High-Strength Electroformed Nanostructured Aluminum for Lightweight Automotive Applications

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Xtalic Corporation
2016 DOE Vehicle Technologies Program
Annual Merit Review

Project ID: LM089

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Overview

Timeline

- Project start: Oct 2014
- Project end: Sep 2018
- Percent complete: 40%

Budget

- Total project funding
  - DOE share: $2.50 M
  - Xtalic cost share: $2.56 M
- Funding for FY15
  - DOE share: $643 K
  - Xtalic share: $660 K
- Funding for FY16
  - DOE share: $679K
  - Xtalic share: $697K

Barriers

- Performance: Achieve substantially better properties. (Minimum specifications: UTS> 600 MPa, ductility>8%).
- Manufacturability: Manufacture advanced materials in production quantities and with the required precision and reproducibility.
- Cost: High potential cost 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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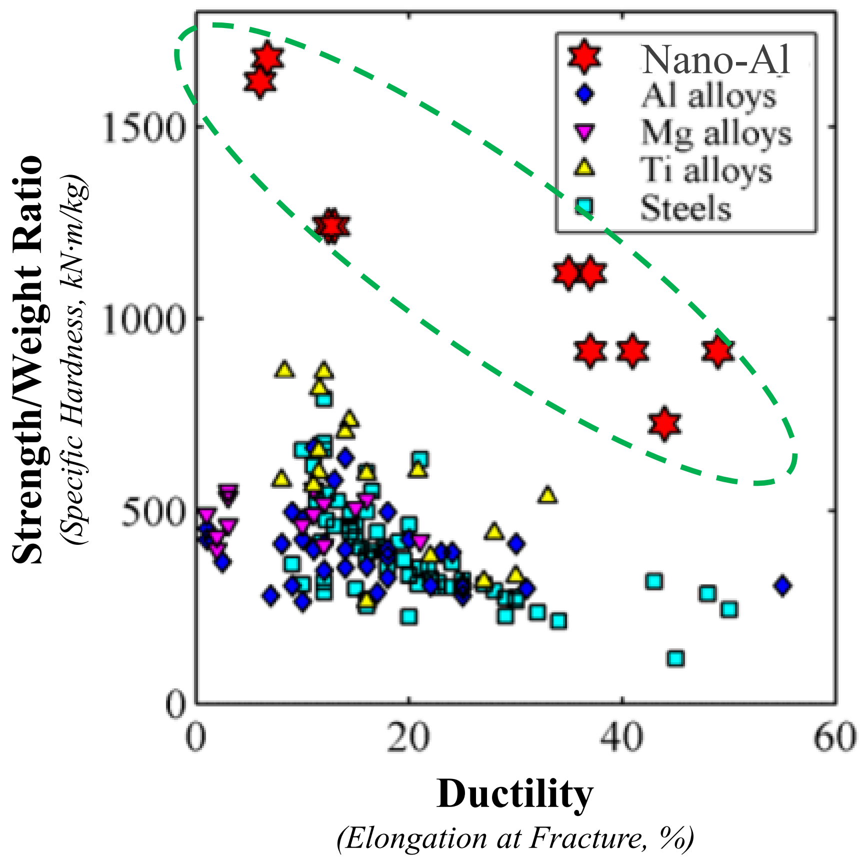
Relevance and Project Objectives

Commercial Alloys vs. Nano-Al



- The weight-normalized strengths of most metals fall within overlapping bands
- New nanostructured Al alloys (nano-Al) are disruptively strong
- Objectives:
  - To meet DOE targets, optimize alloys for:
    - Strength > 600 MPa
    - Ductility > 8%
    - Cost < $2/lb of weight saved
  - Develop chemistry and electroforming process to make automotive sheet
  - Demonstrate performance in a real part

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

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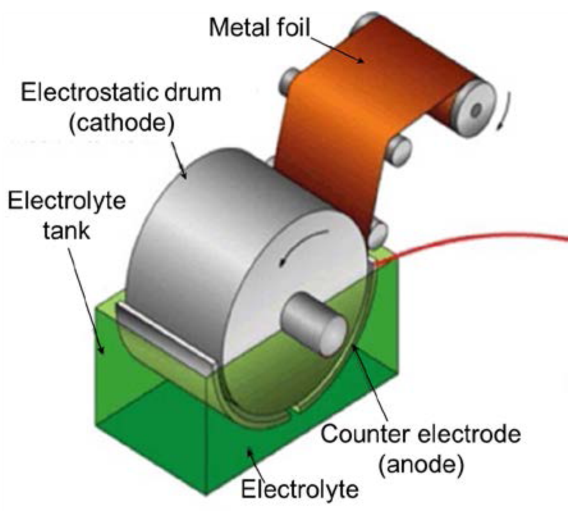
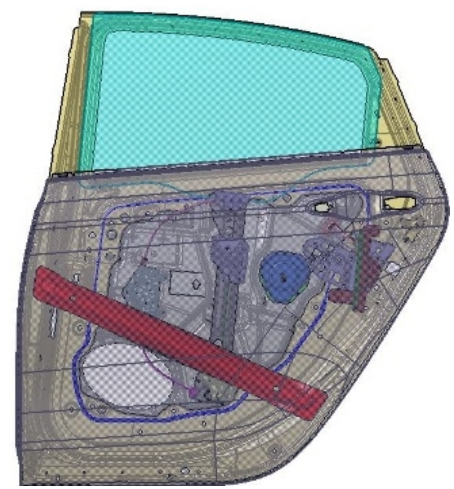
Relevance and Project Objectives

- **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 2)**:**
  - Develop nano-Al sheet electroforming capacity
  - Optimize process output and consistency

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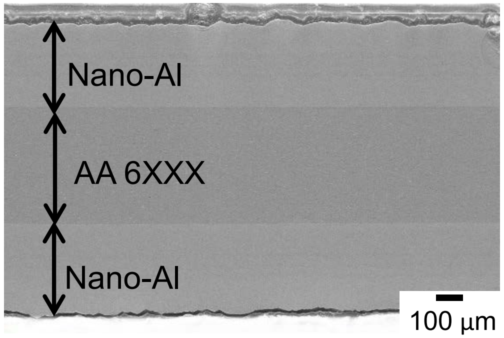
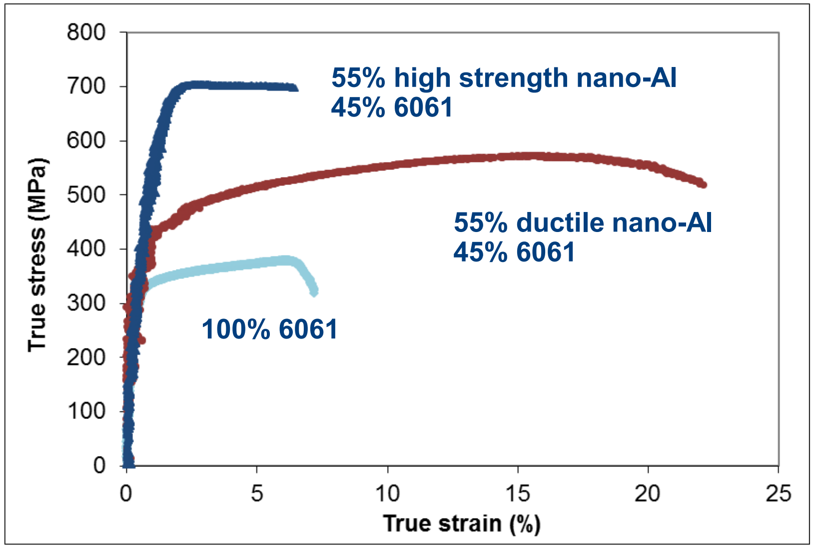
Relevance and Project Objectives

