High-Strength Electroformed Nanostructured Aluminum for Lightweight Automotive Applications

Shiyun Ruan
Xtalic Corporation

2015 DOE Vehicle Technologies Program
Annual Merit Review
June 10, 2015
Project ID: LM089

Overview

Timeline

- Project start: Oct 2014
- Project end: Sep 2018
- Percent complete: 15%

Budget

- Total project funding
  - DOE share: \$2.50 M
  - Xtalic cost share: \$2.56 M
- Funding received in FY 14
  - DOE share: \$0
  - Xtalic cost share: \$0
- Funding for FY15
  - DOE share: \$643 K
  - Xtalic share: \$660 K

Barriers

- Performance: Achieve the performance objectives for demanding applications (UTS> 600 MPa, ductility>8%).
- Manufacturability: Manufacture advanced materials in production quantities and with the required precision and reproducibility.
- Cost: High cost of finished materials is the greatest single barrier to the market viability of advanced lightweight materials.

Project Partners

- Xtalic Corporation (Lead)
- Fiat Chrysler Automobiles US
- Tri-Arrows Aluminum

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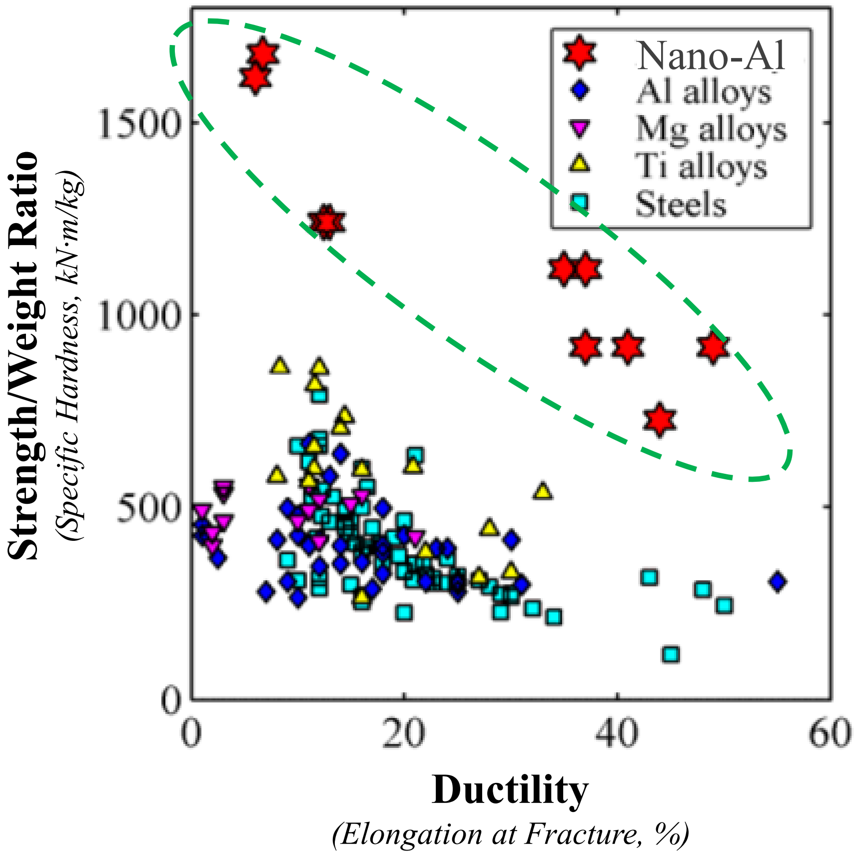
Relevance and Project Objectives

Commercial Alloys vs. Nano-Al



- The <u>weight-normalized</u> strengths of most metals fall within overlapping bands
- New nanostructured Al alloys (nano-Al) developed at MIT are substantially differentiated
  - Potential to replace steel and reduce weight by 50-65%
- Xtalic is the exclusive licensee of the MIT technology

Nano-Al provides the performance of premium steels at the weight of aluminum

**Ruan, S (2010). Hard and tough electrodeposited aluminum-manganese alloys with tailored nanostructures. (Doctoral dissertation, Massachusetts Institute of Technology, Dept. of Materials Science and Engineering)*

