Microstructure Evolution During Friction Stir Processing of Aluminum Cast Alloys

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INTRODUCTION

Friction Stir Processing (FSP) is a recent outgrowth of the Friction Stir Welding (FSW) process and relies on solid-state deformation to modify the surface of the working surface/materials. FSP has been shown to locally eliminate casting defects and to refine the microstructure of alloys to improve their mechanical properties and enhance corrosion resistance. Such improvements have important implications for manufactured components for a variety of automotive and other industrial applications.

In Friction Stir Processing a rapidly rotating pin tool is plunged into the surface of the component and traverses across the surface and locally deforms the component. Frictional heating and extensive plastic deformation occur in the material causing considerable changes in the traversed area. Friction stir processed zones can be produced in metallic components to depths of about 50mm below the surface with a gradual transition from a heavily worked material at the surface to the underlying original material.

OBJECTIVES

1. *Confirm and evaluate microstructure evolution during friction stir processing of aluminum alloys,*

2. *Investigate the potential of friction stir processing to form a particle-reinforced zone in standard Al cast components.*

METHODOLOGY

The objectives were achieved through a judicious selection of the experimental matrix including all friction stir processing parameters, conducting a thorough microstructure analysis, and performing representative mechanical properties tests.

In this study, FSP was carried out in two phases. In Phase I, FSP was applied to one inch thick, sand casting A206 aluminum workpiece under different processing parameters. Optical microscope, SEM and EDS measurements have been performed to reveal and study microstructure before/after FSP. Thermocouples have been applied to acquire the temperature gradient and thermal history during FSP. A range of material properties, including hardness and tensile measurement in A206, were examined after FSP. In Phase II, FSP was used for composite fabrication in the top layer of the A206 substrate. The discontinuously reinforced aluminum (DRA) which contained 15% weight percent SiC was introduced into one inch thick sand cast A206 substrate.

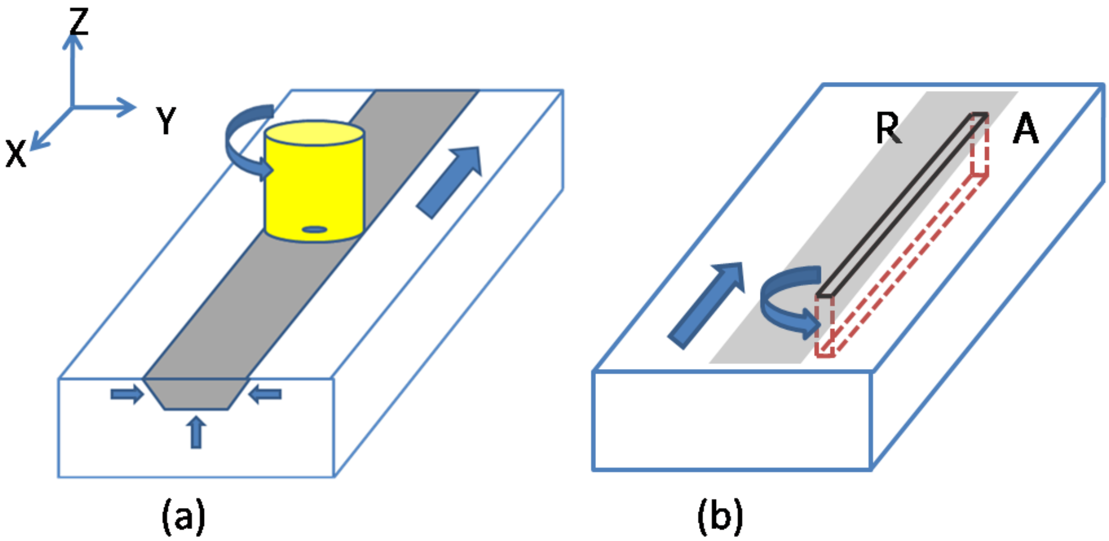


Figure 1: Schematic diagrams of FSP: (a) Phase I; (b) Phase II.

SALIENT RESULTS

A FSP set up was established at WPI, and its capabilities were assessed and validated using Al 356 alloy similar to previous investigators. Once confidence was established and results were validated, we then embarked on a two-phase (Phases I and II) experimental program, coupled with the development of a mathematical model for the process.

Phase I: Microstructure evolution of A206 via FSP

The microstructure evolution of A356 during FSP was verified and validated. Si and Mg_2Si phases were distributed uniformly in the aluminum matrix after FSP, and the size and aspect ratio of these particles decreased significantly. Porosity was nearly eliminated by FSP.

