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# The simultaneous use of two or more friction stir welding tools

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## INTRODUCTION

### Multi-stir, simultaneous double side stir and Twin-stir™ techniques

The simultaneous use of two or more friction stir welding tools acting on a common workpiece was first described in 1991 (1). The concept involved a pair of tools applied on opposite sides of the workpiece slightly displaced in the direction of travel. The contra-rotating simultaneous double-sided operation with combined weld passes has certain advantages such as a reduction in reactive torque and a more symmetrical weld and heat input through-the-thickness (2). The probes need not touch together but should be positioned sufficiently close that the softened 'third-body' material around the two probes overlaps near the probe tips to generate a full through-thickness weld (see fig1).

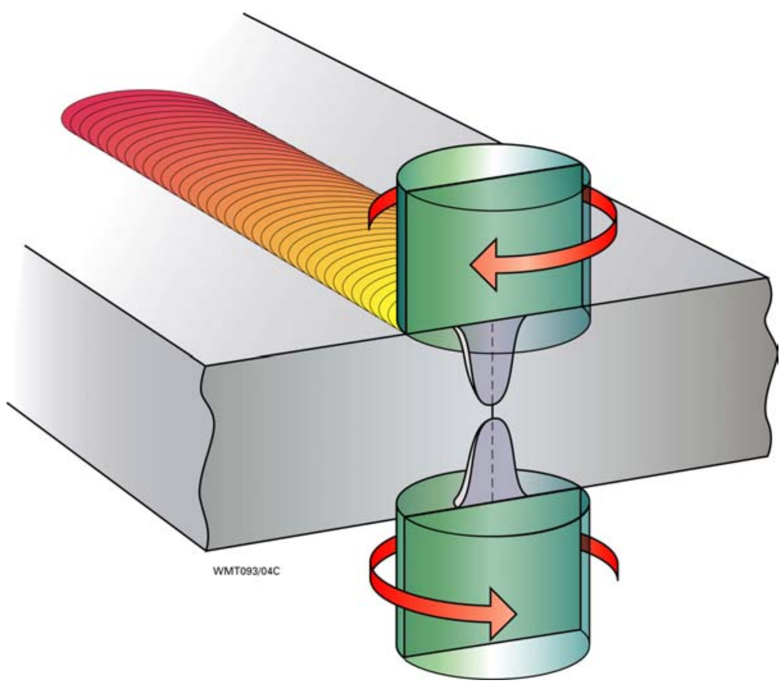



**Fig 1.** Simultaneous double-sided friction stir welding with contra-rotating tools.

To avoid any problems associated with a zero velocity zone in mid-thickness, the probes can be displaced slightly along the direction of travel.

Common to all such simultaneous contra-rotating techniques is a reduction in the reactive forces on the work holding fixtures owing to the reduction or elimination of reactive torque. Moreover, for certain applications, the use of purpose designed multi-headed friction stir welding machines can increase productivity, reduce side force asymmetry, and reduce or minimise reactive torque (3) (see fig 2).

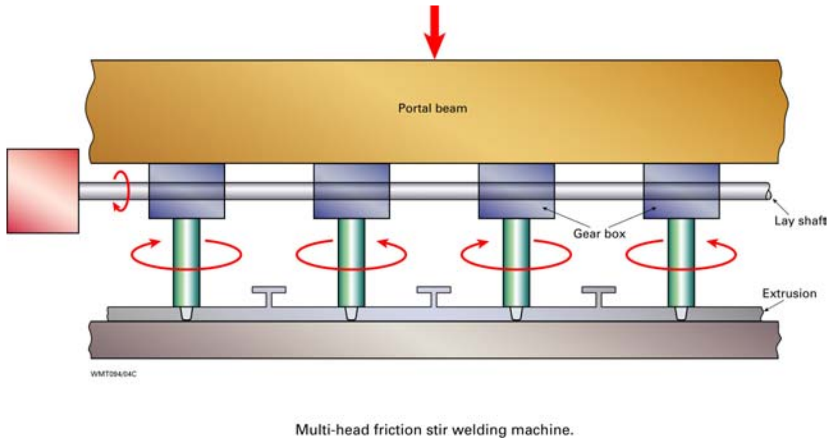



**Fig 2.** Multi-head friction welding machine

## Twin-stir ™ techniques

The use of a preceding friction pre-heating tool followed in line by a friction stir welding tool for welding steel is reported in the literature in 1999 (4). More recently, a similar arrangement has been reported, whereby there are two rotating tools; one used to pre-heat and one to weld (5). This disclosure (5), however, shows a 'tandem' technique with the tools rotating in the same direction.  A further reference is made to tandem arrangements with tools rotating in the same direction (6). The use of 'tandem' contra-rotating tools in-line with the welding direction and 'parallel' side-by-side across the welding direction) is also disclosed (7).