- Many strength limiting parts used in bending
- Xtalic engineers the sheet with high strength metals on the outside layers
- Objectives:
  - Use sandwich structure to reduce cost and simplify manufacturing
  - Sandwich structure will exceed DOE structural targets
- Xtalic has developed technology to plate nano-Al directly onto Al without zincate



Two-sided sandwich panel



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Milestones Budget Period 2

Tasks	Program Quarter			
	1 Oct-Dec	2 Jan-Mar	3 Apr-Jun	4 Jul-Sep
Build and validate pilot line				
• Order all components (M5)				
• Begin installing electroforming system (M6)				
• **GNG: Deliver 1 sample of 6” x 6” sandwich sheet**				
• Fabricate 5 sandwich sheets (6” x 6”) from new system				
• Evaluate tensile properties and adhesion of sandwich sheets				

Approach/ Strategy

Tasks	Year			
	1	2	3	4
Optimize process output and consistency				
Develop continuous electroforming system				
Go/no-go: Engineering feasibility of design				
Build and validate pilot line				
GNG: Verify system functionality, deliver 1 sample of 6” x 6” sheet				
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				

Technical Accomplishments and Progress

Plating Development

- Thick deposits (>500um) were made on idealized rods
- Alloys that were plated immediately after the additive produced a smoother surface
- Some additives did not prevent surface roughening and dendrites

Bath	2 A-hr/L	29 A-hr/L	55 A-hr/L	81 A-hr/L
B	 1 cm		Chemical addition 	
1			Chemical addition 	

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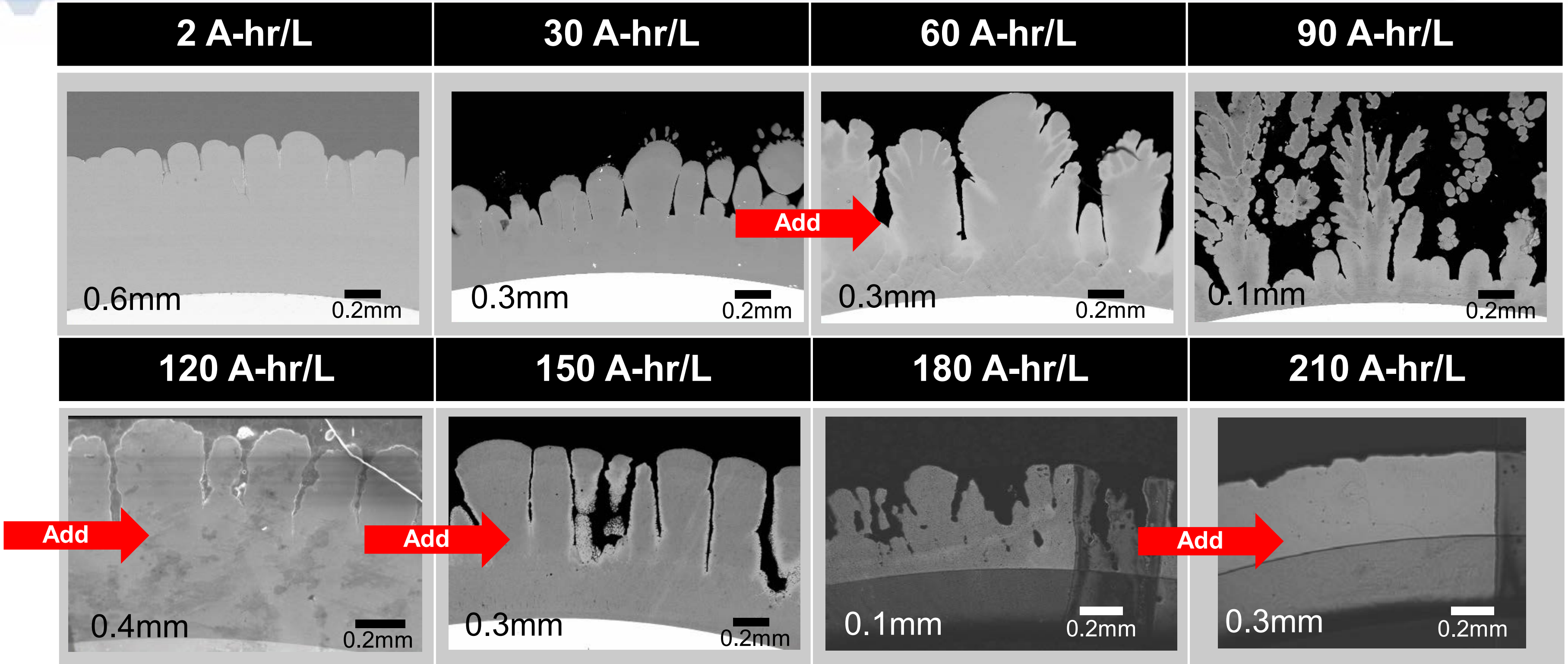
Technical Accomplishments and Progress

Plating Development



- 1st generation additives not effective to prevent dendrite growth
- Bath efficacy decreased without additional additive replenishment
- Coating thickness severely limited