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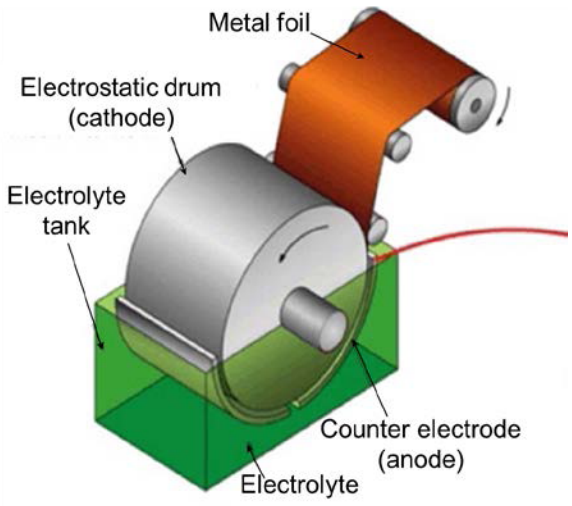
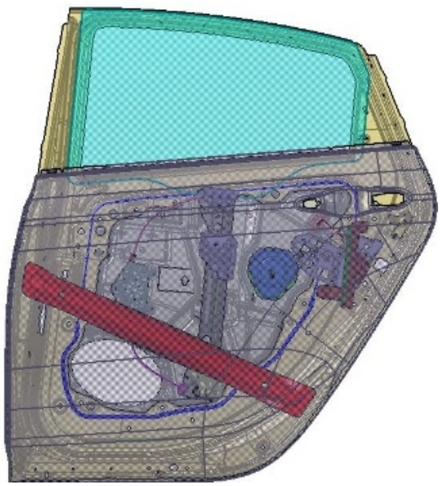
Relevance and Project Objectives

- **Overall objectives of DOE program:**
  - Develop a commercial process to manufacture high-strength nano-Al sheet
  - Demonstrate use of nano-Al in a prototype automotive component



Schematic of a continuous system used to electroform metal foils



Example of nano-Al demo part (Rear door side impact beam)

- **Objectives** (Budget period 1)**:**
  - Develop nano-Al sheet electroforming system
  - Optimize process output and consistency

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Approach/ Strategy

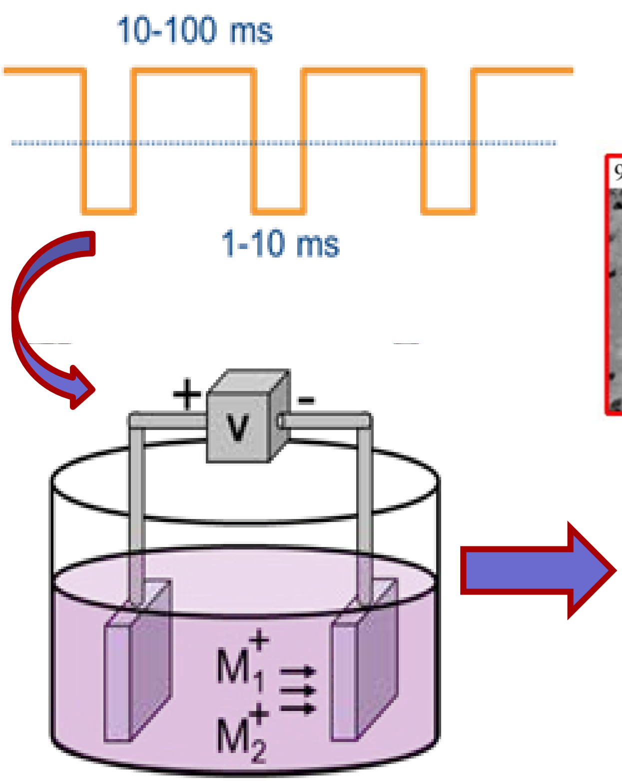
Tasks	Budget Period			
	Yr 1	Yr 2	Yr 3	Yr 4
Optimize process output and consistency				
Develop nano-Al sheet electroforming system				
Go/no-go: Engineering feasibility of design				
Build and validate pilot line				
Go/no-go: Fabricate five nano-Al sheets (6”x6”) from pilot line				
Fabricate alloys, optimize properties, downselect				
Fabricate preferred alloy(s), test against full specs				
Go/no-go: Economic viability of nano-Al sheet production				
Fabricate, test prototype entry point component(s)				
Economic modeling				
Management and reporting				

