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E ects of friction stir processing on mechanical properties of the cast aluminum alloys A319 and A356 ☆

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Abstract

Surfaces of A319 and A356 castings were treated by friction stir processing to reduce porosity and to create more uniform distributions of second-phase particles. Dendritic microstructures were eliminated in stir zones. The ultimate tensile strengths, ductilities, and fatigue lives of both alloys were increased by the friction stir processing.

Keywords: Aluminum alloys; Casting; Friction stir welding; Mechanical properties; Surface structure

1. Introduction

The use of the friction stir process primarily to modify microstructures is not as well developed as it is for welding, but its potential is becoming apparent. Friction stir welding creates bonds through the combined e ects of heat, deformation by a stirring action, and pressure using a nonconsumable tool that is translated along a joint line [1]. While it uses the same type of equipment and procedures, bonding materials together is not the objective of friction stir processing. Instead, friction stir processing is a means to locally modify properties over depths or volumes that depend on the material being processed and the desired e ect. Friction stir processing can dramatically refine grain structures producing improvements in a variety of properties [2–5]. Some examples include conditioning microstructures of wrought Al alloys for high strain rate superplastic deformation [3], and refining microstructures to improve ductility of high-strength powder metallurgy Al nanocomposite alloys [4]. Other innovative applications are for improving the cold-workability of wrought Al plate [6], and improving the mechanical properties of both Al castings [7–9] and fusion welds of wrought Al plate [10,11].

The objective of the present work was also to evaluate the extent to which friction stir processing could improve local mechanical properties of Al castings. Two cast alloys were used, A356 and A319. These were chosen because they are important for many automotive components, such as suspension, driveline, and engine parts, where increased durability and reliability are always desirable.

2. Experimental details

The specimens used for the friction stir processing experiments were machined from sand-cast ingots into

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16 mm × 50 mm × 200 mm bars. Two alloys were used: A356 (nominally Al–7Si–0.3Mg, wt.%) and A319 (nominally, Al–6Si–3.5Cu, wt.%).

The friction stir processing was done on a milling machine with the position of the stir tool fixed relative to the surface of the bars. The tool was made of H13 steel with a shoulder diameter of 13 mm. The pin was cylindrical with a hemispherical tip; its dimensions were 5.2 mm diameter × 3.4 mm length. The working surfaces of the stir tool were smooth. The tool rotation speed was set at 1000 rpm, and the translation speed fixed at 1.7 mm/s throughout the experiments. These conditions were used to make stir passes with lengths of about 150 mm. Some testing and analysis was done using single stir passes. Other bars were processed with 5–6 passes overlapped on intervals of about 4 mm. Overlapping the passes created relatively consistent stir processed volumes on the bars with dimensions of about 3 mm × 20 mm × 150 mm.

The room temperature properties of the friction stir processed bars were measured by Vickers microhardness testing, tensile testing, and fatigue testing. The microhardness measurements were made on metallographically prepared specimens taken to view the surfaces of single stir passes. The indentations were made under a 50 g load in 200 μm × 200 μm arrays extending from the stir zones into the base metal.

The bars with the overlapped passes were used to make both tensile and fatigue test specimens. For the tensile specimens, blanks were electrical discharge machined (EDM) across the stir zones, i.e., transverse to the translation direction. Slices 2-mm thick were then EDM cut from both surfaces of the blanks to provide one specimen of base metal and one specimen where the gage section was entirely within the friction stir processed material. The gage length and width dimensions were 12.5 mm and 3 mm, respectively. The nominal strain rate for the tensile tests was 1×10^{-3}

bution for A356 were virtually identical to those of A319. However, the average hardness values of the A356 casting and stir zone were 583 ± 60 MPa and 522 ± 32 MPa, respectively. These results show that the thermomechanical treatment cycle of the friction stir processing had a hardening e ect in A319 and a slight softening e ect in A356. Others have also found that the hardness of friction stir processed A356 is similar to that of the cast metal [7].

Data comparing the tensile behavior of cast and friction stir processed metal are presented in Fig. 4 and Table 1. Both alloys experienced large ductility increases for friction processed material. The markers in Fig. 4(a) indicate the fracture strains for the A319 specimens which all failed with no significant necking. Friction stir processing of this alloy increased the maximum total elongations from under 1% to over 7%. The yield points of the friction stir processed specimens were also slightly higher than those measured for the cast metal which is consistent with the hardness measurements. In contrast, the A356 specimens did display necking before failure. Friction stir processing increased total uniform elongation values in this alloy from under 3% to over 12%. The stir processed A356 had slightly lower yield strength than the cast metal as the hardness data would indicate. It should be noted that the cast bars were heated by the friction stir processing. As a consequence, the cast specimens of both alloys were subjected to multiple undefined thermal excursions. These unintended heat treatments could influence property values of the casting [13,14]. However, the stir processed material would have been subjected to similar heat treatments so that the comparison of tensile properties is still considered valid.

Because only one specimen in each condition was fatigue tested S–N curves could not be developed. Instead, specimens were tested at 138 MPa to directly compare the as-cast and fricTable 2.tiThe15.9(stir)e55-7.-1200f7-1y2034its are g
reversed. The strain amplitu55.12.8(es)-373(were)-378.9(selected)-38
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illustrated by Fig. 4 and shown in Table 1 for both the cast A319 and A356 deviate somewhat from the typical ranges. This could be the result of unintended heat treat-

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