UNUSUAL CHARACTER OF MATERIAL FLOW DURING FRICTION STIR WELDING WITH LARGE TOOL SHOULDER

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INTRODUCTION

Magnesium alloys, being the lightest metallic materials in practical use and having a very attractive balance of properties, offer a great potential for weight saving in today’s vehicles. However, poor weldability of these materials restricts their widespread industrial application. In this regard, friction stir welding (FSW), an innovative “solid-state” joining technology [1], appears to be a particularly attractive for the magnesium alloys. Unfortunately, inhomogeneous texture distribution associated with the specific nature of the material flow around the rotating pin [2] may significantly deteriorate service properties of the magnesium weldments. In order to overcome the “texture problem”, a simple approach involving FSP by using a tool with a large shoulder diameter has been recently developed. It is believed that this method enables to produce reasonably homogeneous “rolling-type” texture with the shear plane parallel to the sheet (shoulder) plane. In the present study, high-resolution electron backscatter diffraction (EBSD) technique was employed to study the material flow in AZ31 magnesium alloy during FSW with the large tool shoulder.

EXPERIMENTAL

The material used in the present investigation was a commercially graded AZ31 magnesium alloy with a nominal chemical composition (wt.%) of 3.0 aluminum, 1.0 zinc and balance magnesium. The material was supplied as 2mm-thick sheets. The received material had fully recrystallized grain structure with an average grain intercept of \(\sim 20 \mu m\).

A bead-on-plate friction-stir weld was made at a tool rotational speed of 2000 rpm and a travel speed of 600 mm/min. The welding tool consisted of a shoulder having diameter of 15 mm and of a M4 threaded cylindrical pin with 1.7 mm in length. In order to preserve instantaneous microstructure developed during FSW from possible recovery/recrystallization during FSW cooling cycle, so-called “stop-action” technique [3] was applied. That included emergency halt of the welding machine and immediately quenching of the welding tool position. To allow direct examination of the shoulder effect through the sample thickness, the tool stop position was sectioned in a longitudinal plane along the weld axis (through the tool), permitting a side view of the “frozen” tool keyhole. The microstructure directly ahead the keyhole was studied by EBSD technique. To maintain consistency with usual FSW terminology, the principal directions used in present study were denoted as WD (welding direction), TD (transversal direction) and ND (normal direction).

RESULTS AND DISCUSSION

A composite EBSD map taken ahead the keyhole is shown in Fig. 1. For simplicity, a contour of the appropriate tool fragment is superimposed on the figure. Based on morphological and textural differences, the large EBSD map is divided on five microstructural regions (Region 1 to Region 5) and characteristic (0002) pole figures derived from these regions are also shown in Fig. 1.

The initial (base) material has a moderate texture with the \{0002\} basal planes oriented nearly parallel to the WD; this presumably indicates that the material was extruded along the WD.

In Region 1, the initial texture decreases in strength and new \(<0001>/WD\) textural component appears. The formation of the \(<0001>/WD\) texture in the friction-stirred magnesium alloys is well documented [2] and is usually attributed to the simple shear deformation introduced by the rotating pin and corresponding alignment of the \{0002\} basal planes with the pin column surface [2]. Thus the development of this textural component is a quite expectable result.
Fig. 1. A composite EBSD map taken ahead the tool keyhole with superimposed contour of the tool fragment and 0002 pole figures showing texture in various locations. See text for details.

Directly near the tool keyhole, in Region 2, the \(<0001>\)/WD texture is notably strengthened becoming a predominant texture component. This evidences that the material flow in this region arises mainly from the rotating pin. This is also quite predictable because the material in this region directly interacts with the pin.

In the context of our study, of particular importance is the observation that the texture of the material adjacent to the top part of the tool (Region 3) is featured by the significant reorientation of the dominant texture component towards \(<0001>\)/ND. The trend of the alignment of the basal plane with the shoulder surface may be interpreted in terms of the principal influence of the shoulder on the material flow. “Transient” orientation of the basal plane (between the pin column surface and the shoulder surface) presumably indicates that the material flow in Region 3 is driven by the combined effect of the pin and the shoulder. This conclusion appears to be reasonable because the material in Region 3 directly interacts with the pin as well as with the shoulder. Importantly, the shoulder contribution in the material flow appears to gradually decrease towards the pin giving rise a significant texture gradient in Region 3.

Region 4 is featured by an irregular texture. However, taking into account that Region 4 lies between the Regions 1 and 3, the textural pattern in Region 4 may be interpreted in terms of transition between the characteristic textures of these regions.

Of particular interest is the texture in Region 5. Direct orientation measurement shows that the basal planes in this region are oriented nearly parallel to the shoulder surface thus confirming that the material flow is dominated by the shoulder.

Thus the shoulder enlargement significantly complicates the deformation pattern during FSW of AZ31. If the material flow in the bottom part of the sheet to be welded is ordinarily associated with the rotating pin, in the upper part of the sheet (Regions 3 and 5) it is principally influenced by the rotating shoulder. In other words, this simple approach notably increases the contribution of the tool shoulder in the material flow and thus has a good potential for texture optimization in the magnesium friction-stir weldments.

REFERENCES