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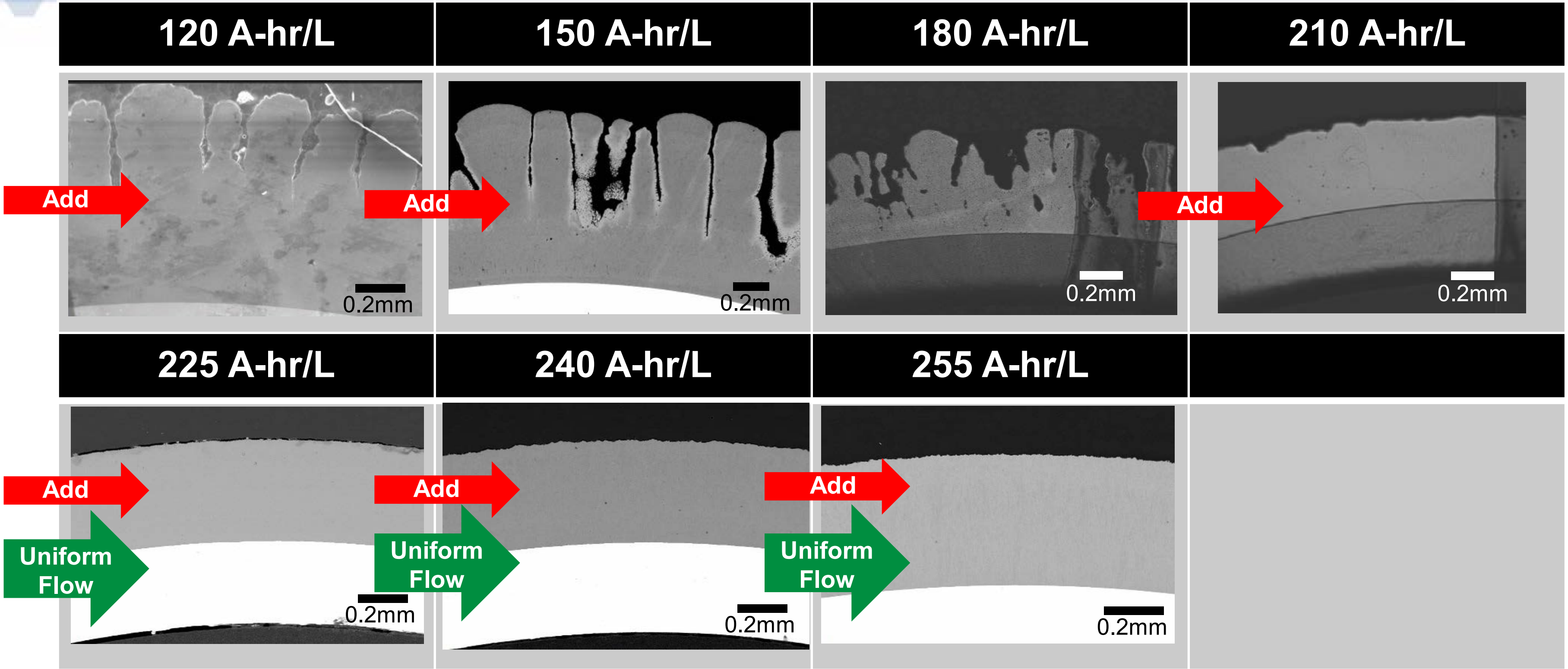
Technical Accomplishments and Progress

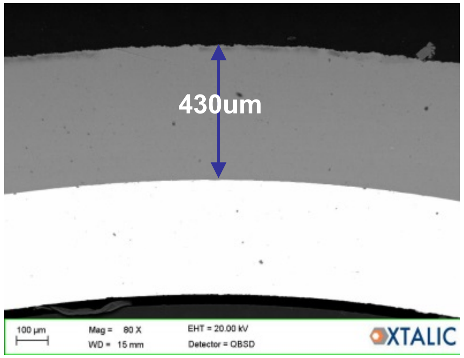
Plating Development



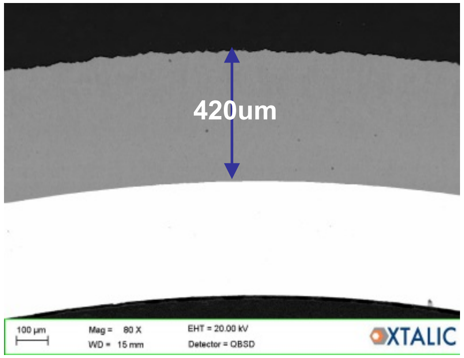
- Combination of optimized additive concentration with improved frequency, and improving flow uniformity increased thickness capability to ~0.4mm
- Bath performs well as it ages

Technical Accomplishments and Progress

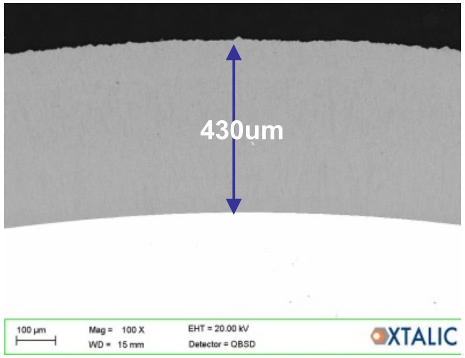
Plating Development



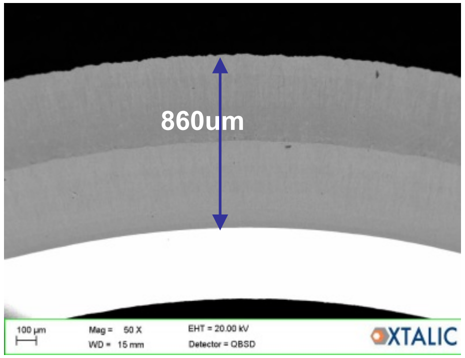
8.3 At.%-Mn
415-430 um (dense)



7.4 At.%-Mn
400-420 um (dense)



7.7 At.%-Mn
425-430 um (dense)



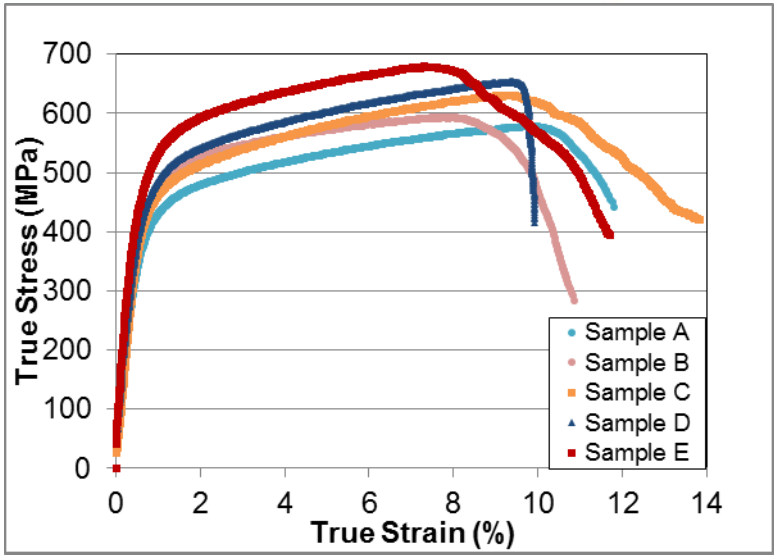
7.2 At.%-Mn
860 um (dense)