FSP was applied to manipulate the A206 microstructure to refine or strengthen locally.

The grains in the stirred zone of A206 were refined to micrometer levels, and the grain boundaries were clearly revealed. Second phase particles were distributed uniformly in the aluminum matrix after FSP, and the size and aspect ratio of these particles decreased significantly. Porosity was reduced significantly, if not almost eliminated via FSP.

Effects of process parameters on A206 alloy, i.e. tool rotation speed and traverse speed were investigated. An optimum experimental condition was established: *FSP at 1000 RPM-1IPM.* The mechanism of grain refinement in A206 is that of dynamic recrystallization (DRX). The temperature evolution in the sample during FSP is key to initiate DRX. The thermal history in the processing direction for A206 shows the same trend at different locations. The FSP temperature was affected by tool rotation speed and traverse speed; temperature reached the dynamic recrystallization temperature of the alloy.

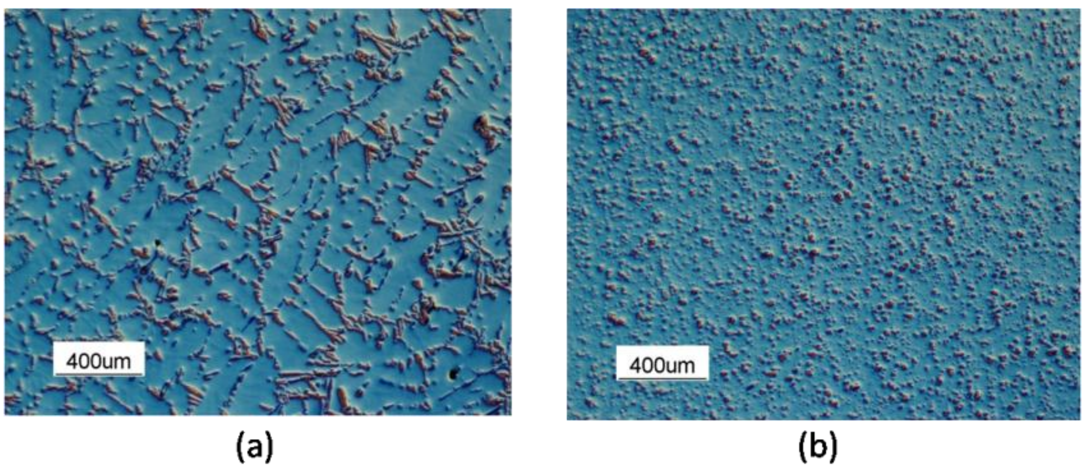


Figure 2: Optical micrographs of A356:
a) As-received; b) after FSP by 1000RPM - 1 IPM.