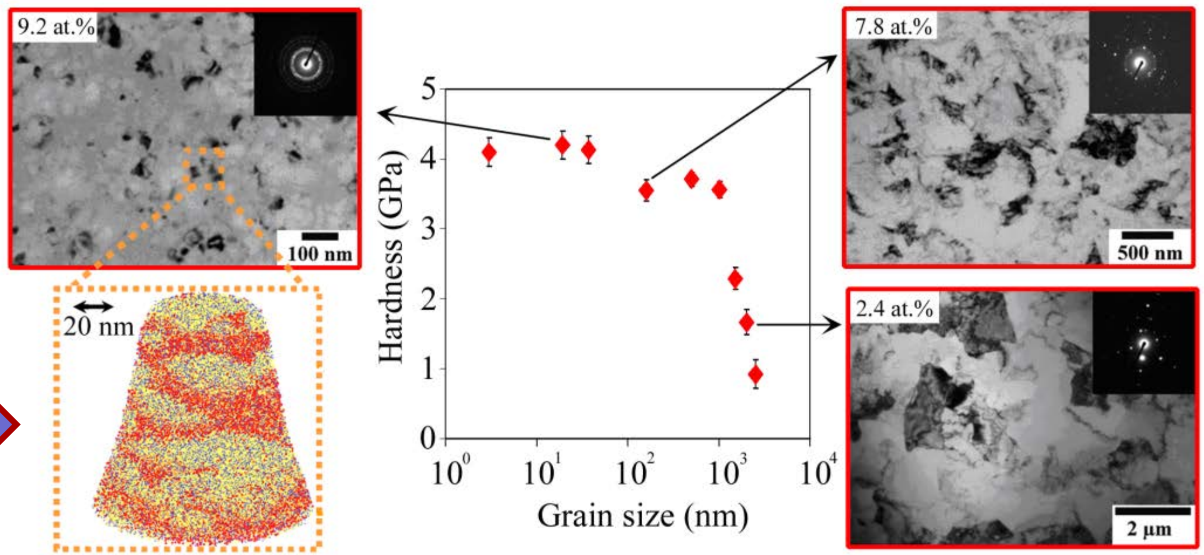
Milestones Budget Period 1

Tasks	FY 2015			
	Q1	Q2	Q3	Q4
Design nano-Al sheet electroforming system				
• Milestone 1: Design rotating mandrel apparatus				
• Milestone 2: Design mechanisms to detach sheet from mandrel				
• Specify dimensions of tank and equipment				
• Design termination unit for rinsing and drying				
Optimize process output and consistency				
• Optimize bath and maximize plating rate				
• Milestone 3: Develop methods to analyze bath				
• Milestone 4: Fabricate samples, validate materials properties				
• Develop methods to maintain bath within specs				
Economic modeling				
• Preliminary cost model				
Go/no-go decision: Engineering feasibility of design				

Technical Accomplishments and Progress

- Xtalic fabricates nanostructured alloys through an electrolytic process
- Intelligent alloying leads to <u>stable</u> nanostructures
- Pulse plating enables ***dynamic nanostructure control***^{TM} with tailored properties





Pulse-plated Al-Mn system exhibits tailorable grain size and properties

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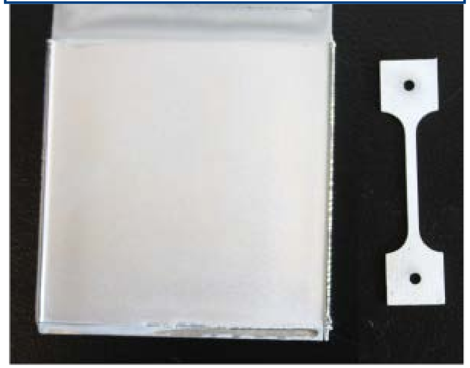
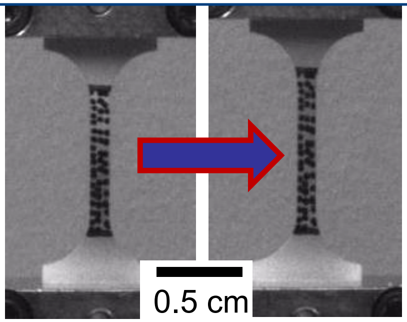
Technical Accomplishments and Progress