Figure 3 shows the three versions of Twin-stir™ welding techniques that are being investigated and developed at TWI.

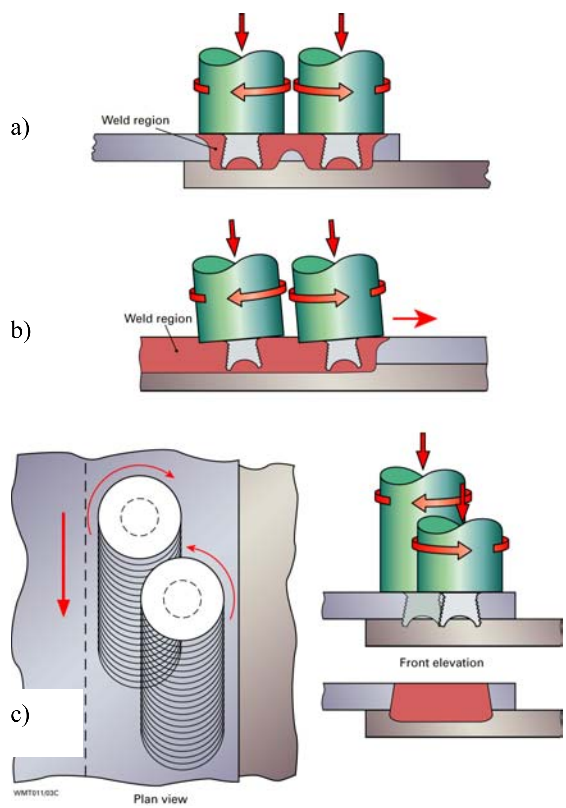



**Figure 3.** Twin-stir™ variants

a)  Parallel side-by-side transverse to the welding direction

b) Tandem in-line with the welding direction
c) Staggered to ensure the edges of the weld regions partially overlap.

## Parallel Twin-stir™

The Twin-stir™ parallel contra-rotating variant (fig 3a) enables defects associated with lap welding to be positioned on the 'inside' between the two welds. For low dynamic volume to static volume ratio probes using conventional rotary motion, a possible detrimental feature will be 'plate thinning' on the retreating side. With tool designs and motions designed to minimise plate thinning, so called hooks may be the most significant possible detrimental feature. This feature can be avoided using Twin-stir™ technology.

The Twin-stir™ method may also allow a reduction in welding time for parallel overlap welding. Owing to the additional heat available, increased travel speed or lower rotation process parameters will be possible.

## Tandem Twin-stir™

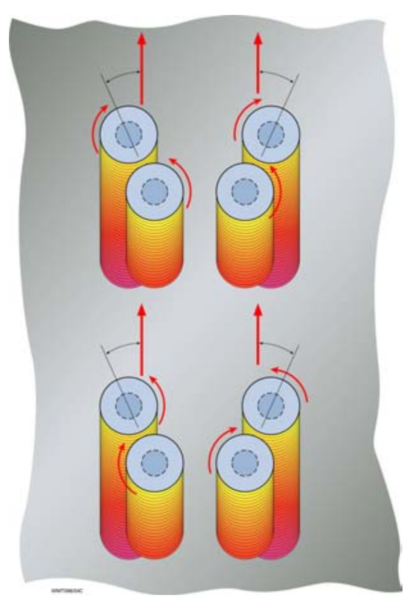
The Twin-stir™ tandem contra-rotating variant (fig 3b) can be applied to all conventional FSW joints and reduces significantly reactive torque. More importantly, the tandem technique will help improve the weld integrity by disruption and fragmentation of any residual oxide layer remaining within the first weld region by the following tool. Welds have already been produced by conventional rotary FSW, whereby a second weld is made over a previous weld in the reverse direction with no mechanical property loss. The preliminary evidence suggests that further break-up and dispersal of oxides is achieved within the weld region. The Twin-stir™ tandem variant will provide a similar effect during the welding operation. Furthermore, because the tool orientation means that one tool follows the other, the second tool travels through already softened material. This means that the second tool need not be as robust. It is noted that under certain circumstances these tools need not always be used in the contra-rotation mode and their rotational speed can also be varied.