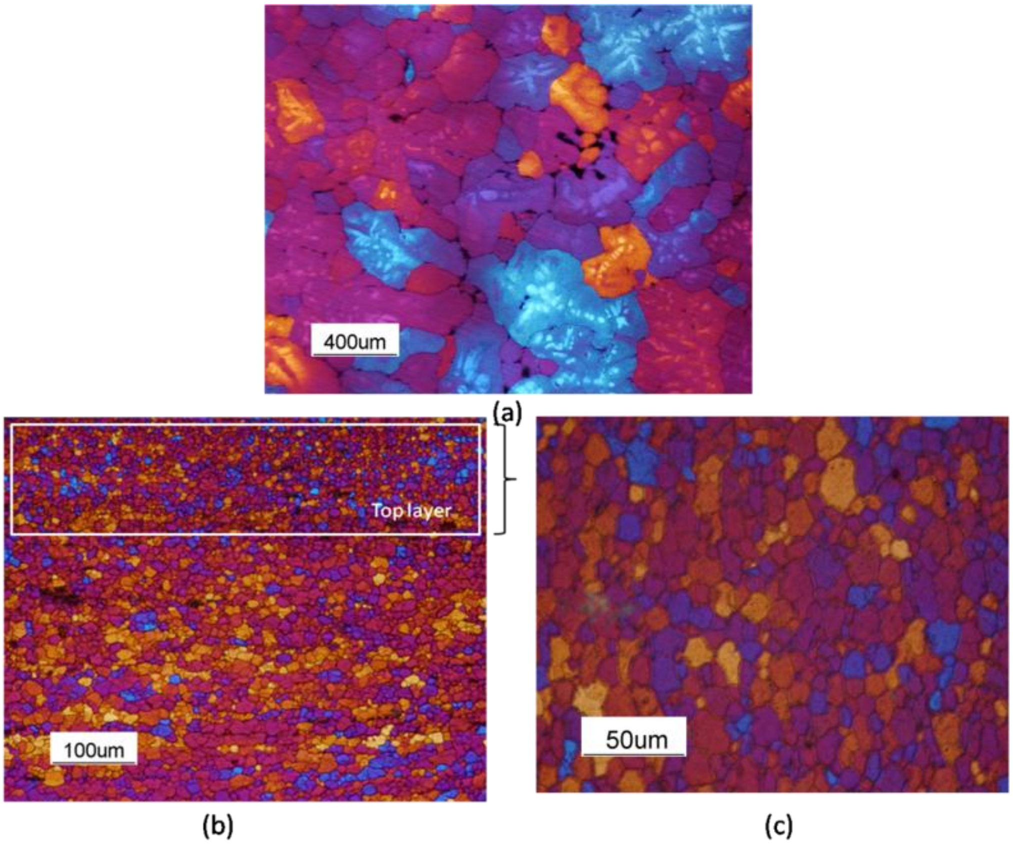


Figure 3: Microstructure of A206 after FSP at 1000RPM – 1IPM: a) as-cast + T4; b) top layer microstructure in nugget; c) refined grains in the nugget.

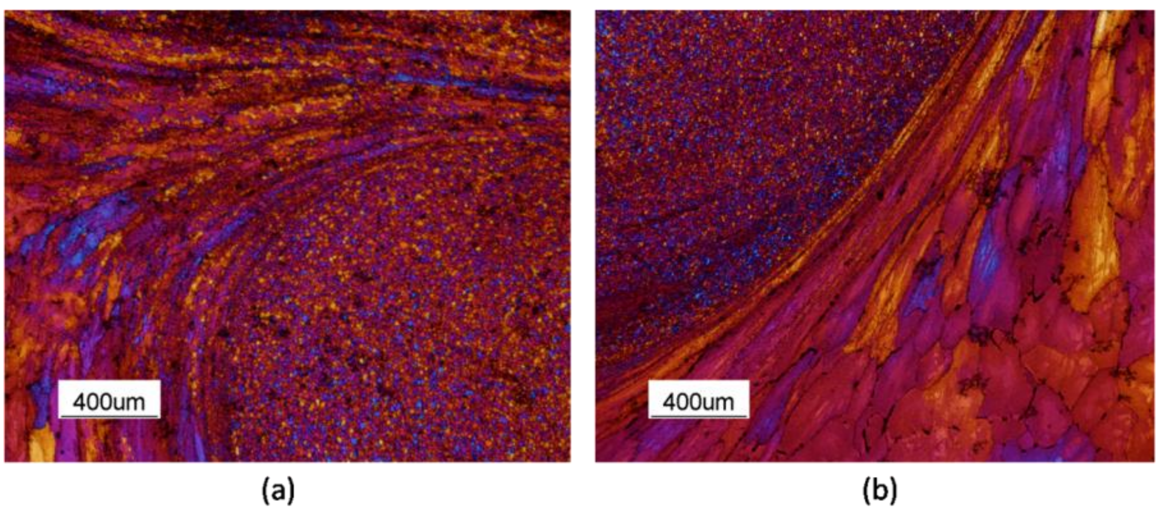


Figure 4: Microstructure of the transition zone between FSP zone and parent material of the A206 sample (1000RPM – 1IPM): a) retreating side boundary; b) advancing side boundary.