- Newly developed additive produces smooth and thick deposit
- Longer plating runs produce thicker deposits
- These samples are all rods – need to prove technology works on sheets
- Nanostructure is present throughout the thickness
    - This will lead to increases in strength when tested on sheets

Technical Accomplishments and Progress

Alloy Properties

- Sandwich structure properties:
  - Typical test samples are:
    - 130um nano-Al
    - 55um AA 3104
  - Can get strengths > 600 MPa with good elongation
  - Additional strength improvements expected with
    - New additive
    - Greater nano-Al/substrate ratio
    - Stronger substrate
  - Ductility can further improve with smoother as-plated surfaces

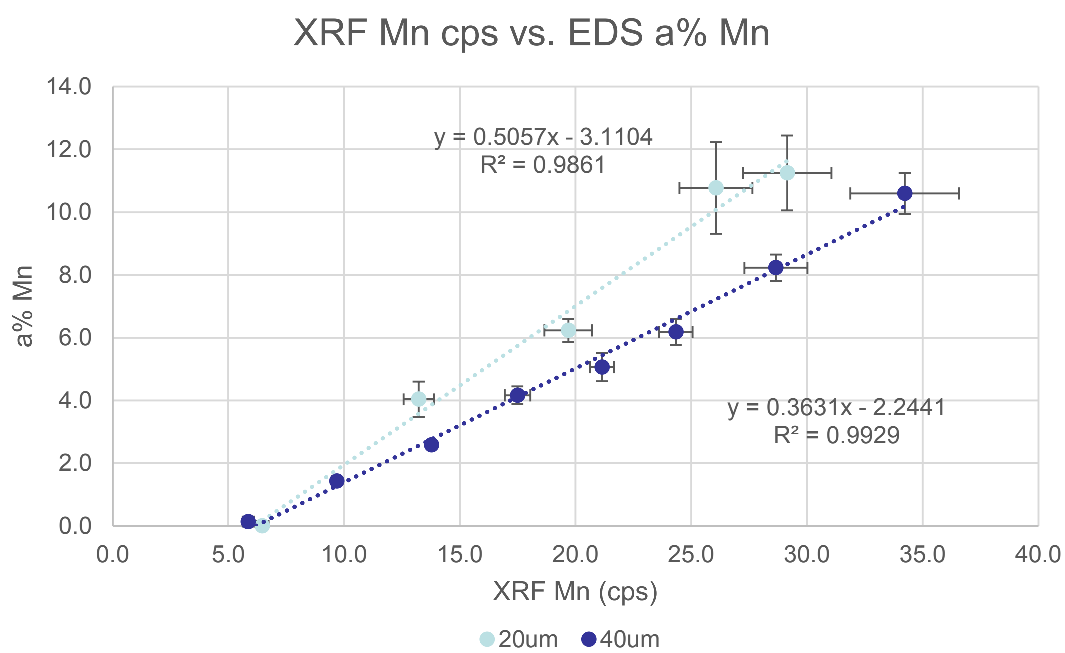


Sample	UTS (MPa)	Ductility (%)
A	580	9.8
B	590	7.6
C	**630**	**9.4**
D	**650**	**9.5**
E	680	7.0

Technical Accomplishments and Progress

Process Control Development

- Manganese is the primary alloying element
- Normally quantify Mn by SEM/EDS
  - Slow and harder for production
- XRF methods were developed to measure Mn non-destructively
  - Fast and accurate for production control
  - Good for up to 100um thick



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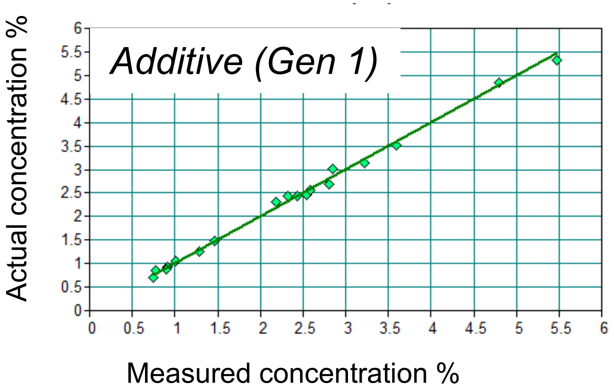
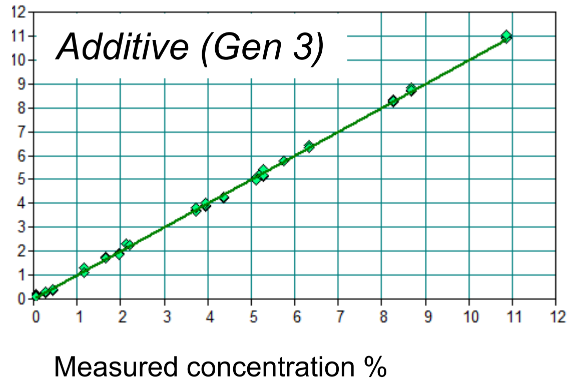
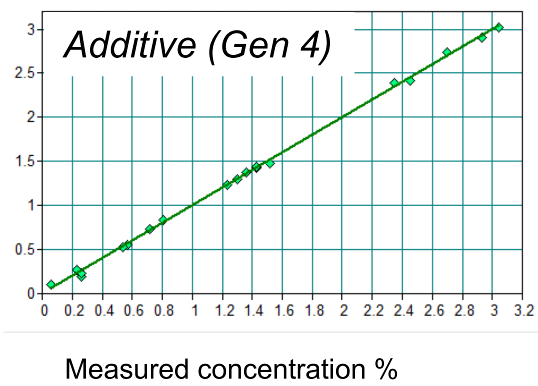
Technical Accomplishments and Progress

Process Control Development

- We validated our ability to quantify various components of our bath by FTIR
  - Co-solvent concentration
  - Mn concentration
  - Ionic liquid concentration
  - Additives
- We obtained excellent correspondence between actual and measured concentrations







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Technical Accomplishments and Progress

