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REVERSAL STIR WELDING - RE-STIR™ - Preliminary trials

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The continuing development of Friction stir welding (FSW) has led to a number of variants of the process. The following describes preliminary studies being carried out on Re-stir™ welding at TWI. The salient features of the Re-stir™ welding technique are illustrated in fig 1. This illustration applies to both angular reciprocating, where reversal is imposed within one revolution, and rotary reversal, where reversal is imposed after one or more revolutions.

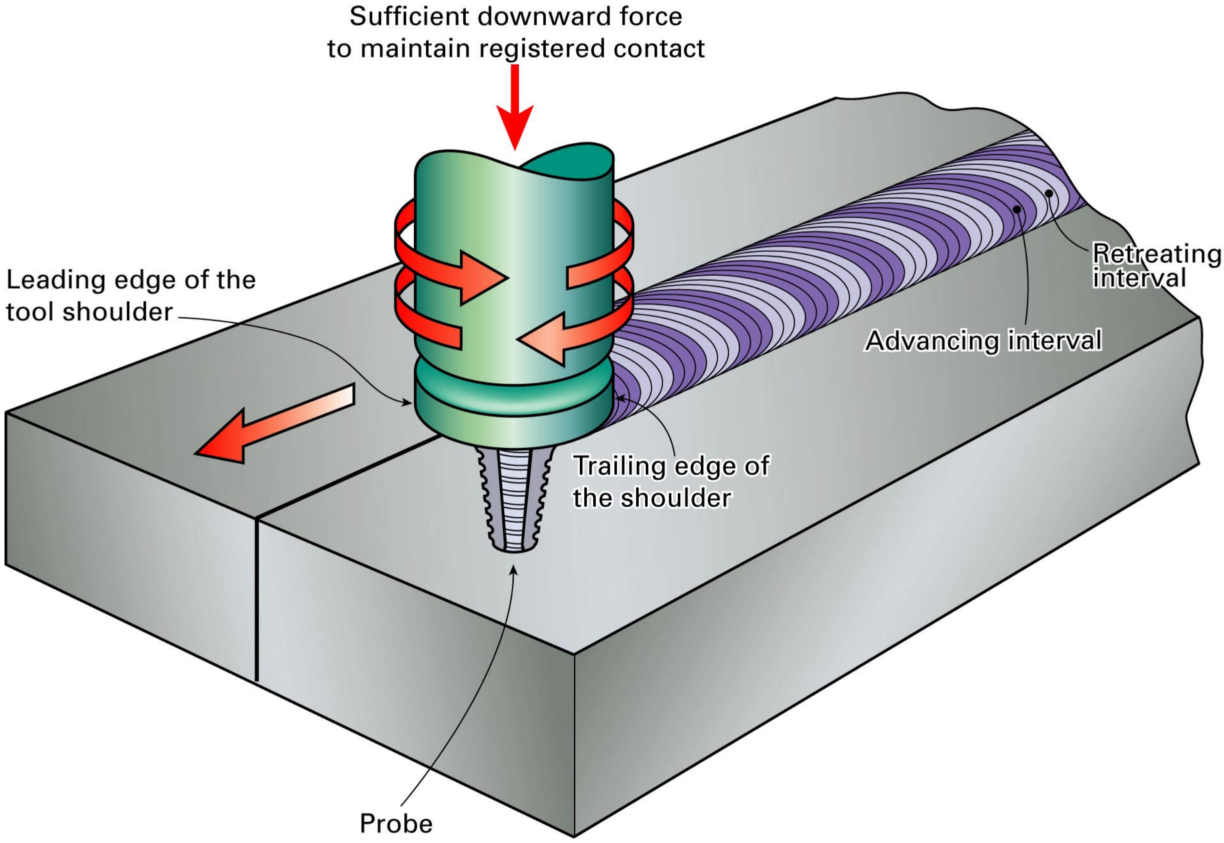


Fig 1. The basic principle of Re-stir™, showing the reversal technique

The use of the Re-stir™ (angular reciprocating/reversal motions) welding technique provides a cyclic and essentially symmetrical welding and processing treatment (ref 1-3). Most problems associated with the inherent asymmetry of conventional rotary FSW are avoided.

PRELIMINARY RESULTS

Butt Welding

The results from preliminary Re-stir™ welding trials with 6 mm thick 5083-O condition aluminium alloy show considerable promise. A transverse macrosection of a Re-stir™ butt weld made in this material using a conventional MX-Triflute™ probe is shown in fig 2. The weld region is essentially symmetrical in shape tending to become narrower towards the top of the plate. This is in marked contrast to conventional rotary friction stir welding in which an asymmetrically shaped weld is obtained (4&5).