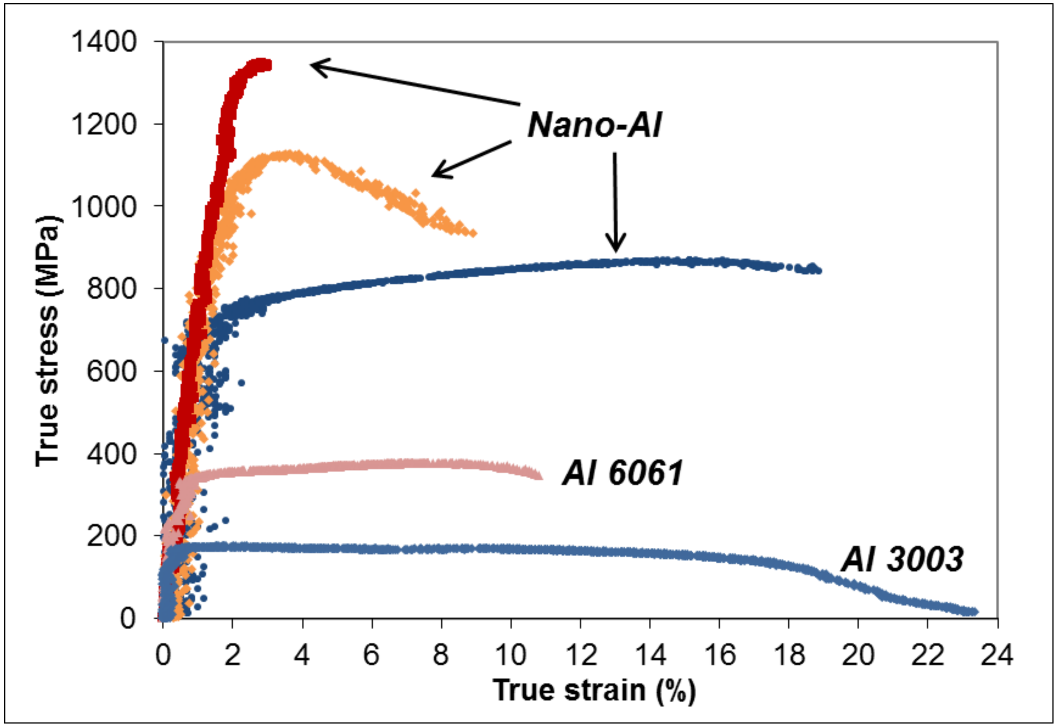
- Nano-Al has been shown to exhibit high strength with good ductility

Machined dogbone



Standard tensile testing

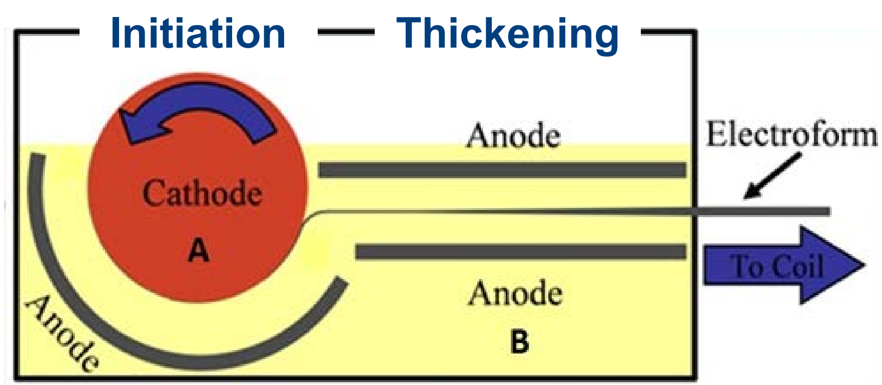




Technical Accomplishments and Progress

(1) Develop nano-Al sheet electroforming system

- Our proposed sheet electroforming system will comprise two modules
  - Rotating mandrel for film initiation
    - Widely used in the electroplating industry to produce metal foils
  - Parallel anodes for sheet thickening
    - Required to achieve >1mm thickness for automotive applications



