerta et al. 2011; Dalder et al 2007**)**. As well, the steady back could be removed. So, the progress gets more flexible and could be used to more applications, such as circumferential direction welding, which is mentioned above.

In this paper commercially pure aluminium plates of 6 mm thickness were successfully welded by R-DSFSW technique using 3 mm commercial pure aluminium as a filler plate at different tool rotation speeds and mechanical properties have been observed in the welds. Comparative study has been carried out with joints of DSFSW made with the same process parameters used in R-DSFSW.

2. Experimental procedure

A double shoulder tool with a pin in between has been fabricated and it is shown Fig. 1. Frictional heat generated by the friction between the tool shoulder and the material causes the materials to soften and reach plastic state. The softened material is stirred together by the rotating tool pin resulting in a solid state bond. In this method a 3 mm thick commercial pure aluminium plate was kept at the bottom of joint line. The gap between the shoulders is 7 mm. While the tool is traversed through the joint line as in DSFSW, welding takes place without any material loss as shown in Fig. 2. and Fig. 3. Welding was carried out in an in-house developed, modified vertical milling machine. The machine consists of a vertical tool holder, spindle, table and a supporting structure. The tool is fixed on the tool holder. The plates to be welded were clamped on a specially designed clamping block to facilitate the movement of double shoulder tool.

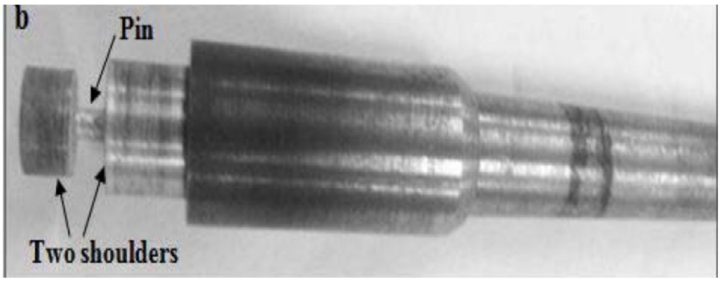

Fig. 1. DFSW Tool.

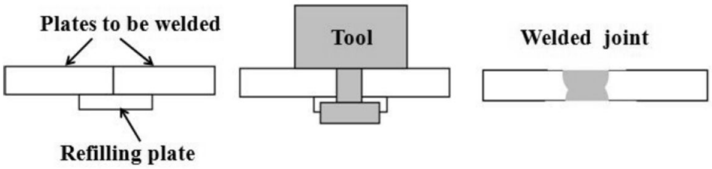

Fig. 2. Schematic diagram of R-DSFSW.

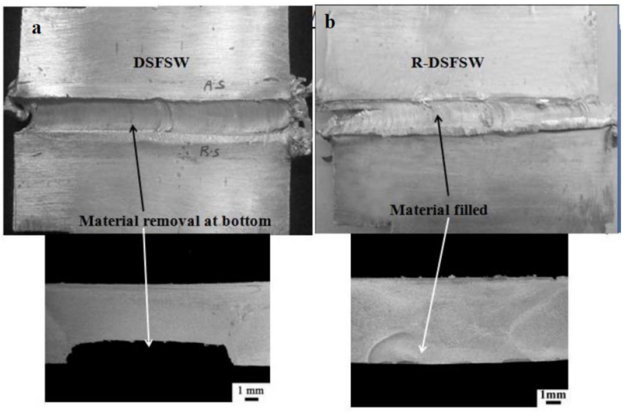

Fig. 3. Welded samples (a) DSFSW; (b) R-DSFSW.

Commercially pure aluminium (CP Al) cold rolled plates of 6 mm thickness were used as the base material at different stages of the present study. The plates were made into required size (90 mm x 50 mm x 6 mm) and edges were made flat 3 mm thick commercial pure aluminium plate is used as a filler plate. The tool material used is EN 31 steel. The upper and lower shoulders were 25 mm and 12 mm in diameter, respectively. The tool pin is a cylindrical configuration, and 8 mm in diameter. The plates cut into required dimensions were clamped on the specially prepared clamping block fixed on the machine table. The clamping block had a horizontal groove to facilitate the traverse of double shoulder tool.

3. Results and discussion

3.1. Macrostructure

Sample were prepared according to standard metallographic procedures and etched with Poultron reagent (30 ml HCl, 40 ml HNO3, 2.5 ml HF, 12g CrO3 and 52.5 ml H2O). Samples welded at tool rotation speed of 900 rpm and 1120 rpm gave defect free joints and there was no material loss in these joints. Joints made at 1400 rpm showed defects and improper refilling. While welding at 1400 rpm the refilling plate was simply carried away by the tool from the joint line due to overheating. This resulted in insufficient compaction and defective welds. Macrostructures of the welded samples are shown in Fig. 4.