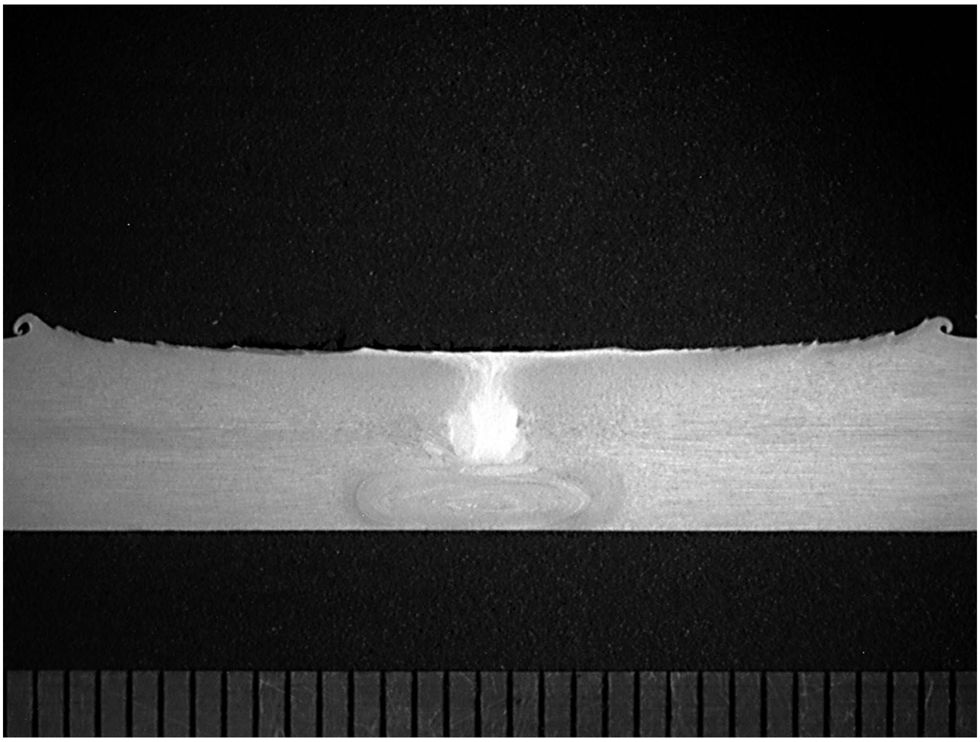
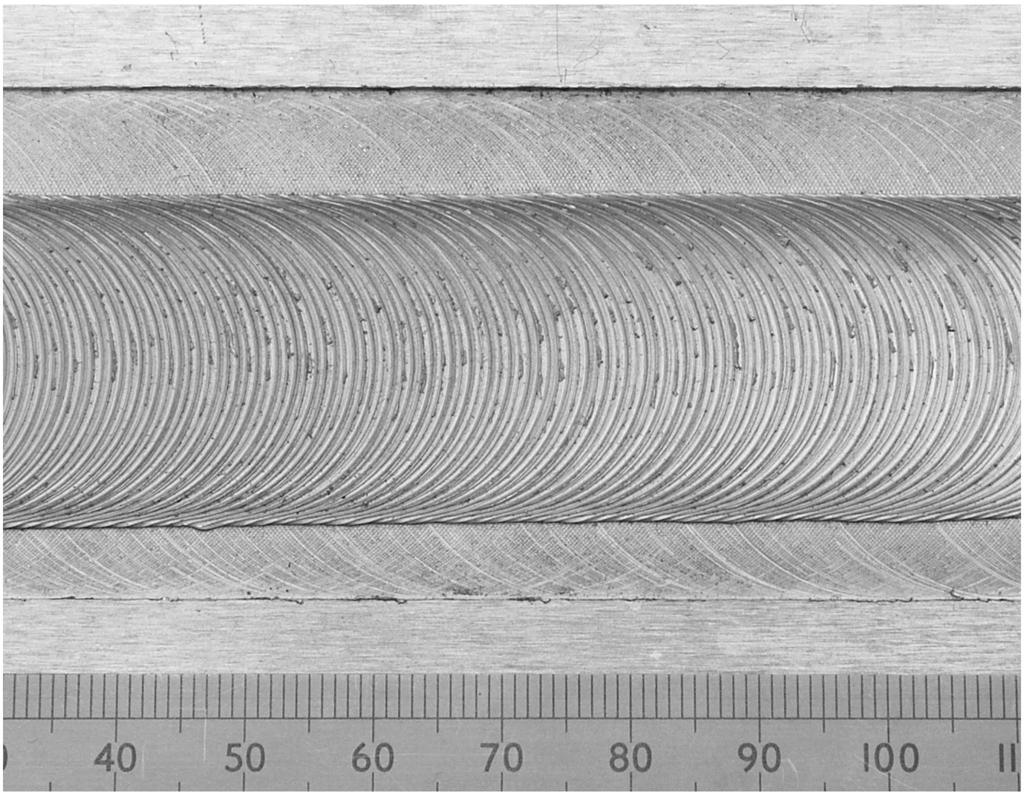