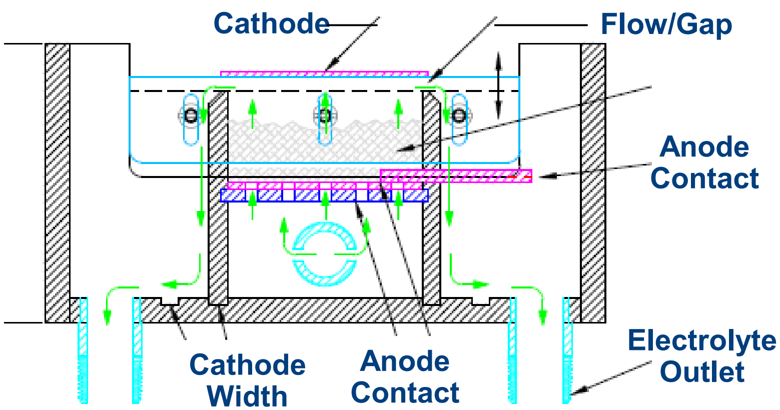
Schematic of a continuous electroforming system

- Xtalic will design and build both modules separately for independent optimization

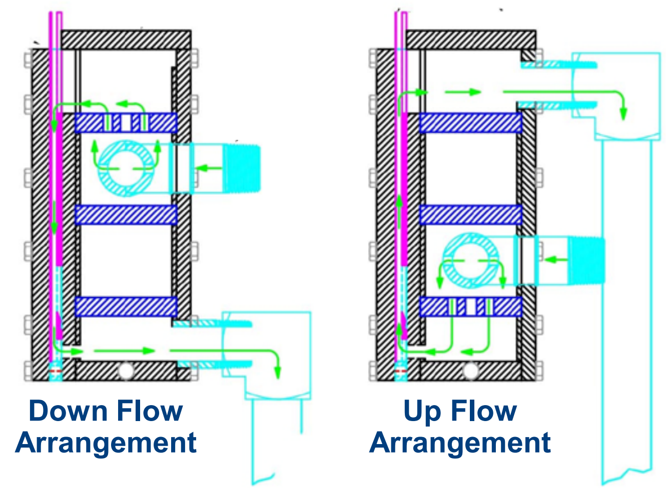
Technical Accomplishments and Progress

(1) Develop nano-Al sheet electroforming system

- Xtalic has designed test cells to evaluate high flow and plating rate requirements
  - Learnings will be used to guide the design of our electroforming system



Schematic of horizontal test cell



Schematic of vertical test cell

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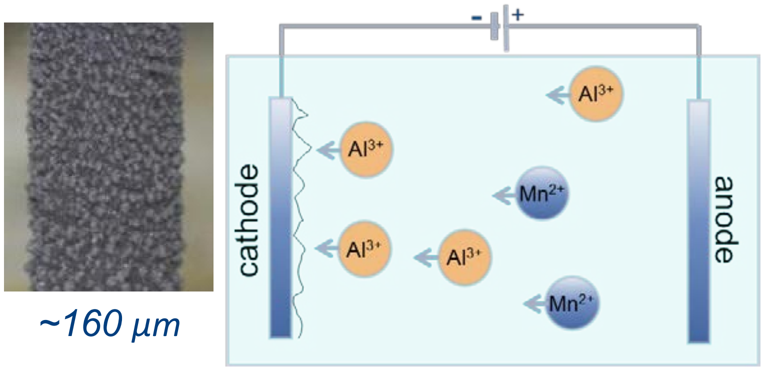
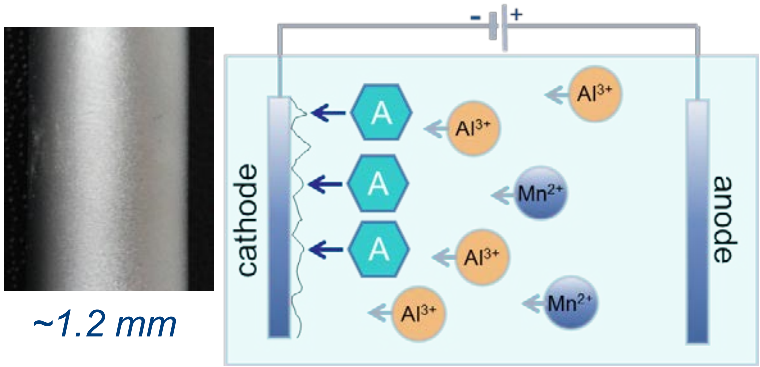
Technical Accomplishments and Progress

