Friction Stir Processing of Aluminum Cast Alloys for High Performance Applications

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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. Our work to date has shown to locally eliminate casting defects and refine the microstructure 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.

The project, "Microstructure Evolution during Friction Stir Processing of Aluminum Cast Alloys", has already been completed in the summer of 2009. In this completed project, we verified and validated the potential of FSP processing to locally strengthen cast components, and to enhance mechanical properties.

Based on the encouraging research to date, the ACRC consortium has decided to continue this project to further investigate four (4) specific interests; there are:

- Thermal processing response to FSP (T4, T7, as cast etc.)
- Mechanical property enhancement, particularly dynamic properties
- Establish a feasible process scheme and methodology for localized composite manufacture zones via FSP
- Develop a predictive model for the evolution of the FSP microstructure (incorporating thermal energy input and resultant structure)

OBJECTIVES

Based on these specific interests, objectives for this project are:

1. Explore the mechanism for microstructure evolution of A206 Al cast alloy via FSP.
2. Evaluate mechanical properties enhancement of A206 Al cast alloy via FSP.
3. Investigate the potential of FSP to form a localized particle reinforcement zone in the standard Al cast component.

METHODOLOGY

The principal goals of this work are to fully understand the mechanism that governs the microstructure evolution of aluminum cast alloys during FSP, to explore the behavior of the alloys in the thermal treatment afterwards, and to investigate the feasibility of FSP to manufacture a particle-reinforced zone in standard aluminum cast alloys. In order to achieve these goals, the following methodologies and strategies will be pursued:

1. Design experimental apparatus and conduct experiments to apply FSP and post-FSP heat treatment on aluminum cast alloys.

Figure 1: Main facility for FSP – HAAS VM3 mold machine.

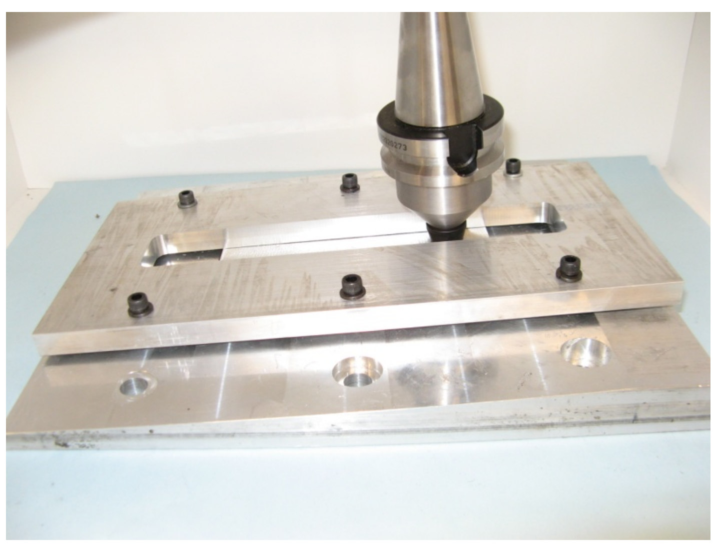

Figure 2: FSP tool and fixture.

2. Perform systematic experiments to fully characterize the effects of various variables (rotation speed, traverse speed and download force) in FSP on the

performance of aluminum cast alloys. Establish optimum parameters for microstructure evolution.

Table 1: List of FSP parameters

	Rotation speed (RPM)	Traverse speed (IPM)	Depth (MM)
Microstructure Manipulation (FSP only and FSP + heat treatment)	1000	1	3.5
	1000	2	3.5
	500	1	3.5
Composite fabrication	1000	2	3.5

3. Based on the experimental results, a predictive model that can take into account thermal and force factors will be established and validated through experiments.