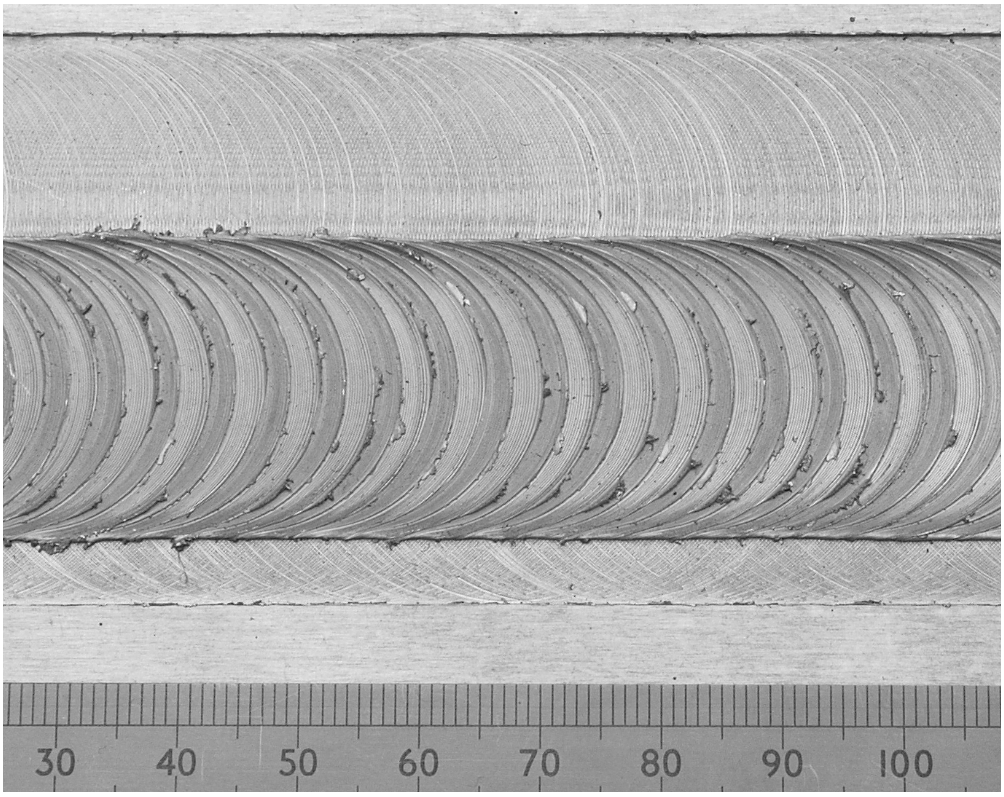
Fig. 2 Microsection of a Re-stir™ butt weld, produced at a welding travel speed of 4.2 mm/sec (250 mm/min), using 8 revolutions per interval, which shows an essentially symmetrical, shaped weld region.

Surface appearance of Butt and lap welds

Figure 3a shows the appearance of the weld surface that is formed beneath the tool shoulder produced at a welding travel speed of 1.6 mm/sec (96 mm/min), using 5 revolutions per interval. Figure 3b shows the coarser surface obtained using 10 revolutions per interval, at a similar welding travel speed



3a)



3b)

Fig. 3 Surface appearance of Re-stir™ welds made in 6 mm thick 5083-O condition aluminium alloy at a welding travel speed of 1.6 mm/sec (96 mm/min)

a) Surface of weld made using 5 revolutions per reversal interval.

b) Surface of weld made using 10 revolutions per reversal interval.

Fig 4 shows the detail of the surface of a weld made at 4 mm/sec (240 mm/min) travel speed, using 10 revolutions per interval. The fine surface ripples reveal the number of rotations and the extent of the interval, while the less frequent, coarser and wider surface ripples reveal the position of the change in rotation direction. For Re-stir™, the distance and time between each interval depends on the combination of rotational speed and the travel speed used.