(2) Optimize process output and consistency

- Additives are required in most electroplating systems for thick coherent growth



Without additives, surface roughening leads to dendritic growth



Appropriate additives suppress surface roughening and minimize dendritic growth

- Xtalic is identifying additive systems to enable thick coherent plating in high speed continuous plating of sheets
- To evaluate process consistency, Xtalic has performed the following tasks:
  - Developed methods to quantify additive and other organic components
  - Measured bath metal content and alloy composition as bath aged

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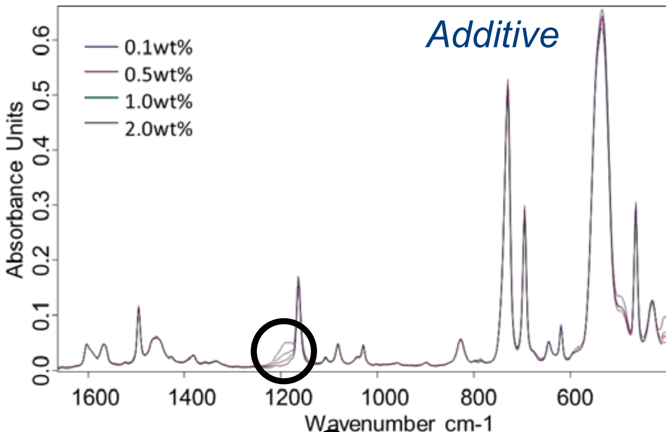
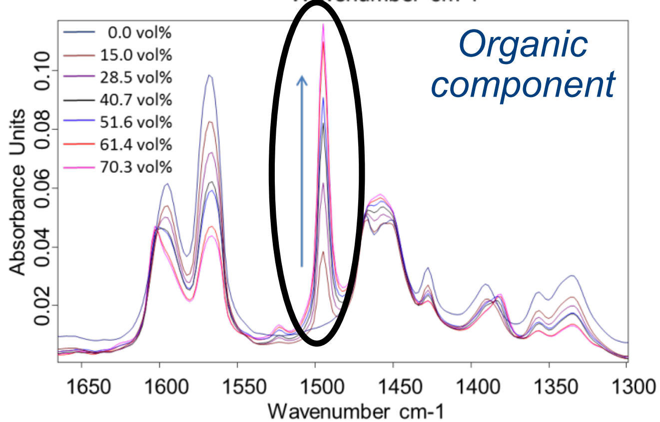
Technical Accomplishments and Progress

(2) Optimize process output and consistency

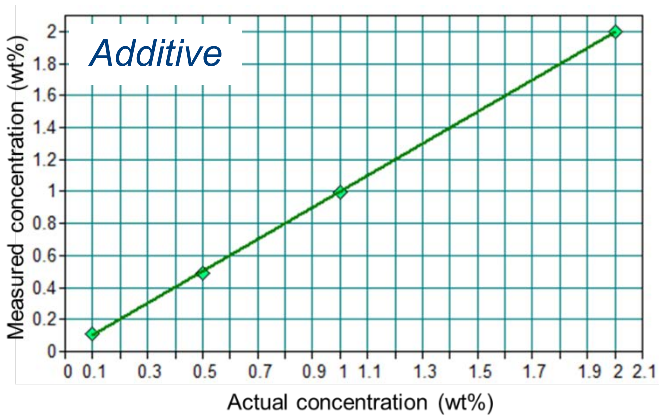
- Developed methods to quantify organic components
  - Demonstrated ability to use IR spectroscopy to quantify additive and organic component with high accuracy