## Staggered Twin-stir™

The staggered arrangement for Twin-stir™ (fig 3c) means that an exceptionally wide 'common weld region' can be created. Essentially, the tools are positioned with one in front and slightly to the side of the other, so that the second probe partially overlaps the previous weld region. This arrangement will be especially useful for lap welds, as the wide weld region produced will provide greater strength than a single pass weld, given that the detail at the extremes of the weld region are similar. Residual oxides within the overlapping region of the two welds will be further fragmented, broken up and dispersed. One particularly important advantage of the staggered variant is that the second tool can be set to overlap the previous weld region and eliminate any plate thinning that may have occurred in the first weld. This will be achieved by locating the retreating side of both welds on the 'inside' (see fig 4).

For material processing, the increased amount of material processed will also prove advantageous. In addition, for welding, it would enable much wider gaps and poor fit-up to be tolerated.

a) c)



b) d)

**Fig 4.** Arrangement of Staggered Twin-stir™ contra-rotating tools with respect to rotation and direction

a) Advancing sides of the 'common weld region' are positioned outwards with left-hand tool leading.
b) Retreating sides of the 'common weld region' are positioned outwards with left-hand tool leading
c) Retreating sides of the 'common weld region' are positioned outwards with right-hand tool leading
**d)** Advancing sides of the 'common weld region' are positioned outwards with right-hand tool leading

## Welding trials

A Series of preliminary welding trials has been carried out using an experimental Twin-stir™ head developed at TWI in order to investigate the characteristics of welds made in a variety of configurations. The welding trials were carried out with the prototype Twin-stir™ head as shown in fig 5.

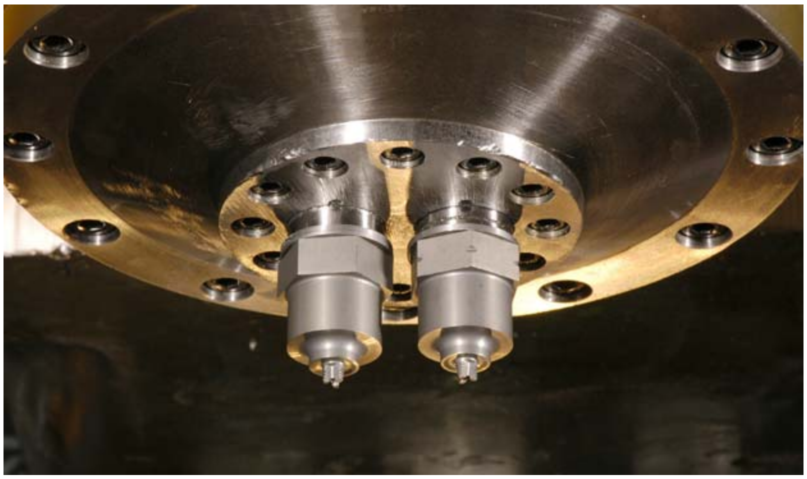


**Fig 5.** Twin-stir™ prototype head assembly

The welding trial demonstrated the feasibility of Twin-stir™ and showed that welds of good appearance were produced as shown in fig 6.

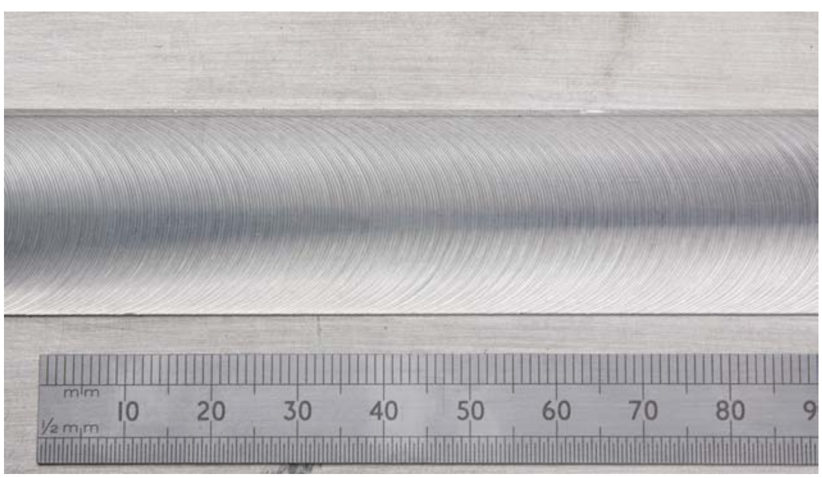



**Fig 6.** Surface appearance of a typical Tandem Twin-stir™ weld made in 6083-T6 aluminium alloy

The two exit holes produced in a tandem weld showed that a similar footprint was achieved for both the lead and following tool (see fig 7).