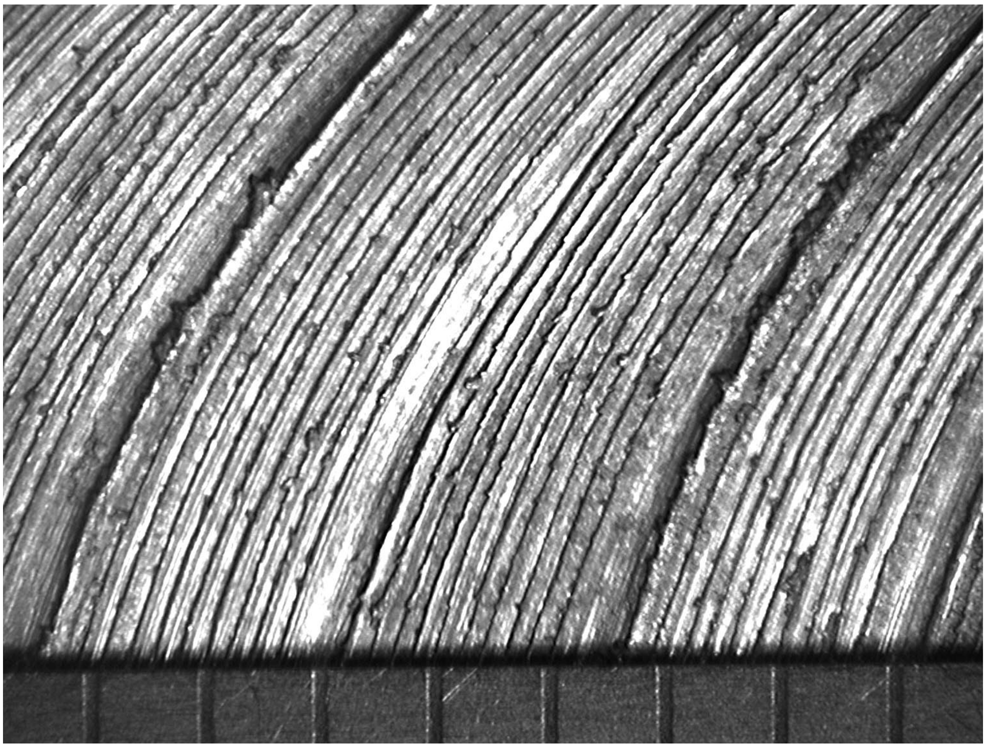


Fig. 4 Close up of Re-stir™ weld surface formed beneath the tool shoulder showing surface rippling and reversal interval. Produced at 4 mm/sec (240 mm/min) welding travel speed), using 10 revolutions per interval.

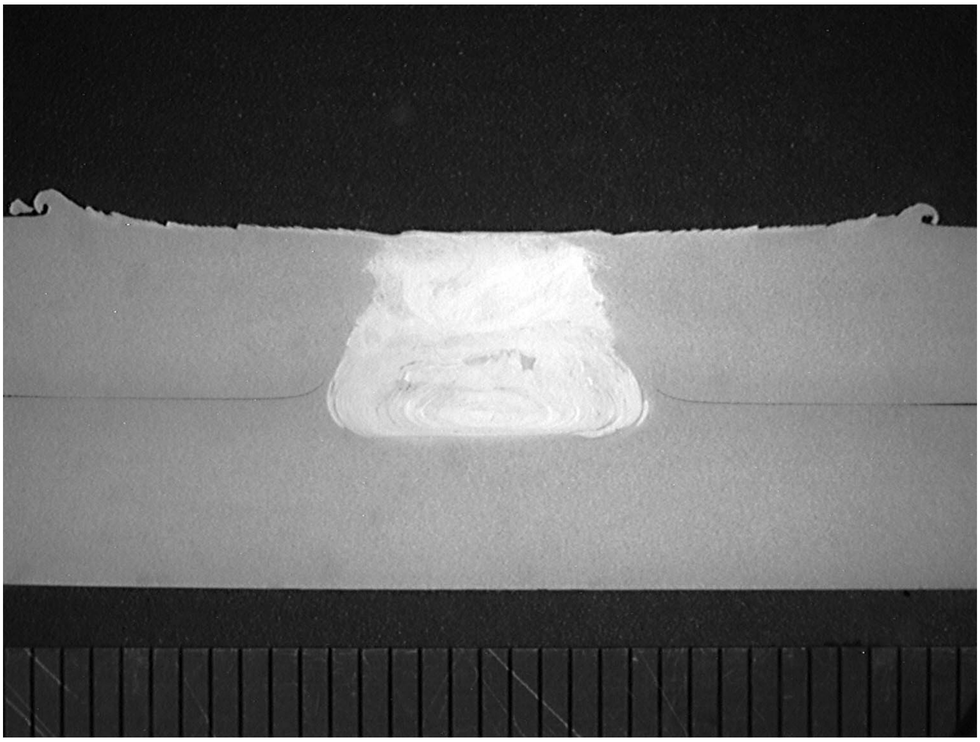
Lap Welds

Lap welding by conventional rotary FSW is more difficult than butt welding as:

