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Texture in friction stir welds of Timetal 21S

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Abstract

The β-titanium alloy, Timetal 21S, was welded by the friction stir welding process. Good weldability was demonstrated for a range of welding parameters. A torsion texture was observed in all welds.

Keywords: Friction stir welding; Titanium; Texture

1. Introduction

Friction stir welding (FSW) [1] has been used to weld a wide variety of metals and alloys, including nearly all types of Al alloys [2], some Mg alloys, e.g. see Ref. [3], as well as ferrous and austenitic steels [4,5]. Friction stir welding of titanium alloys (primarily Ti-6-4) has been reported, e.g. see Ref. [6], but there is very little information in the archival literature regarding the development of microstructure in titanium alloys due to FSW.

The goal of this paper is the elucidation of the texture resulting from FSW of Timetal 21S. Orientation imaging microscopy studies of aluminum alloy friction stir welds indicate a predominant shear texture in the weld (assuming proper choice of reference frame) [7,8]. The limited reports on FSW of Ti-6-4 indicate a refined structure relative to the base metal and moderate overmatching of the weld zone relative to the base metal [6]. However, no texture studies of any friction stir welded titanium or any body-centered cubic (BCC) metals have been published.

The alloy welded in this study, Timetal 21S, belongs to the meta-stable β family of alloys (Moly equivalent ≈ 13) [9]. That is, by suitable processing, the alloy can be produced with a single phase BCC crystal structure that is retained at room temperature. The strength of the alloy may be increased by subsequent aging treatments that cause the precipitation of α-phase particles in the β matrix. The alloy is readily cold formable and finds its primary applications in sheet gage: it is used especially in applications where resistance to attack by aircraft hydraulic fluid is required [10]. Because the alloy does not undergo allotropic transformations upon rapid heating and cooling, it is anticipated that the texture formed during FSW will be preserved in the remnant microstructure.

2. Materials and experimental procedure

2.1. Timetal 21S

Rolled and annealed Timetal 21S sheets, 1.59 mm thick, were used for all of the welding studies. The as-received sheet has an equiaxed grain structure with an average grain size of approximately 30 μm based on the mean linear intercept method (some elongated grains are occasionally observed in the base metal microstructure). No evidence of precipitated α-phase was detected optically.

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2.2. Friction stir welding

Welding blanks, 304.80 mm long and 101.60 mm wide, were cut from the supplied sheet with the long direction perpendicular to the rolling direction. Blanks were initially cut with an abrasive water jet cutter. The edges to be welded were milled to provide square and parallel surfaces for butt welding. The welding blanks were cleaned with detergent to remove grease and coolant used during milling.

The FSW of the sheet was performed with the MTS FSW Process Development System (PDS) at the University of South Carolina. The sheet blanks were clamped to an austenitic stainless steel backing plate. The welding tool was fabricated from a tungsten alloy rod. The tool geometry was very simple, but details are proprietary to the sponsors of the work.

To prevent oxidization of the titanium sheet and of the welding tool, all welds were performed in a plexiglass box which was backfilled with argon. Welds were made at welding speeds of 0.85, 2.54, 3.39 and 5.08 mm/s. The tool rotation rate was held constant at 200 rpm.

2.3. Weld characterization

Transverse cross-sections of all welds were prepared by standard metallographic procedures. Samples were mounted in epoxy and ground with abrasive paper. Polishing was conducted with diamond paste abrasive. Final polishing was in basic, 0.05 μm colloidal silica in a vibratory polisher for 4 h.

Orientation imaging microscopy was performed in a Philips XL30 ESEM with a TSL OIM Electron Backscatter Diffraction module. Specimens were observed with an electron accelerating voltage of 30 kV. Weld zone OIM data were obtained at the midplane of the sheet on the weld centerline for all of the welds. For the 0.85 mm/s weld, texture was measured at locations on the weld centerline near the crown and root as well. Base metal data was obtained well away from the weld zone. In the weld zone, a step size of 0.15μm was used and each data set contained approximately 53,000 points. The base metal texture was assessed using a step size of 5 μm.

3. Results

Fig. 1 is a macro-image of a typical weld cross-section. The section was etched with Kroll's reagent and scanned with a flatbed scanner. The central, darker appearing region corresponds to the refined microstructure in the weld material. The lighter appearing material is base metal. The nearly constant thickness in the scanned section indicates that there was very little sheet thinning during the FSW process. No volumetric defects were observed in the cross-sections of any of the welds. Fig. 2 is a higher magnification view of the boundary between the coarse grain base metal and the weld nugget. In the weld nuggets, the average grain size varies from 2 μm (fastest welding speed) to 3 μm (slowest welding speed). The nugget grain sizes are the area averages determined during the OIM studies. Nugget grains are generally equiaxed and no details of material flow can be deduced from the nugget grain structure.

Fig. 1. A typical weld cross-section. In the pole figures shown in Figs. 2 and 3, ND corresponds to the vertical direction in this image, RD corresponds to the normal to this image and TD corresponds to the horizontal direction. (A) Indicates the advancing side and (R) the retreating side of the weld.

OIM was used to determine crystallographic texture at the center of each weld on the sheet midplane. For the 0.85 mm/s weld, texture was measured at additional locations on the centerline near the root and the crown. Figs. 3 and 4 are, respectively, base metal {1 1 1} and {1 1 0} pole figures, and weld nugget center 110 pole figures ({1 1 1} pole figures from the nugget were also produced but are omitted to save space). All of the pole figures have been rotated 90° about the transverse direction (perpendicular to the welding direction in the plane of the sheet) so that the welding direction corresponds to the vertical (RD) in the pole figures. In these views, the transverse direction is perpendicular to the welding direction and tangent to the pin of the welding tool. For the weld pole figures, the normal direction will very nearly correspond to the rotational axis of the tool which was very slightly inclined to the plate normal (1°).

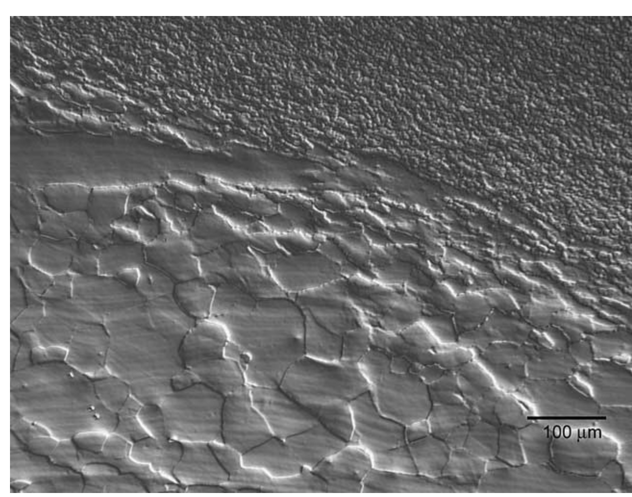

Fig. 2. Boundary (advancing side) between the refined structure in the weld nugget and the coarse grain base metal. Location of this image is approximately at the sheet midplane.