4. Develop/standardize a methodology that can be utilized to manufacture localized zones of composite material that is made by the emplacement of a second phase into the Al alloy matrix during FSP. The particle-reinforced zone can be created by:
   - Emplacing discontinuous reinforced aluminum (DRA)
   - Mixing-in nano-sized encapsulated Ta powders
   - Mixing-in nano-sized encapsulated SiC powders

OUTCOMES

Phase I: Microstructure Evolution

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 is nearly eliminated by FSP. Dynamic recovery occurred during FSP before recrystallization.

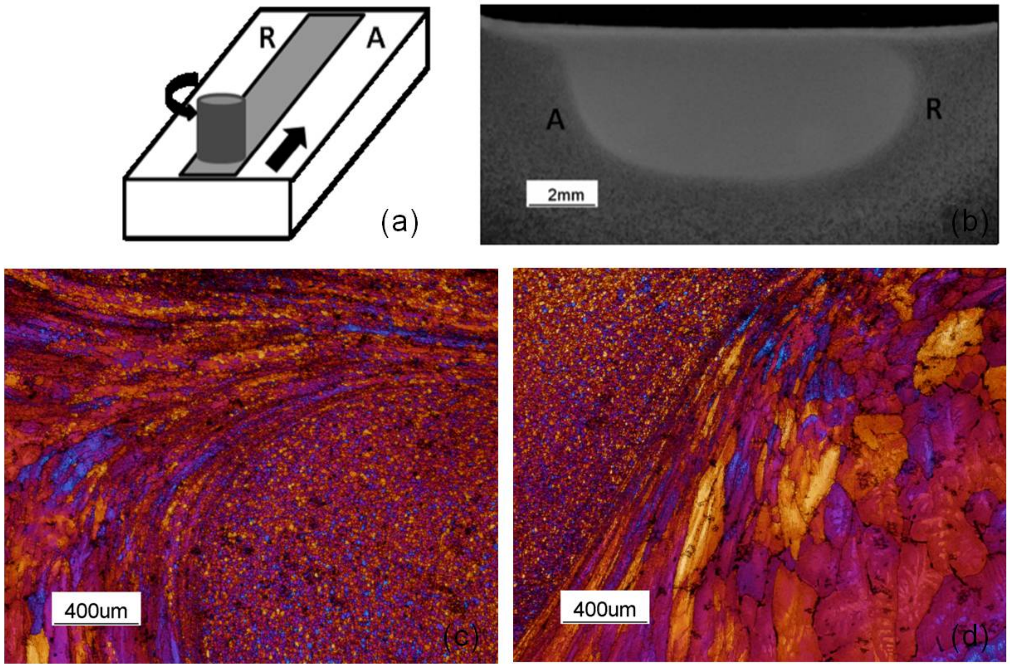

Figure 3: Macro and Micro images of FSP (a) FSP schematic diagram (b) macrograph of FSP region (c) micrograph of retreating side (d) micrograph of advancing side.