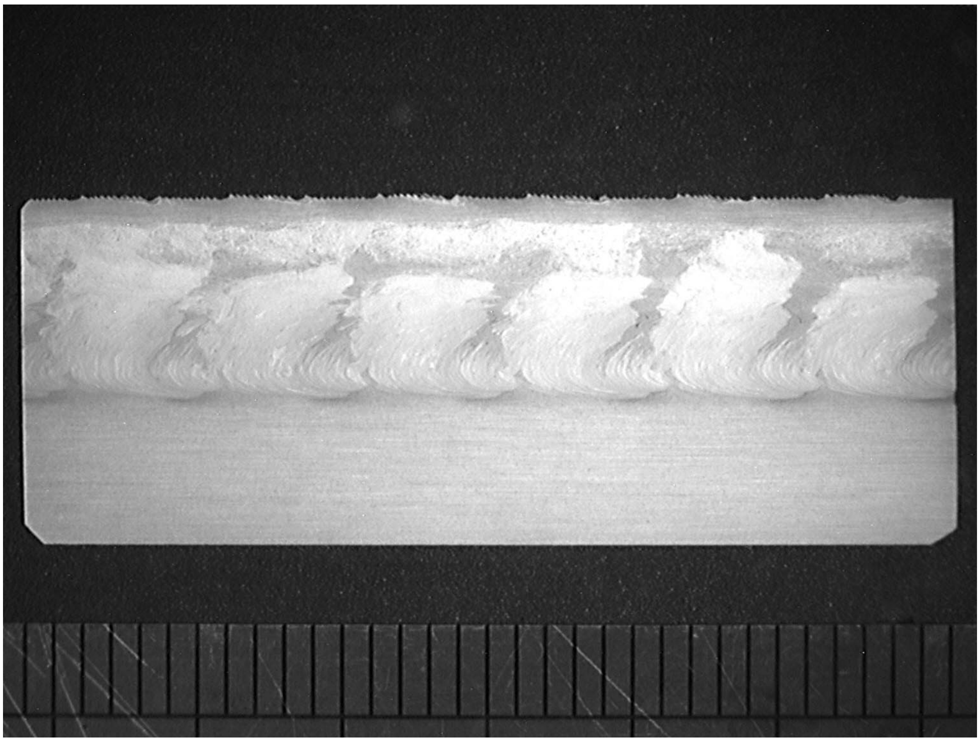
- the process asymmetry associated with rotary FSW means that the retreating side of the weld can sometimes suffer from plate thinning defects.
- wider welds are necessary to transmit the load properly in the manufactured structure.
- the form of the notch (plate deformation - thinning /hooking), particularly at the tip at the edge of the weld, must be modified to ensure maximum strength (particularly fatigue strength) of the manufactured structure
- the oxide disruption at the sheet interface is more difficult than when butt welding because of the orientation of the joint interface with respect to the FSW tool.

Macrosections of a lap weld made by Re-stir™ are shown in fig 5 a b & c. This weld was made in 5083-O condition aluminium alloy, using a Flared-Triflute™ type probe designed for rotary stir, at a travel speed of 3.3 mm/sec (198 mm/min) using 10 revolutions per interval. Figure 5a shows an essentially symmetrical weld. It should be noted that this weld shows detrimental plate thinning/hooking owing to the non-optimisation of welding parameters but does serve to illustrate the symmetrical nature of the weld produced by the Re-stir™ technique.