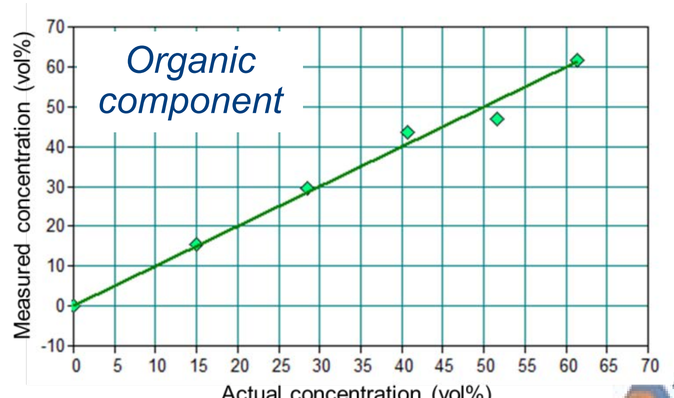
FTIR spectra with known standards





Method validation





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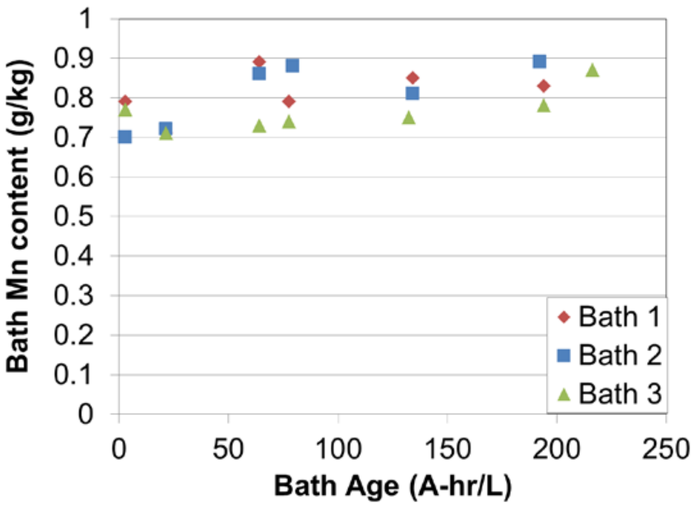
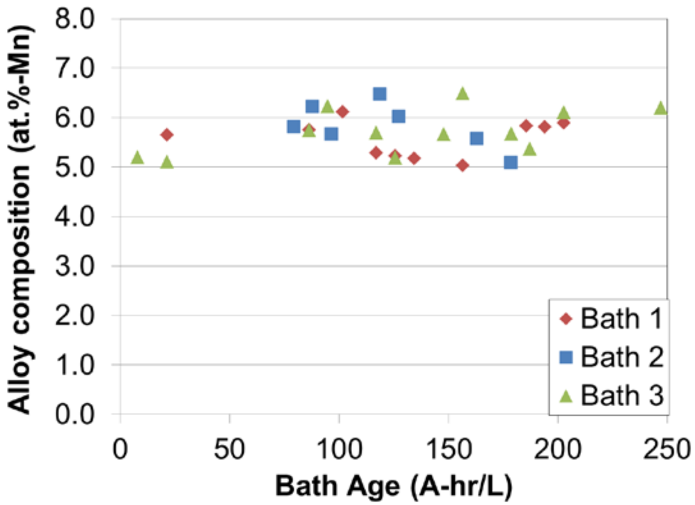
Technical Accomplishments and Progress

(2) Optimize process output and consistency

- Demonstrated good process control during bath aging study (250 A-hr/L)
  - Quantified bath metal content using atomic absorption spectroscopy
  - Replenished bath composition using liquid Mn concentrate
  - Maintained bath and alloy compositions within specifications over 250 A-hr/L of bath age
    - Bath Mn content within ±0.1g/kg
    - Alloy Mn content within ±1.0 at.%





Good process control demonstrated during bath aging study

Response to Previous Year Reviewers' Comments

- This project is a new start.