**Fig 7.** Tandem Twin-stir™ lead and follow exit holes

Metallographic observations revealed a marked refinement of grain size in the weld region and comminution of oxide remnants and particles. This is consistent with the microstructural features previously observed in conventional rotary stir welds in aluminium alloys. An upturn on both sides of the weld region is also shown (fig 8). All sections were prepared in the direction looking towards the start of the weld.

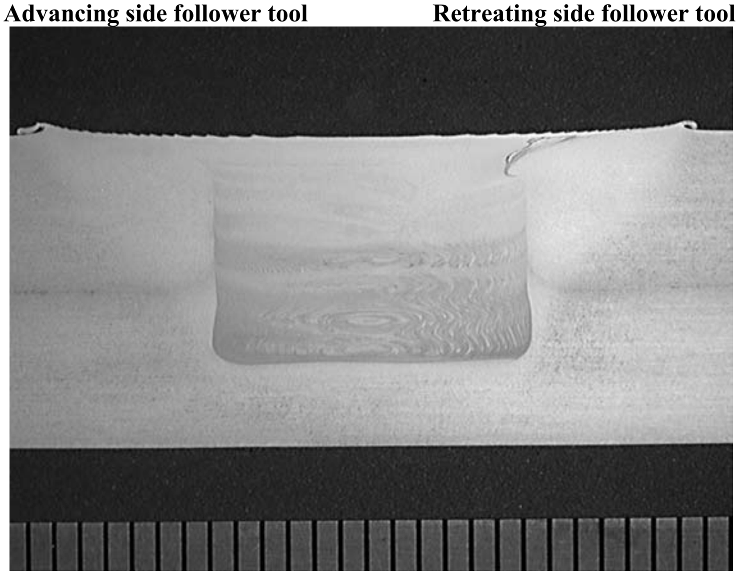



**Fig 8.** Macrosection of Tandem Twin-stir™ lap weld in 6 mm thick 6082-T6 aluminium alloy

Metallographic examination of Staggered Twin-stir™ welds revealed a 'common weld region' as shown in fig 9.

**Advancing side of follower tool** **Advancing side of leading tool**

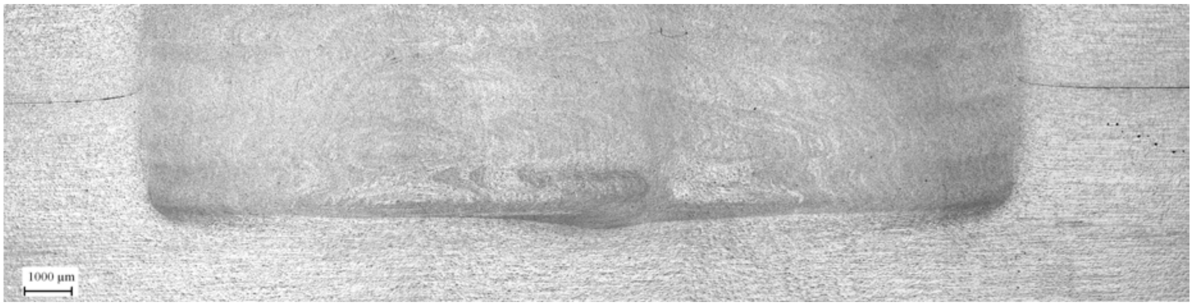



**Fig 9.** Montage of macrosections taken from the 'common weld region' of a Staggered Twin-stir™ weld

The tool arrangement used to produce this Staggered Twin-stir™ weld is that illustrated in fig 4a; whereby the advancing sides of the 'common weld region' are positioned outwards. Consequently, both retreating sides face inwards with the lead weld retreating side receiving further friction stirring treatment from the retreating side of the follower tool.

## Concluding remarks

It is to be expected that the tandem and staggered Twin-stir™ variants will further fragment and disperse tenacious residual oxides within the weld region or part of the weld region respectively. This will lead to improved weld integrity and performance. Moreover, the staggered Twin-stir™ method is likely to provide advantage and be preferred for safety critical applications for both butt and lap joints.

The simultaneous use of two or more friction stir welding tools and contra-rotating concepts have as yet not been fully developed or exploited, mainly because of the added complexity of two instead of one rotating tool and concern about the additional thermal energy available. However, following the improvement in weld integrity and joint symmetry, the twin parallel, tandem, and staggered tool FSW concepts are likely to provide advantages that out weigh the disadvantages. All contra-rotating systems help to reduce the reactive torque necessary to secure plates to the machine. The use of Staggered Twin-stir™ is expected to prove advantageous for material processing, lap welding and it would enable much wider gaps on butt welds to be tolerated.

Although much more development work is required before the technique can be used commercially, the prognosis for the successful implementation of Twin-stir™ variants is good. Development work will continue at TWI.

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