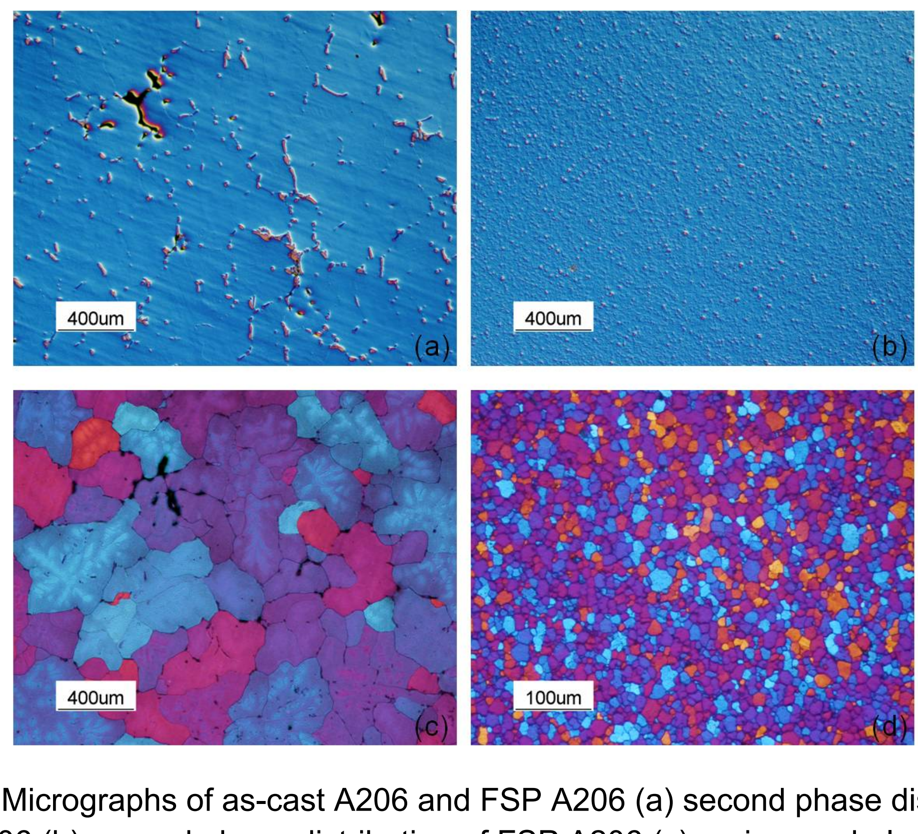

Figure 4: Micrographs of as-cast A206 and FSP A206 (a) second phase distribution of as-cast A206 (b) second phase distribution of FSP A206 (c) grain morphology of as-cast A206 (d) grain morphology of FSP A206.

Phase II: Mechanical properties

FSP strengthened A206 locally. Microhardness was increased in the FSP region. The shoulder-affected zone became harder than other locations in the FSP region. Strength (both the yield strength and the ultimate tensile strength) and ductility of the A206 improved via FSP. These enhanced mechanical properties resulted from elimination of porosity, breaking of coarse second phases and grain refinement. The fatigue endurance at 108 for the FSPed A206 was almost doubled compared with the as-cast A206. Crack initiated at pores near the surface of the as-cast specimens, whereas the crack initiated in the defect-free surface of the FSPed specimen from slip bands or microcracks caused by the debonding of the second phase particle from the aluminium matrix.