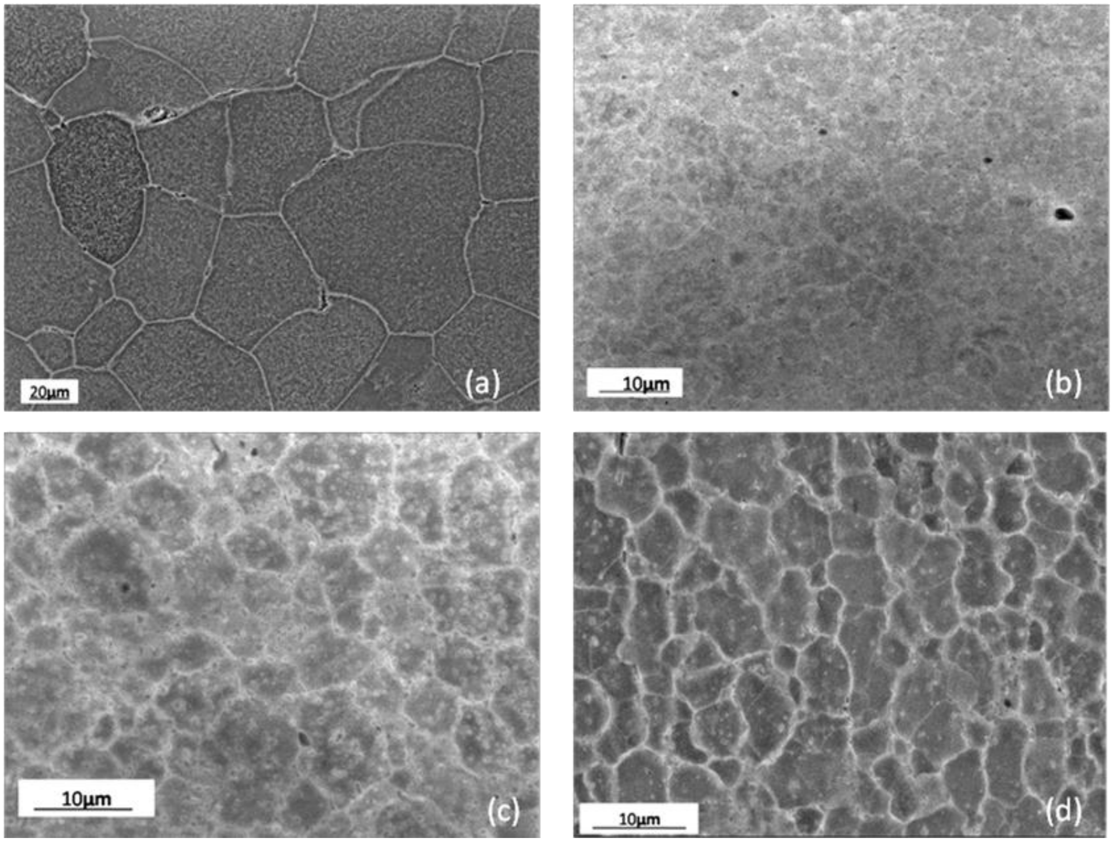


Figure 5: SEM micrographs of A206 grain size: (a) as received; no FSP; (b) FSP 500 RPM – 1IPM; (c) FSP 1000 RPM – 2IPM; (c) FSP 1000RPM – 1IPM.

A mathematical model was established to quantitatively calculate the heat input from different parts of the tool referring to the real tool geometry.

Tensile and microhardness tests on the as-processed A206 specimen were carried out to investigate the effect of FSP on mechanical properties of the alloy. FSP resulted in higher ductility in the as-cast-T4 A206. The higher ductility was due to the elimination of porosity and the breakup of coarse second phase particles. The microhardness profile in the majority of the nugget after FSP improved because of grain refinement, which was in accord with the Hall-Petch relationship. The relatively lower microhardness in TMAZ could have resulted from the large grain size and the dissolution of precipitates into the matrix during FSP.