Process Development

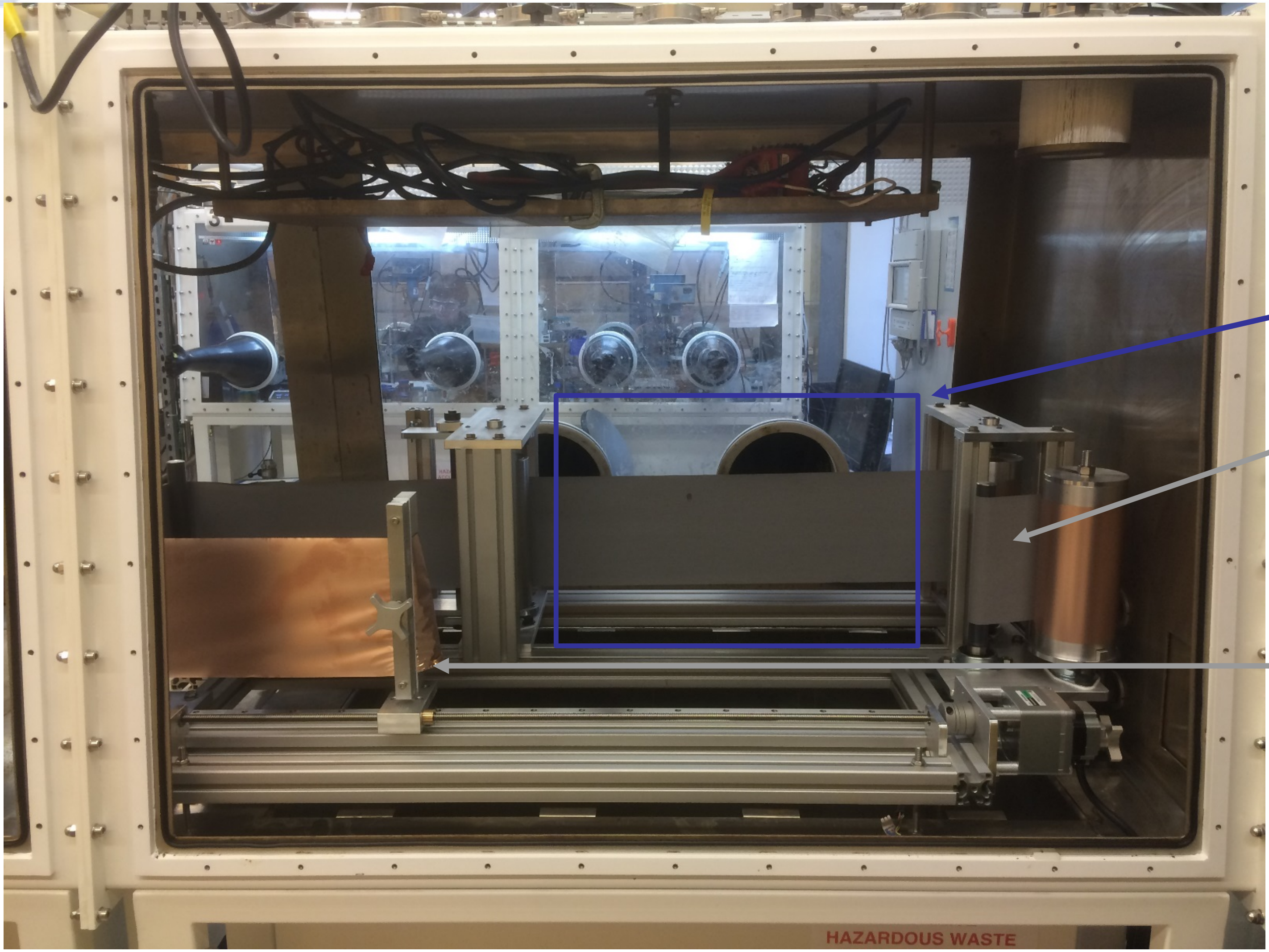
- Xtalic has designed and built electroforming flow cells
  - Lab devices used to measure and optimize configuration for plating rate

- Xtalic has designed and begun to build a continuous electroforming system

- Copper web used to check tension, draw speed and tracking of sheet through the station
- Input stock will be light gage Al alloy sheet
- 7 inch web used to produce 6 inch wide samples

Technical Accomplishments and Progress

Process Development



Plating cell location

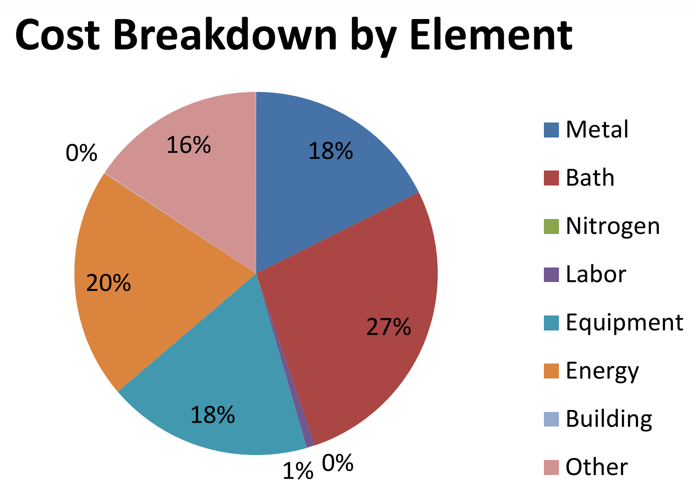
Cu web for testing

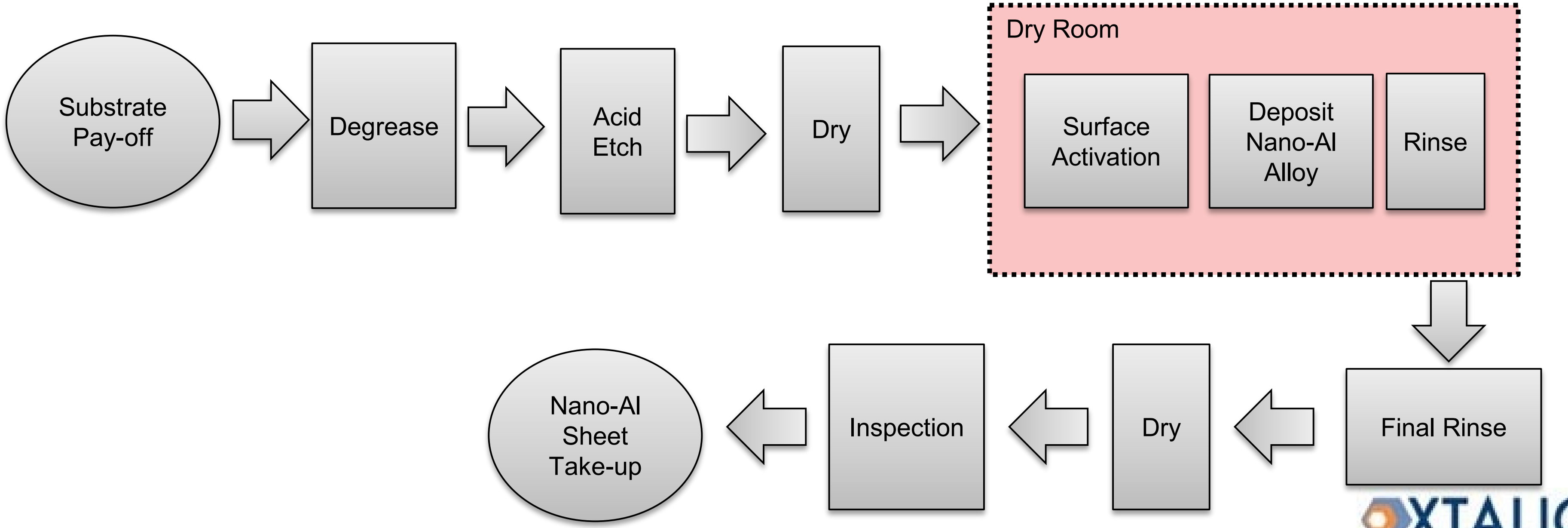
Drive mechanism

Technical Accomplishments and Progress

Cost Model

- IBIS Assoc. aided with cost model development
- Focus on sheet thickening step
- Continuous, high-volume production