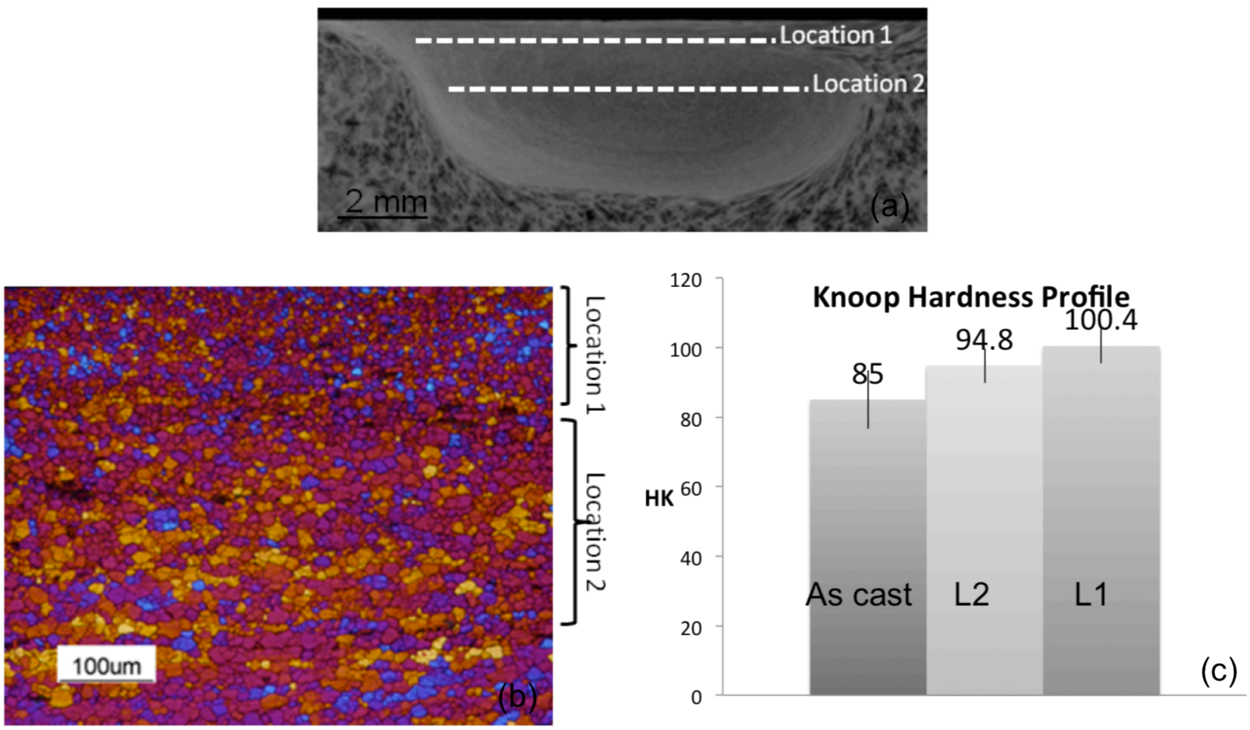

Figure 5: Microhardness profile of the as-cast A206 and FSP A206: (a) macrograph of the FSP region (b) grain size difference in the FSP region (c) microhardness profile.

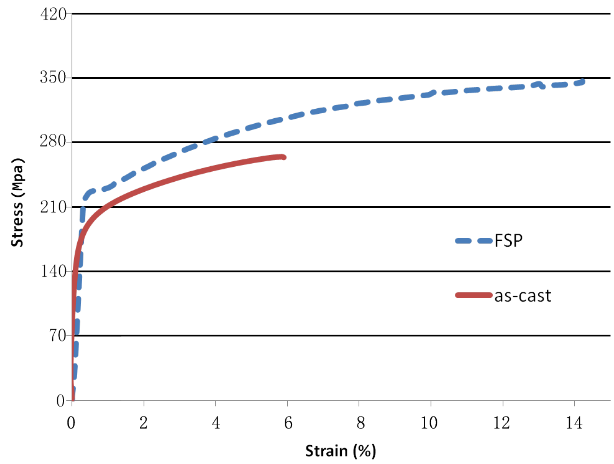

Figure 6: Typical stress-strain curves for as-cast and FSP A206.

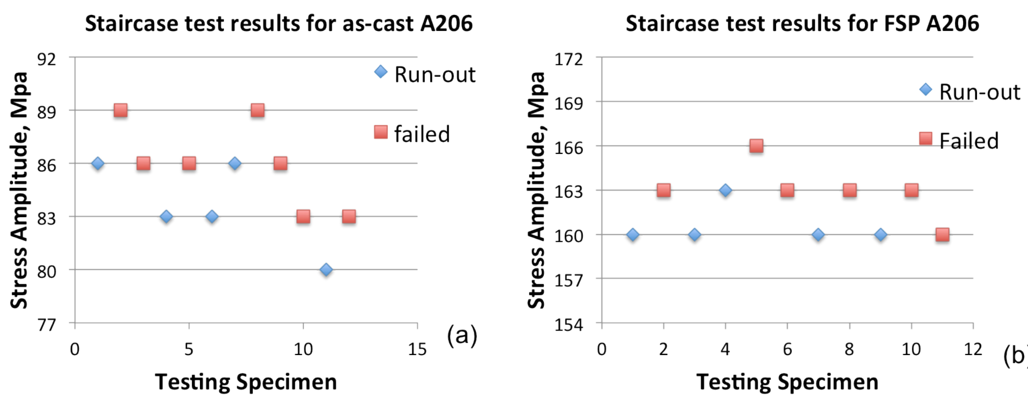

Figure 7: Experimental staircase test results for A206 at 108 cycles (a) as-cast A206 (b) FSPed A206.