The longitudinal section shown in fig 5b is taken at a position at the edge of the weld region and shows the effect of the change in the direction of rotation. The plan view in fig 4c reveals a patterned weld region surrounded by a HAZ. There is some evidence that during the reversal stage some of the 'Third-body' plasticised material close to the probe is 're-stirred' back in the opposite direction.



a)



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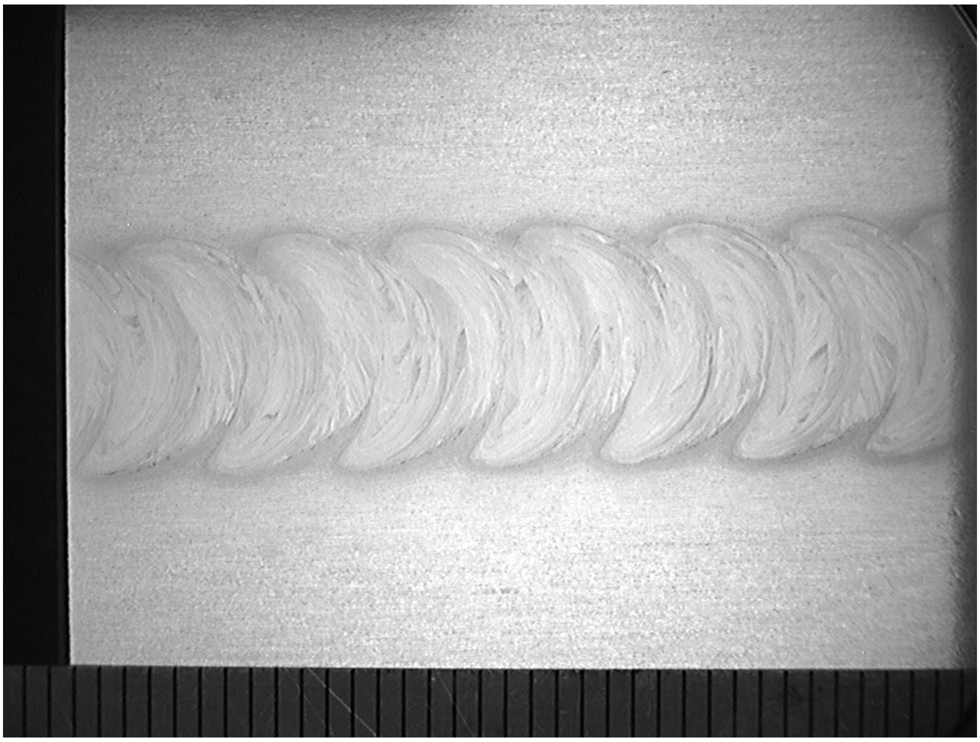


c)

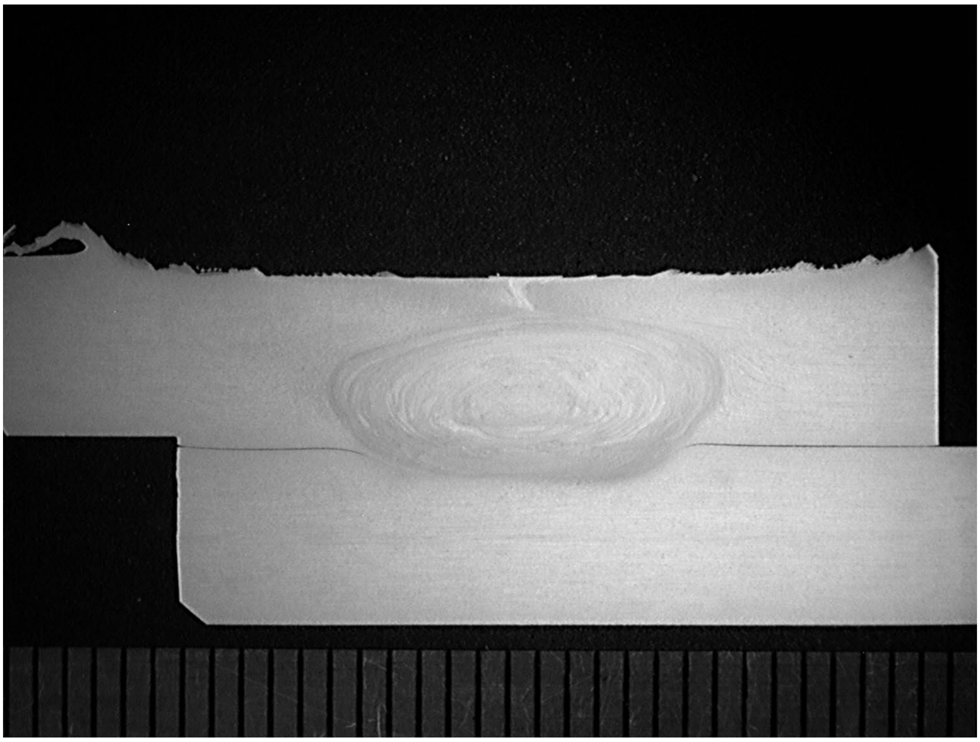
Fig. 5 Metallurgical sections showing the effect of the Re-stir™ technique on the weld shape, produced at a welding speed of 3.3 mm/sec (198 mm/min), using 10 revolutions per interval.

a). Macrosection shows an essentially symmetrical dovetail shaped weld with a similar amount of upturn of the plate interface each side of the weld.