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Response to Previous Year Reviewers' Comments

- Approach
  - Compare to AA 7075
  - Sandwich approach now planned for final product, reducing cost and technical challenges
  - Electroforming is a fundamental shift in manufacturing process
- Technical Accomplishments:
  - Alloy development, chemistry and plating process on track or in place
  - Detailed cost model has been developed
- Collaboration:
  - FCA, Tri-Arrows, IBIS, Oak-Mitsui
- Future Research
  - Scale-up: Significant area of concern, especially with respect to manufacturing cost. Primary focus of BP3 development.

Partners/ Collaborators

- Xtalic – Project Prime
  - Develop nanostructured alloys with unique strength/weight
  - Build and 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

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FCA
FIAT CHRYSLER AUTOMOBILES

TRI-ARROWS ALUMINUM INC.

Challenges and Barriers

- Validation of manufacturing process on industrial scale
  - Nano-Al bath chemistry and process are unique
  - Scale up to larger format and continuous plating
- Materials need to meet full specifications
  - Demonstrated target strength requirements of >600 Mpa, 8% elongation
  - Need to meet the broader spec for a given application
- Achieving target cost of $2/lb of weight saved
  - Layered structure improves cost without sacrificing performance
  - Cost model has been built and will be used to identify best opportunities to reduce manufacturing costs

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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	■	■	■	■

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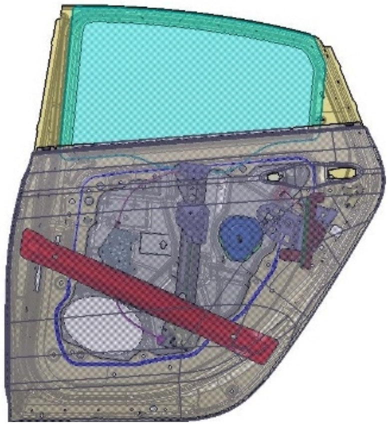
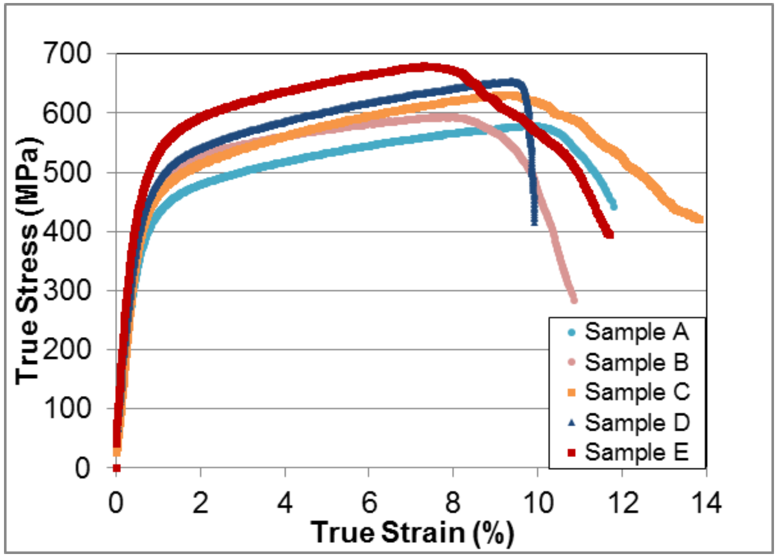
Summary

- Xtalic's nano-Al alloys exhibit unparalleled strengths
  - Potential to reduce weight by 50-65%
- Nano-Al sheet electroforming system is designed and being built
  - Includes process control development
- Nano-Al vehicle components to be built and tested





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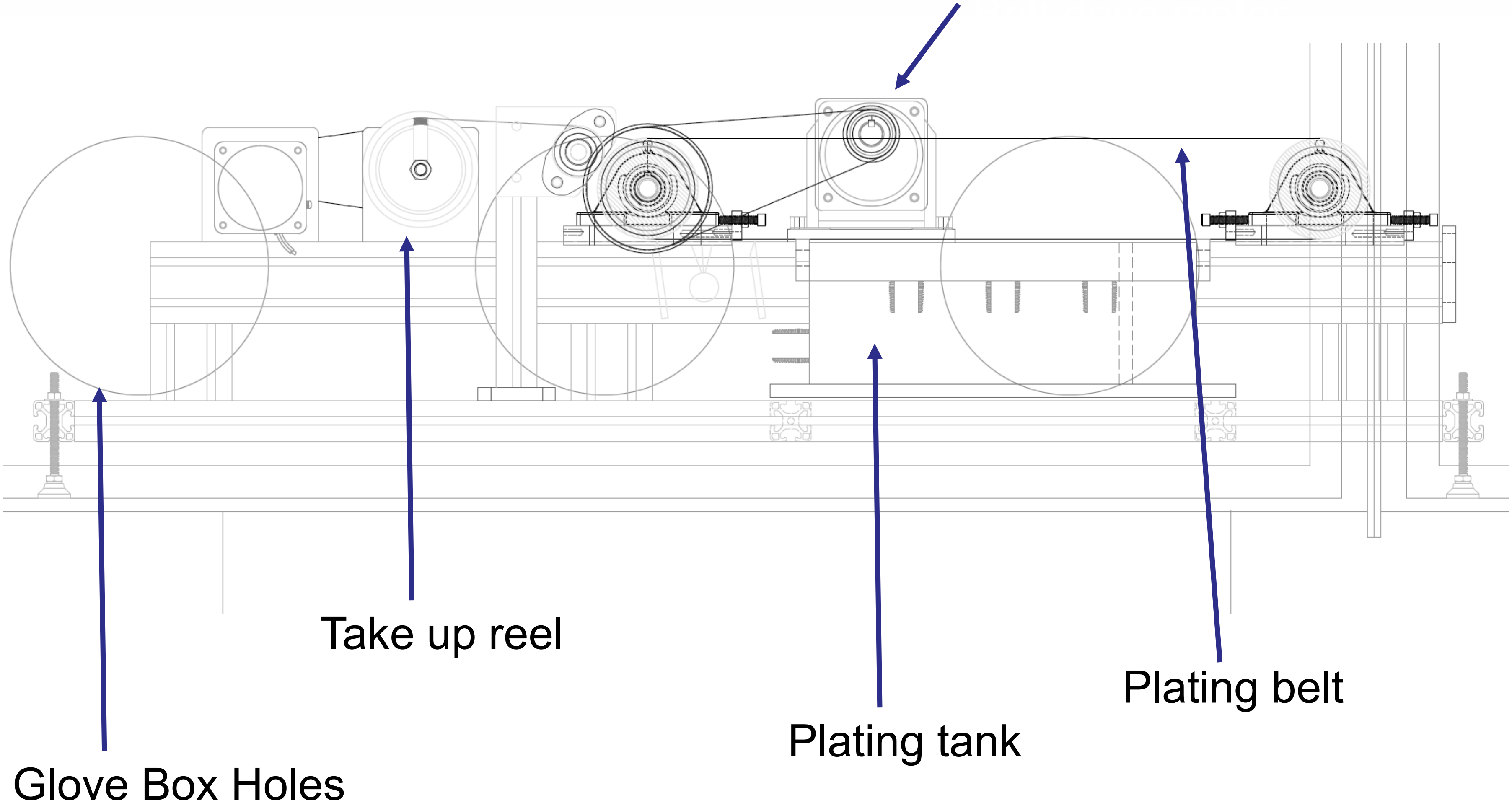
Technical Back-up Slides