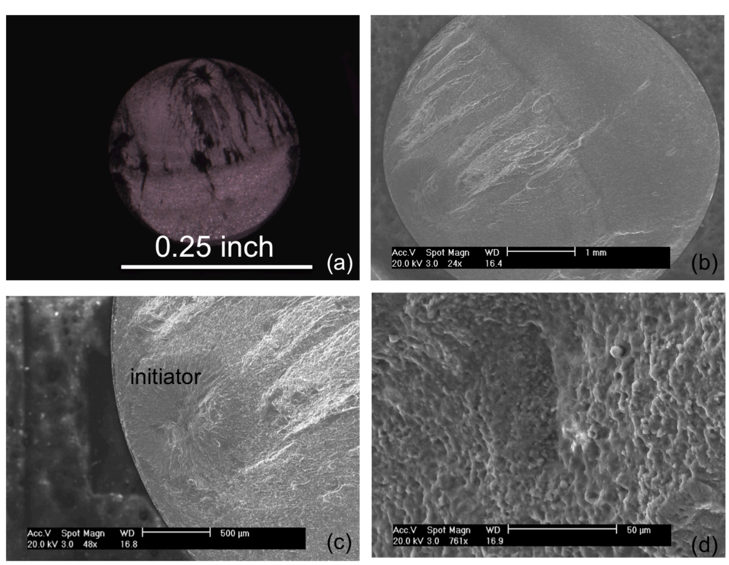

Figure 8: Fractographs of the FSPed A206: (a) low magnification fracture surface (b) the whole fracture surface at higher magnification (c) crack initiation region (d) higher magnification showing the morphology of the crack initiator.

Phase III: Composite fabrication

- FSP has emerged as an advanced post-processing tool to produce surface composites and synthesize second phase into the Al matrix in the solid state.
- Three different methodologies to fabricate the composite layer have been investigated: composite fabrication via FSP can be realized by mixing-in nano-sized Ta powders, mixing-in nano-sized SiC powders, and emplacing discontinuously reinforced aluminum in the cast aluminum matrix.
- Effects of process parameters have been explored. A good particulate distribution in the composite layer requires enough heat input, sufficient material wrapping and plastic deformation during FSP; composite fabrication by two-pass FSP with 100% cavity filling is the optimum procedure in the current study.