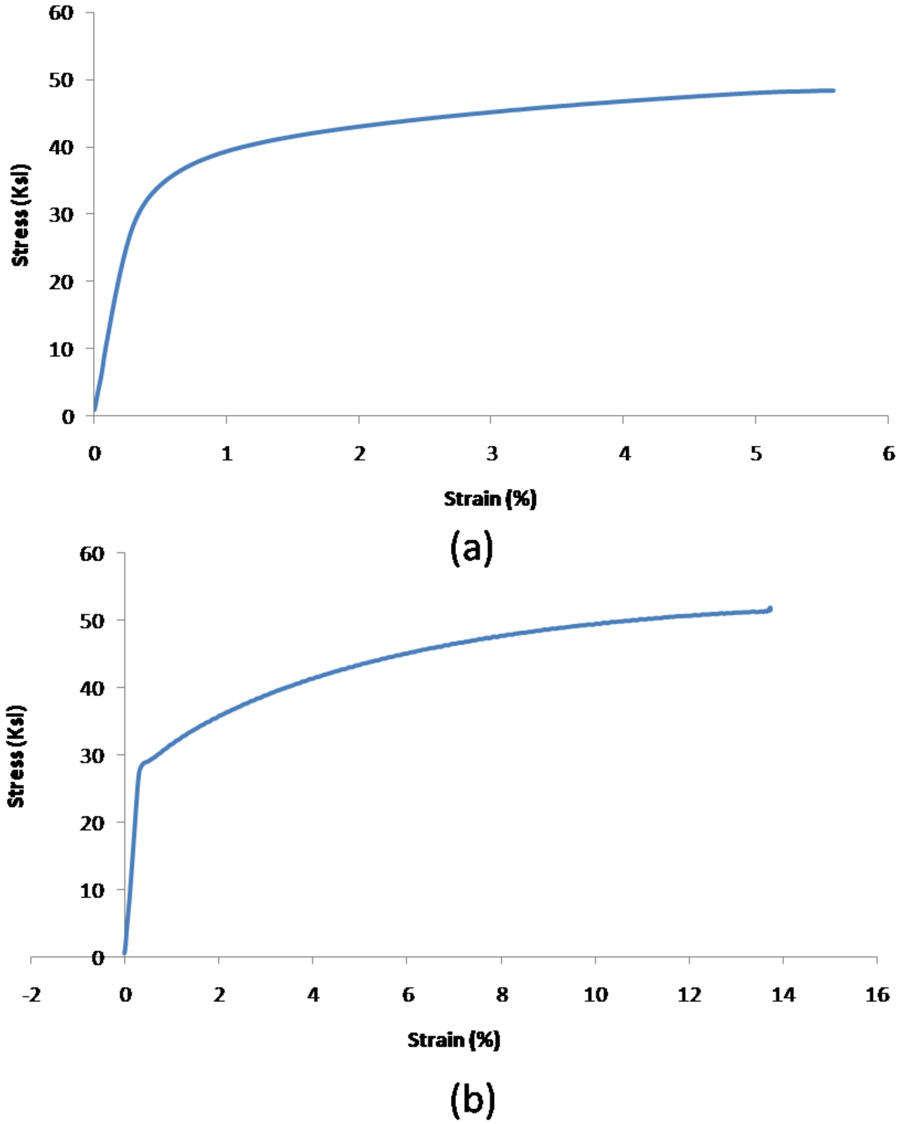
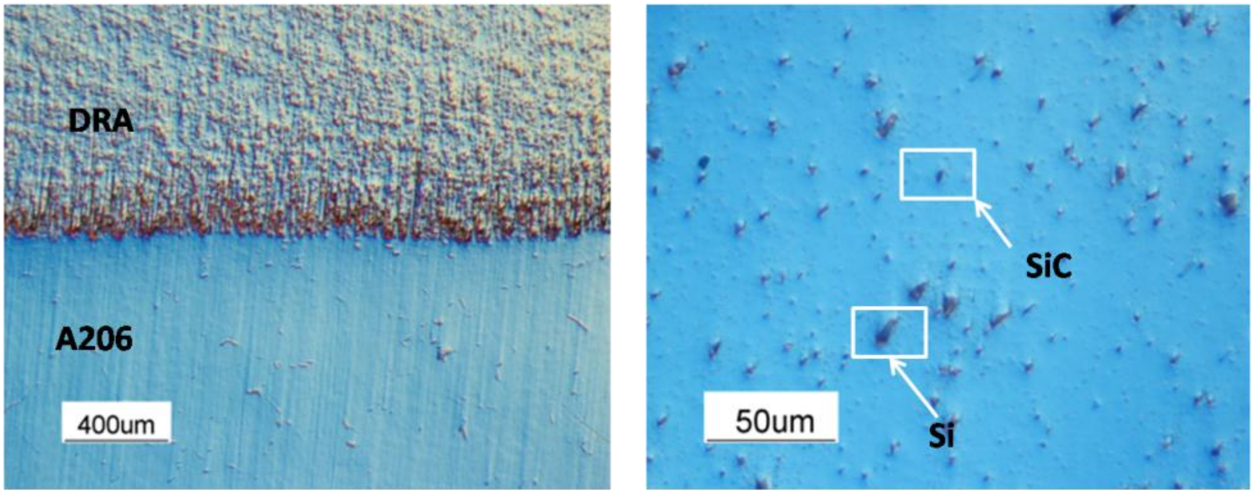


Figure 6: Stress-strain plots from room temperature tensile test of A206:
a) as-cast-T4; b) FSP at 1000RPM – 1IPM.

Phase II: Composite fabrication via FSP

In Phase II, FSP was used for composite fabrication in the top layer of A206 substrate. The discontinuously reinforced aluminum (DRA) which contained 15% weight percent SiC was introduced into one inch thick sand cast A206 substrate. The surface composite layer is well bonded to the aluminum alloy substrate. Defects were not visible validating that FSP is an effective way for composite fabrication in Al cast alloys.



(a) (b)

Figure 7: Optical micrograph showing (a) uniform distribution of DRA in aluminum alloy matrix; (b) perfect bonding between surface composite and aluminum alloy substrate.

PUBLICATION

N. Sun, D. Apelian, "Microstructural Modification of A206 Aluminum Via Friction Stir Processing", in Material Science Forum, Vol. 618-619, pp. 361-364, 2009.