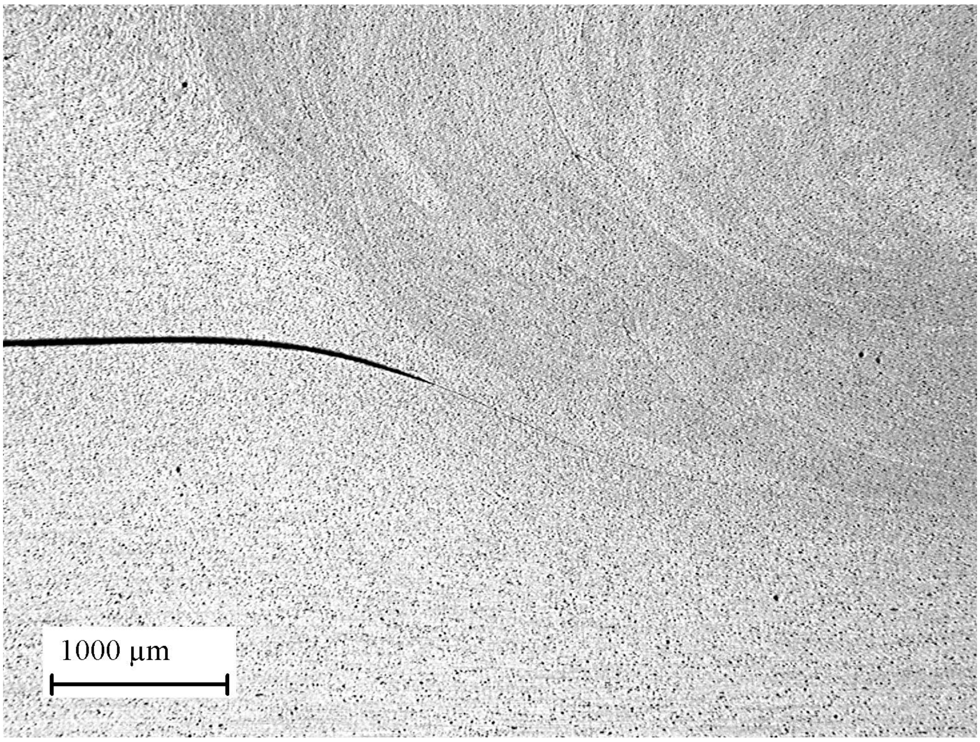
b). Longitudinal macrosection showing regular patterns caused by rotation reversal.

c). Plan macrosection taken mid thickness showing the effect of reversal motion.

The Re-stir™ process requires further optimisation to achieve welds of reproducibly high quality and freedom from defects but early trials suggest benefits in terms of weld symmetry. Initial work using an A-skew™ probe also suggests that it may be possible to achieve a slight down turn in the overlapping plate/weld interface at the outer regions of the weld which may be beneficial in particular structures and loading situations. Figure 6 a b & c illustrates this effect in an overlap weld in 5083-O condition aluminium alloy.



a)



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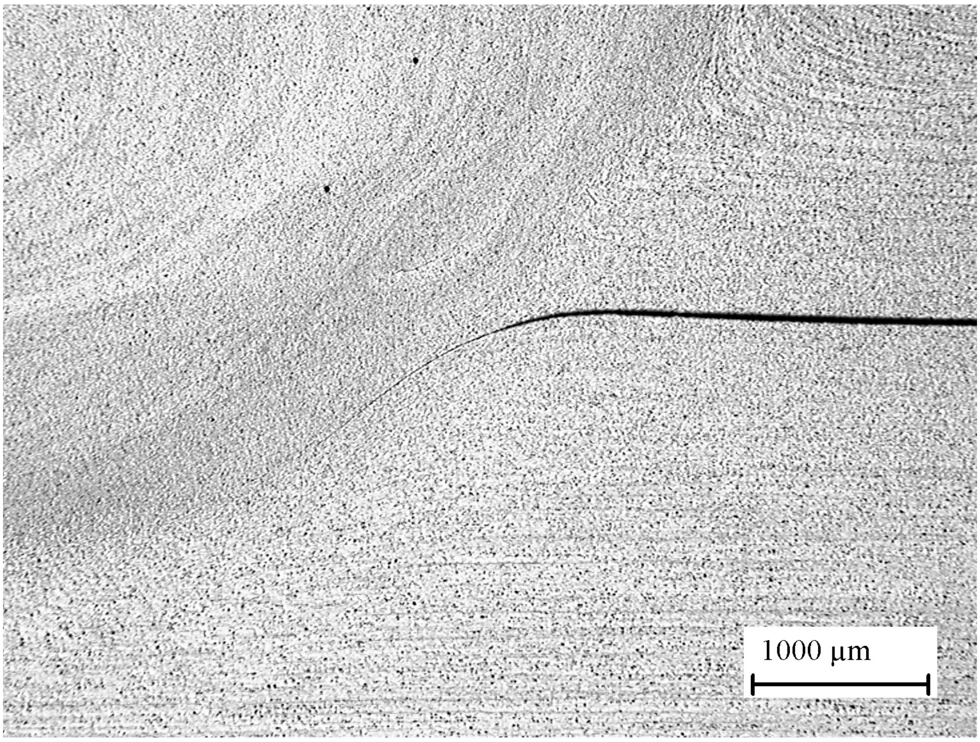

