FRICTION STIR WELDING OF THIN-SHEET, AGE-HARDENABLE ALUMINUM ALLOYS: A STUDY OF PROCESS/STRUCTURE/PROPERTY RELATIONSHIPS

By

Alpesh Khushalchand Shukla

An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Materials Engineering

The original of the complete thesis is on file
in the Rensselaer Polytechnic Institute Library

Examining Committee:

Prof. William A. Baeslack III, Thesis Adviser
Prof. Robert W. Messler, Jr., Thesis Adviser
Prof. David J. Duquette, Member
Prof. Aleksandar G. Ostrogorsky, Member

Rensselaer Polytechnic Institute
Troy, New York

January 2007
(For Graduation May 2007)

ABSTRACT

Friction Stir Welding (FSW) is a relatively new joining process that, as a solid-state process, offers several advantages over conventional fusion welding. Although FSW has been used extensively for the joining of age-hardenable aluminum alloys, the detailed effects of process parameters on the microstructures and mechanical properties of these welds have not been studied, especially for thin-sheet alloys. The present study investigated the FSW of thin-sheet, age-hardenable aluminum alloys, including: the development and optimization of welding process parameters that produce high-integrity, defect-free welds; the systematic evaluation of the effect of the base metal microstructure, FSW process parameters, and corresponding weld zone thermal conditions on microstructure evolution across the weld zone; the analysis of FSW mechanical properties and fracture behavior; and the development of relationships between the process parameters, microstructure, properties, and fracture that allow the optimization of weld performance. Two alloy systems, viz., Al-Cu-Mg (2024) and Al-Cu-Li (2195) in naturally-aged and artificially-aged conditions, respectively, were studied.

Process optimization in 1 mm thick 2024-T3 sheet resulted in superior properties versus those of FS welds in thick sheet and plate, and nearly 100% joint efficiency. Microstructures, hardness and tensile properties of FS welds in 2024-T3 exhibited a strong dependency on process parameters. The heat of welding promoted various weld zone microstructures that were produced via the dissolution of base metal GPB zones, the nucleation of GBP and GPB II, and the nucleation and coarsening of S phase. SZ hardness for 2024-T3 welds exhibited a strong, but unusual dependency on the FSW process parameters, which was related to different mechanisms related to GPB zone formation.

The microstructures of FS welds in 1 mm thick 2195-T8 were generally insensitive to the FSW process parameters. For all weld heat inputs, FSW resulted in almost complete dissolution of the base metal strengthening phases T_1 and θ' in the SZ and their partial dissolution in the HAZ, resulting in FSW hardness and

tensile strength below that of the base metal and that were comparable to FSW weld properties obtained in thicker materials.