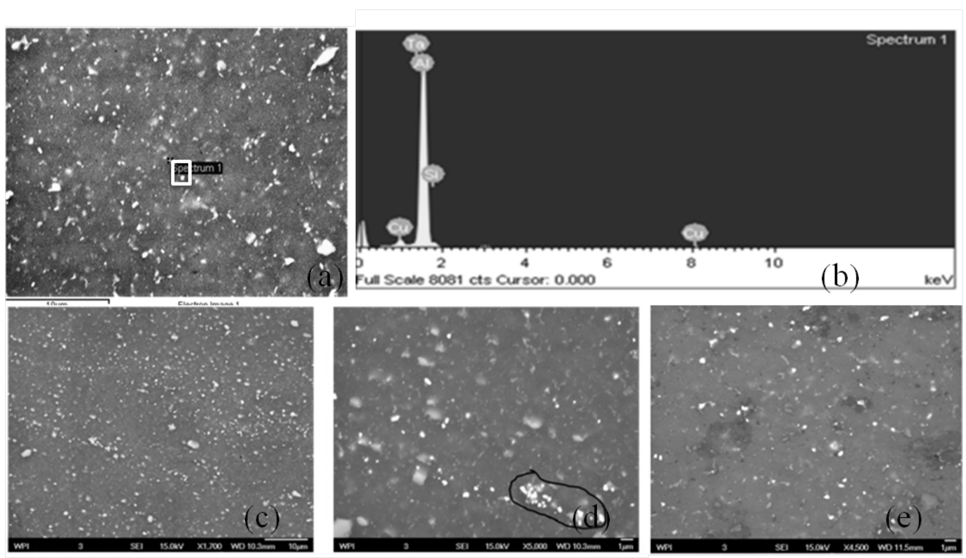

Figure 9: SEM/EDS analysis of the Ta-Al composite layer: (a) micrograph showing Ta inside the composite layer; (b) EDS analysis; (c) Ta distribution in the composite layer after 1-pass FSP; (d) agglomerations inside the composite layer after 1-pass FSP; (e) homogenous Ta distribution in the composite layer after 2-pass FSP.

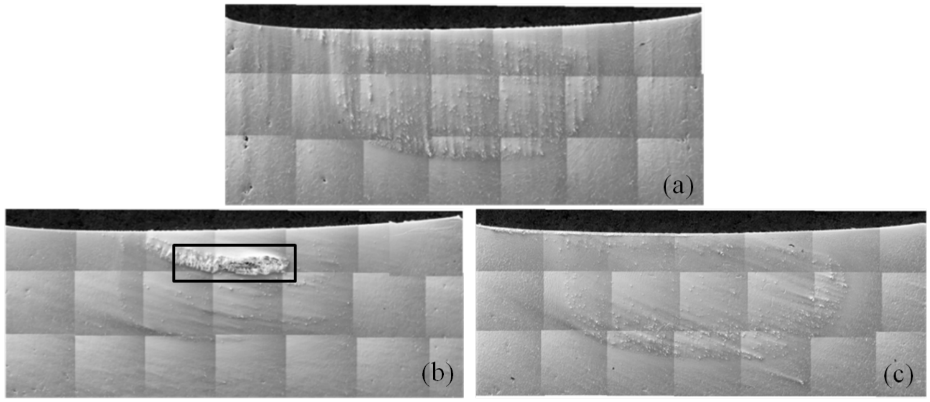

Figure 10: Macrographs of the SiC dispersion in the FSP region – effects of multi-pass FSP and the amount of the SiC particles: (a) 2-pass FSP with 100% cavity filling; (b) 1-pass FSP with 100% cavity filling; (c) 2-pass FSP with 50% cavity filling.

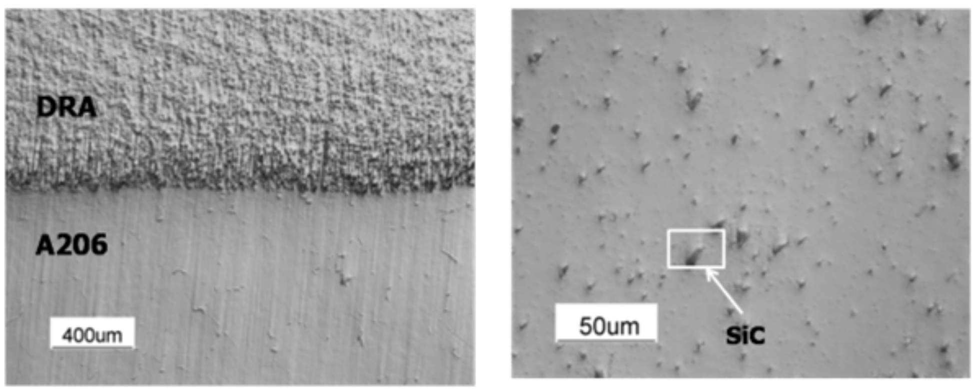

Figure 11: Optical micrographs of DRA/Al composite layer: (a) perfect bonding between surface composite and Al alloy substrate; (b) uniform distribution of DRA in Al alloy matrix.

Acknowledgments

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