c)

Fig. 6 Detail of the outer regions of a Re-stir weld made with an A-skew™ probe in combination with a skew motion, at a travel speed of 1.6 mm/sec (96 mm/min), using 8 revolutions per reversal interval.

a) Macrosection

b) detail of notch (that would formerly have been at the retreating side with conventional rotary FSW)

c) detail of notch (that would formerly have been at the advancing side with conventional rotary FSW)

For conventional FSW a pair of hammer 'S' bends would be used to establish weld quality on both sides of the lap weld. This arrangement effectively tests the lap weld for plate thinning and for any notch effect (hook) by subjecting both sides of the asymmetric weld to the same test criteria. For Re-Stir™, providing the width of the bend specimen is more than two-reversal intervals in length, one hammer 'S' bend will suffice, see fig 7. (Any asymmetric type defect such as plate thinning or notch effect formed will be tested on this one specimen).

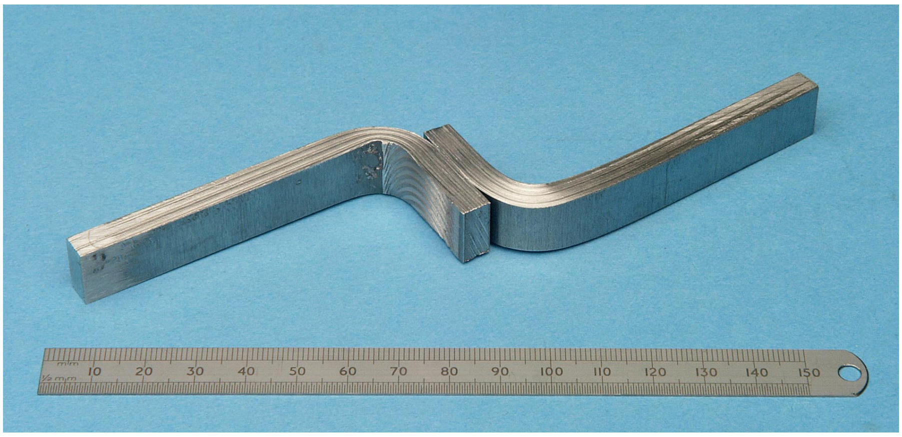

Fig. 7 Hammer 'S' bend of a Re-stir™ lap weld made in 5083-O condition aluminium alloy material showing good weld integrity

Discussion and Concluding Remarks

Initial investigation of the Re-stir™ process has demonstrated that it may offer significant benefit in generating essentially symmetrical welds and hence has the potential to overcome some of the problems associated with the asymmetry inherent in conventional friction stir welds. In addition, it can be speculated that the process may offer benefits in:

- Controlling the morphology of the notch tips either side of a lap weld.
- Welding of dissimilar materials with widely differing flow properties. i.e. by using more revolutions in one direction to compensate for different material characteristics and joint geometries.

Although it is early days and much more development work is required before the technique can be used commercially, the prognosis for the success of Re-stir™ welding is good. The process has been found to be robust in trials to date although the probe geometry, the rotational speed, and the reversal frequency have yet to be optimised. Work is continuing at TWI with purpose-designed tools with straight flutes and neutral or balanced ridges. It seems likely that an essentially symmetrical technique like Re-stir™ may well become the preferred option for certain butt, lap, compound lap and spot welding and material processing applications.

Acknowledgements

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