Side View – Initiation Stage



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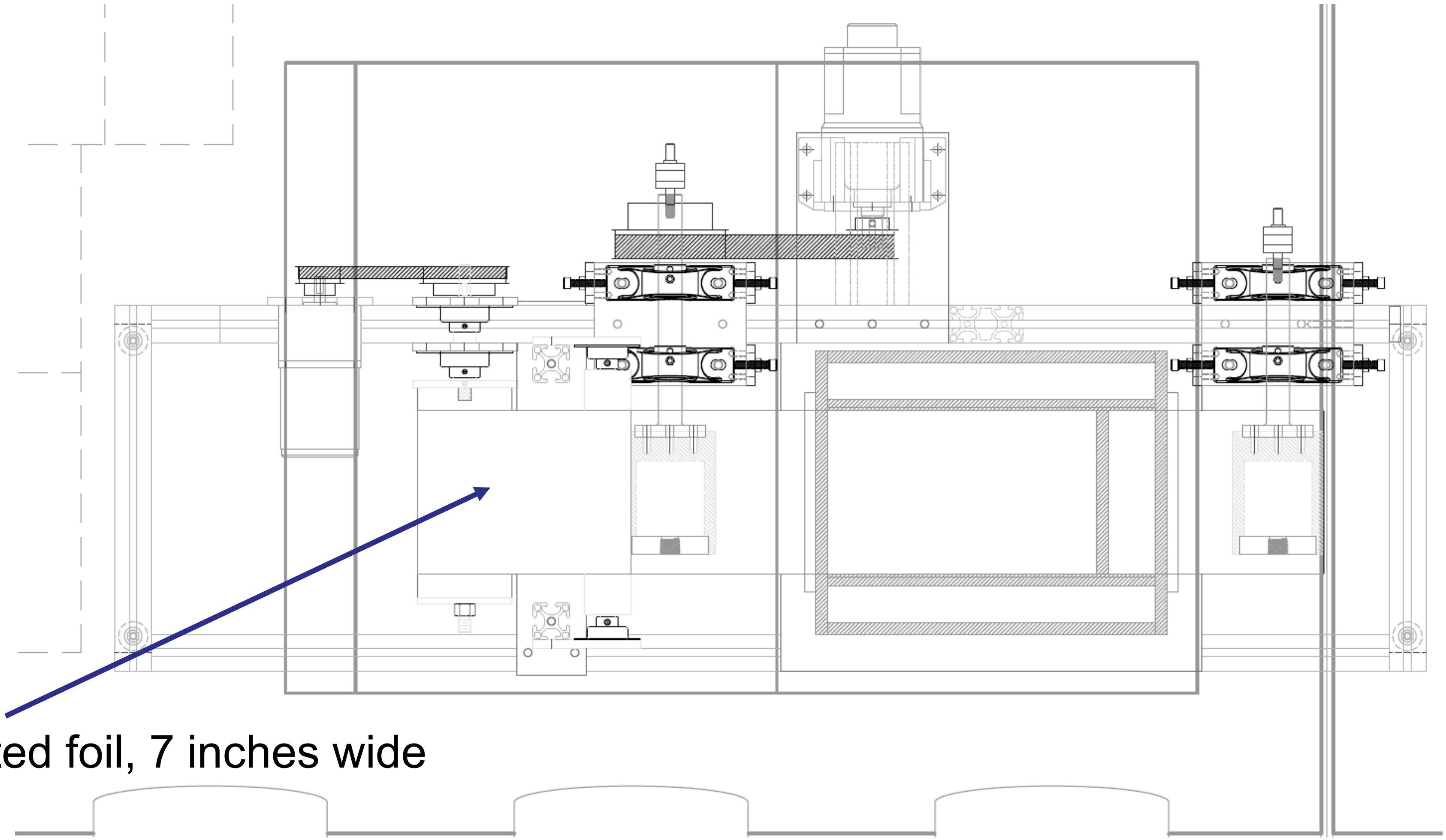
Top View – Initiation Stage