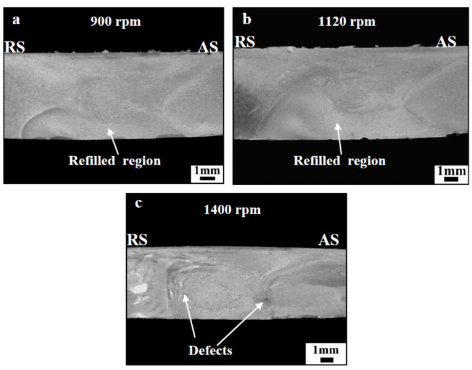

Fig. 4. Macro structures of Welded samples (a) 900 rpm; (b) 1200 rpm; (c) 1400 rpm.

3.2. Microstructure

Sample preparation was done according to standard metallographic procedures and microstructures were analysed. All the samples except those made at 1400 rpm showed complete metallurgical bond. Refilled region and the base material region were completely bonded. It was observed that grain size in SZ of refilled region is less than in SZ of base metal region. In welds of 1400 rpm, many partial bonded regions and cracks were found due to improper refilling. Microstructures at different regions are shown in Fig. 5. and partial bonds in samples of 1400 rpm are shown in Fig. 6.

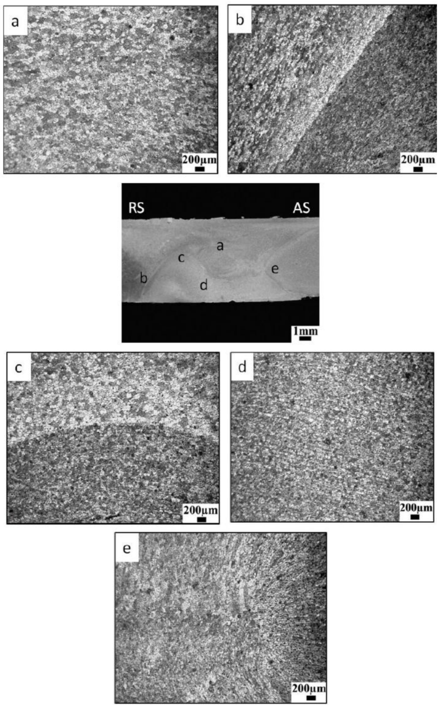

Fig. 5. Microstructure at different regions – R-DSFSW (a) SZ-base material; (b)TMAZ-refilled zone; (c) SZ-refilled region and base material; (d) SZ-refilled region; (e) TMAZ- refilled region and base material.

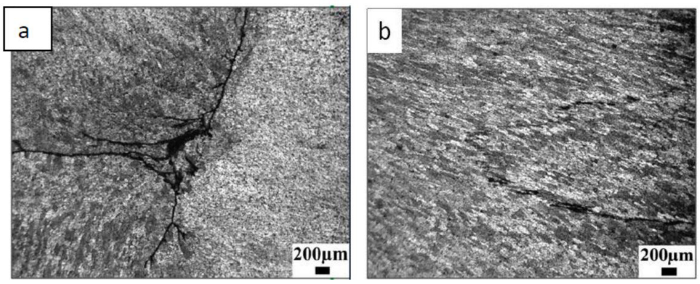

Fig. 6. Defects in R-DSFSW welds at 1400 rpm (a) Cracks; (b) Partial bond.

3.3. Microhardness

Microhardness distribution of refilled region and welded base material region were taken. Similar to DSFSW, SZ hardness was higher than TMAZ hardness and lower than BM. Notable difference in hardness can be found in SZ of base material and SZ of refilled region. Average SZ hardness was high in refilled region (52 Hv) than in SZ of base material (50 Hv). This was due to the fine grains in the refilled region and hardness distribution is shown in Fig. 7.

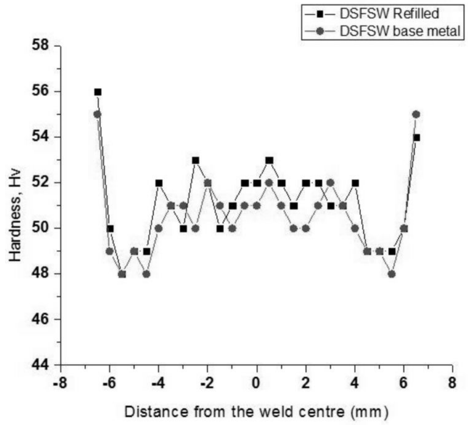

Fig. 7. Microhardness distribution R-DSFSW.

3.4. Tensile test

Tensile samples were prepared from the welded joints and were tested according to the standard procedures. Fig. 8. Shows the tensile samples before and after testing Fig. 9. depicts the trend of joint strength with tool rotation speed. Table1. Shows the strength, joint efficiency and the failure locations.