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Partners/ Collaborators

- Xtalic – Project Prime
  - Build pilot-scale nano-Al sheet manufacturing system
  - Optimize nano-Al process capability
  - Electroform nano-Al sheets
- Fiat Chrysler Automobiles US – Project Subcontractor
  - Evaluate applicability of nano-Al sheets for automotive applications
  - Fabricate, integrate and test nano-Al component in actual vehicle
- Tri-Arrows Aluminum – Project Subcontractor
  - Evaluate continuous electroforming as potential sheet manufacturing process

Challenges and Barriers

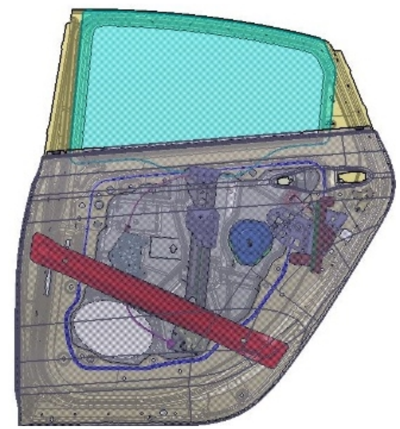
- Validation of manufacturing process on industrial scale
  - Nano-Al bath chemistry and process are unique
  - Need to adapt to existing process for aqueous systems
- Materials need to meet full specifications
  - Demonstrated target strength requirements of >600 MPa
  - Need to meet the broader spec for a given application
- Integration of a new material into the vehicle component manufacturing process
  - New sheet material properties lead to potential concerns for post fabrication, such as spring-back and joining methods
- Achieving target cost of $2/lb of weight saved
  - Economic cost model and detailed cost analysis are being developed to evaluate feasibility

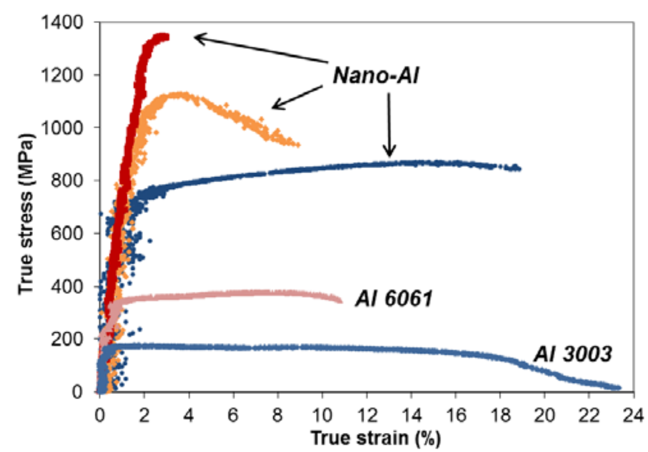
Proposed Future Work

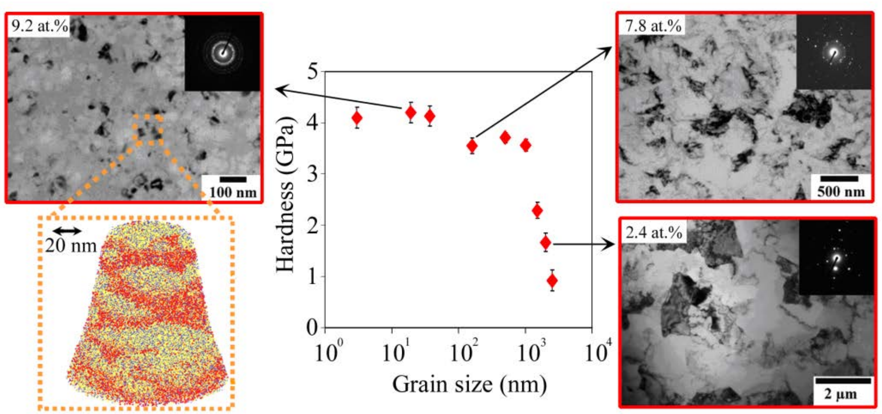
Challenge	Future Work	Budget period			
		1	2	3	4
Validation of manufacturing process	• Design pilot-scale system				
	• Build and test system				
Material properties need to meet full specs	• Fabricate ≥2 target alloys • Optimize properties • Downselect				
Integration of new materials into manufacturing process	• Develop post-fabrication steps • Fabricate and test prototypes • Perform failure analysis • Improve methods				
Target cost of <$2/lb weight savings	• Increase fabrication rate • Increase bath lifetime				
	• Develop cost model				

Summary

- Xtalic's nano-Al alloys exhibit unparalleled strengths
  - Potential to reduce weight by 50-65%
- Nano-Al sheet electroforming system will be designed and built
- Nano-Al vehicle components will be built and tested
- Significant progress has been made
  - Test cells designed and under construction
  - Validating process measurement and control







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