Plated foil, 7 inches wide

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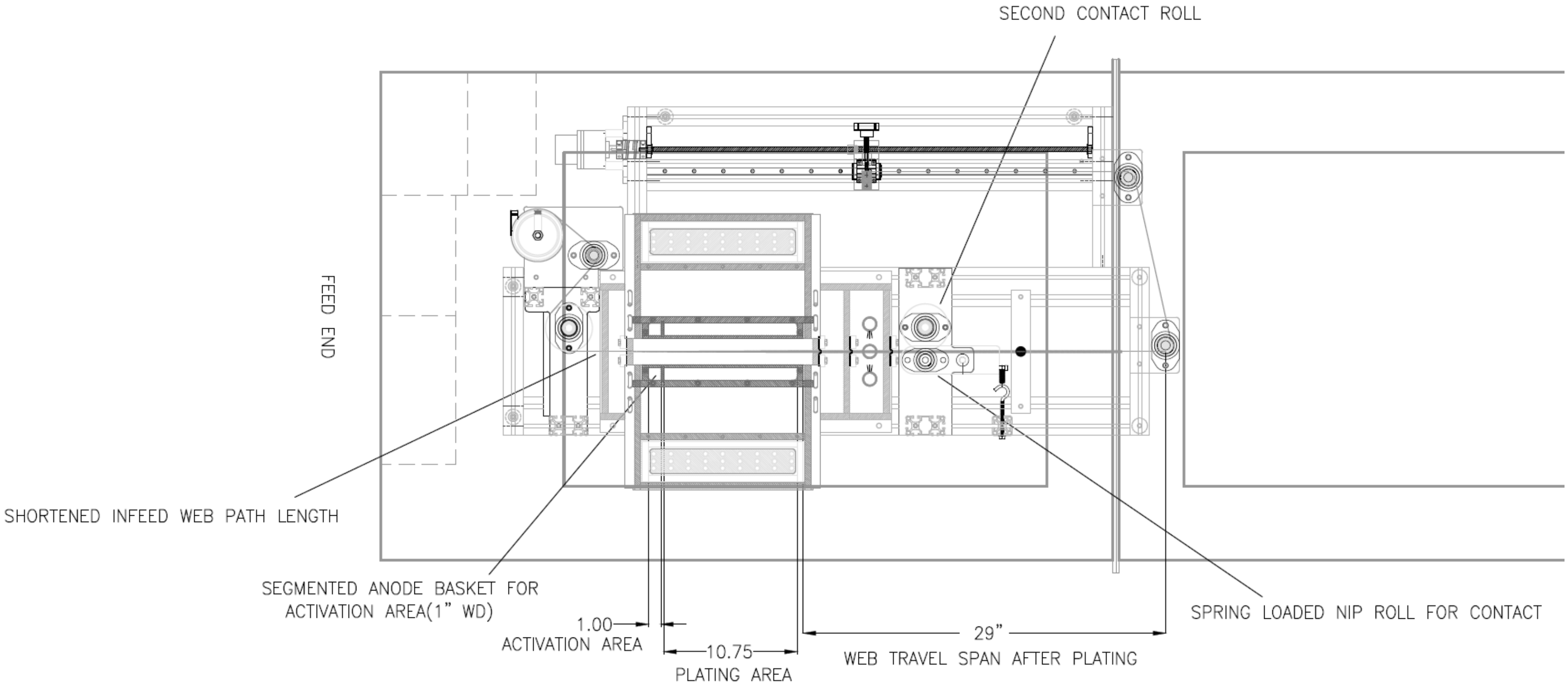
Thickening Station: Top View



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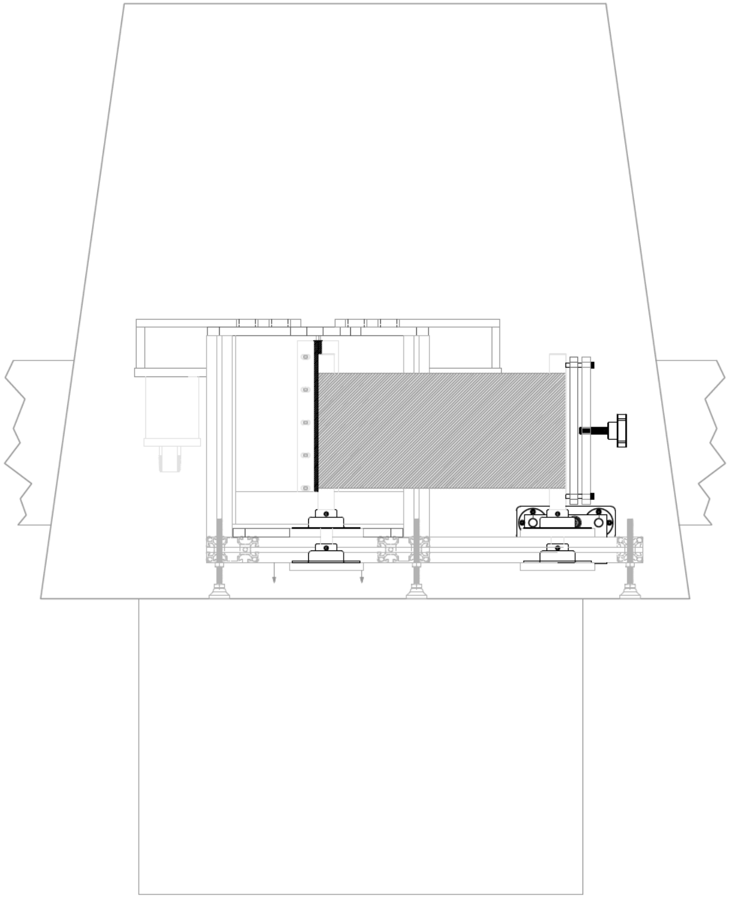
Thickening Station: Side Views



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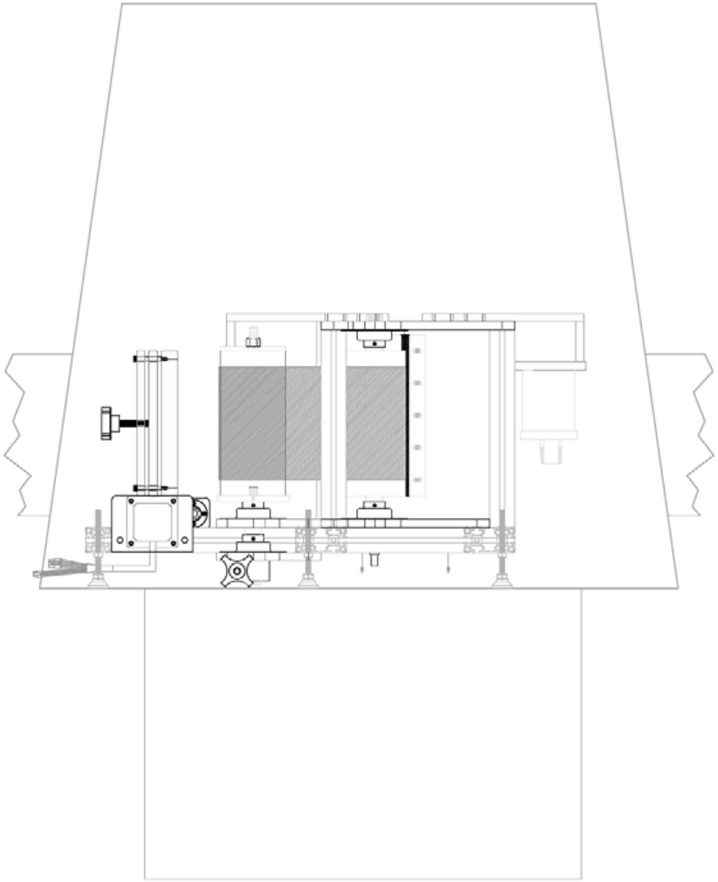

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