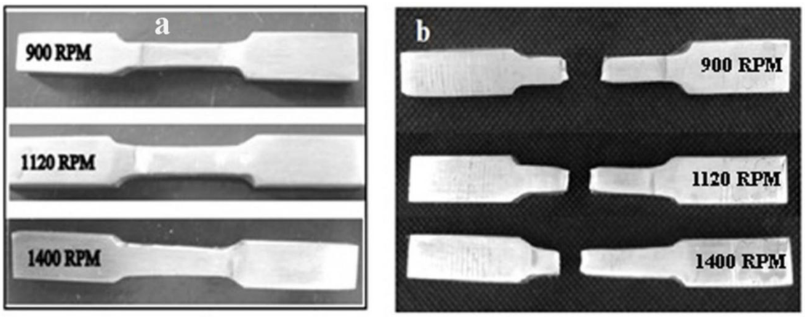

Fig. 8. Tensile samples RR-DSFSW (a) Before testing; (b) After testing.

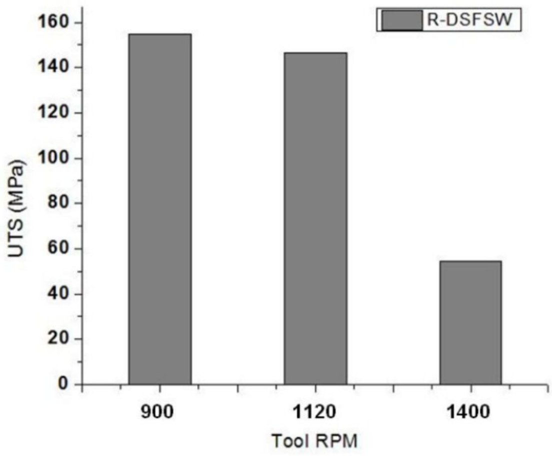

Fig. 9. Joint strength vs tool rpm R-DSFSW

Table 1. Tensile test results R-DSFSW.

Tool rpm	UTS (MPa)	Joint efficiency (%)	Failure location
900 rpm	154.76 MPa	93.8	AS of refilled region
1120 rpm	146.56 MPa	88.8	AS of refilled region
1400 rpm	54.64 MPa	33.1	Rs of refilled region

It was observed that joint strength decreased with increase in tool rotation speed. Tool rotation speed of 900 rpm gave welds of maximum strength. Lower strength at 1120 rpm may be due to the overheating developed by the bottom shoulder interaction with the filler plate. It can be seen that frictional heat developed increased with increase in tool rotation speed. This is evident from the improper refilling at 1400 rpm.

All the failures of the samples were initiated from the TMAZ region of bottom shoulder since TMAZ grains will be coarser which makes it a favourable failure location. It was observed that as the tool rotation speed increased from 900 rpm to 1400 rpm, the failure location was shifted from advancing side to retreating side. Lack of metallurgical bond at 1400 rpm may be the reason for this shift.

4. Comparison with DSFSW

The trend of joint strength with tool rotation speed has been compared in Fig.10. and Table 2. gives the comparison of joint strength. Trend of joint strength with tool rotation speeds were different in DSFSW and R-DSFSW. It was observed that in R-DSFSW there was an increase of 80% and 35% in joint strength at 900 rpm and 1120 rpm respectively when compared to DSFSW. However joint strength decreased by 53% at 1400 rpm. Failure locations were also found to be different from each other. Refilling of the material reduced the notch effect in the joints made by R-DSFSW. Moreover fine grains were found in the refilled region. These may be the factors which contributed to the increase in joint strength at 900 rpm and 1120 rpm in R-DSFSW.

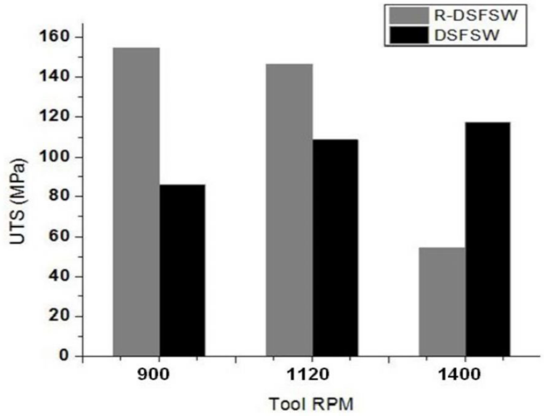

Fig. 10. Comparison of R-DSFSW and DSFSW - Joint strength vs Tool rpm.

Table 2. Comparison of R-DSFSW and DSFSW- Tensile test results.

Tool rpm	Strength (MPa)		Failure location	
	DSFSW	R-DSFSW	DSFSW	R-DSFSW
900	86.01	154.76	RS	AS
1120	108.75	146.56	RS	AS
1400	117.26	56.64	AS	RS

5.Conclusions

- A new technique was applied to overcome the loss of material, by using a refilling plate of 3mm thickness and was named refilled DSFSW (R-DSFSW).
- R-DSFSW method significantly improved the joint strength at all tool rotation speeds except at 1400 rpm.
- SZ hardness of refilled region was higher than the SZ of base material region.
- Maximum joint strength obtained by R-DSFSW technique was 154.76 MPa at 900 rpm with a joint efficiency of 93.8%.
- Comparative study has been carried out with joints made with the same process parameters used in DSFSW and R-DSFSW.

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