Shear Assisted Processing and Extrusion (ShAPE) of Lightweight Alloys for Automotive Components

Project ID: **MAT149**
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PNNL-SA-183899

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Solid Phase PROCESSING

Overview

Timeline

- Start date: Nov. 2018
- End date: Sept. 2022
- % complete: 100% as of Sept. 2022

Barriers

- Aluminum (Al)
  - Improved ductility and fatigue
  - Recycling of scrap directly into product

Budget

- Total project funding
  - $2,000K
- $1,000K - DOE share
  - $1,000K Costs incurred through Sept. 2022
- $1,000K - Industry share
  - ~2,000K Costs incurred through Sept. 2022

Partners

- Magna International, Inc. (Magna)
  - Stronach Center for Innovation
  - Cosma Engineering
  - Magna R&D
- Pacific Northwest National Laboratory (PNNL)

Relevance

Challenge

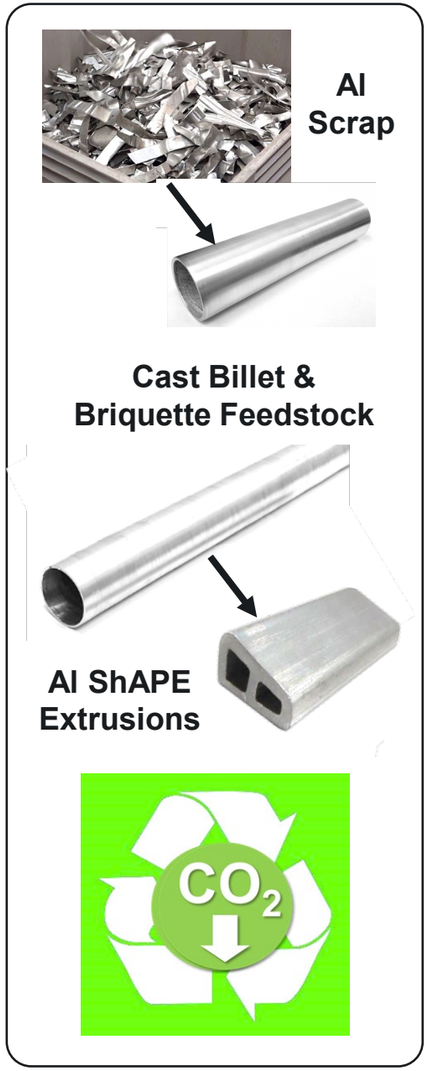
- Reduce carbon footprint and manufacturing cost (Al)
- Increase energy absorption (Mg)

Objectives

- Direct recycling of 100% secondary Al scrap into extrusions meeting industry property requirements
- Manufacture non-circular multi-cell extrusion profiles by ShAPE using porthole dies

Benefits

- Reduced cost, energy, and CO_2 footprint using 100% secondary Al scrap



Milestones

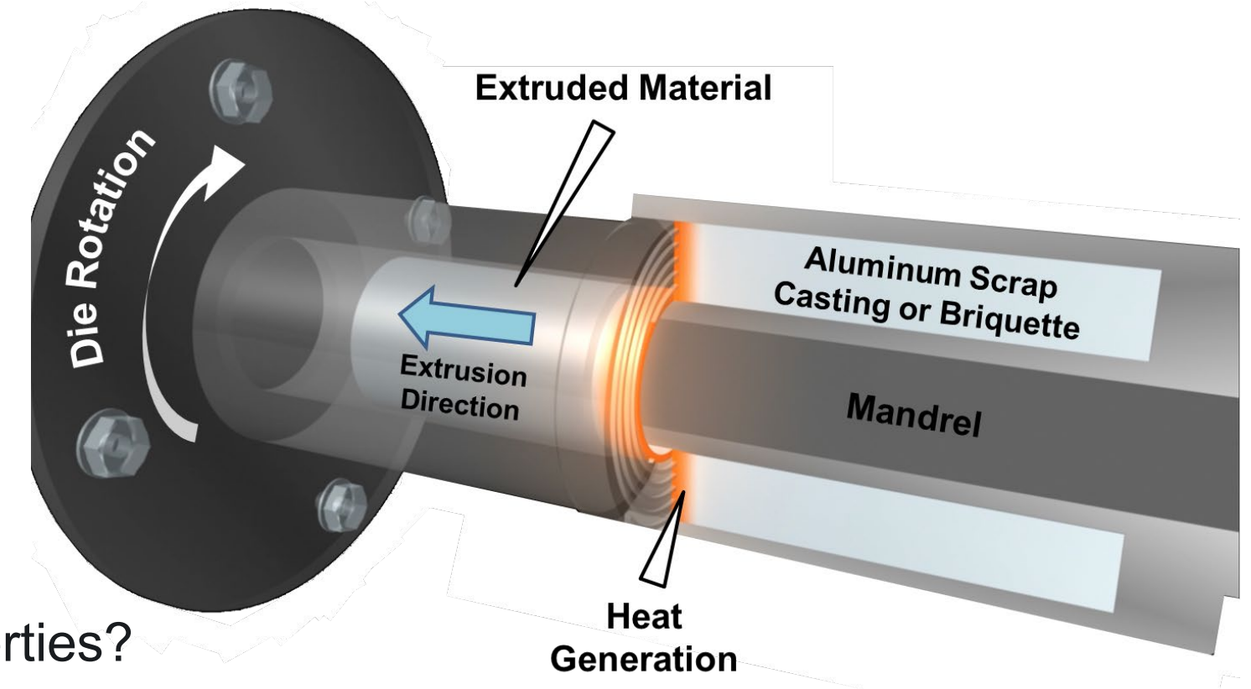
Task Description	FY 2019			FY 2020				FY 2021				FY 2022			
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Extrude Al 6063 tube at industry relevant rate using wrought billets ✓				◆ Extruded 12 mm diameter Al 6063 tubing wit… wall at the maximum ShAPE machine… …min											
Task 2: Extrude 100% secondary scrap Al 6063 with equivalent T5 and T6 properties ✓				Extruded 12 mm diameter Al 6063 tubing with 1 m… wall using briquettes made from 100% secon…				◆							
Task 3: Extrude Al 6063 round profile using porthole die ✓				Extruded 12 m… …th 2 mm wall usi… …billets						◆					
Task 4: : Extrude non-circular profile from ZK60 and 100% secondary Al 6063 scrap					Extruded square and trapezoidal 1-cell profiles with 2 mm wall from ZK60 and 100% secondary Al 6063 scrap using briquette and cast billets							◆			
Task 5: Multi-cell no… from 100% sec… …ap ✓						Extruded 2-cell trapezoidal profile with 2 mm wall from 100% secondary Al 6063 scrap using cast billets							◆		
Task 6: Cha… …rize material properties and microstructure ✓					Al 6063-T5 and T6 extrusions using cast and briquette billets meeting ASTM standard for strength and elongation								◆		

All Milestones Completed Prior to FY 22 AMR

Approach

- **What is ShAPE?**
  - Linear and rotational shear are combined to impart extreme deformation into the material
  - Scalable method of extruding circular, non-circular, and multi-cell structural profiles

- **Benefit for Al**
  - ShAPE processing enables use of 100% secondary Al scrap
  - Re-purpose Al scrap without adding primary Al (lower cost, energy savings, reduced CO_2 footprint in manufacturing)

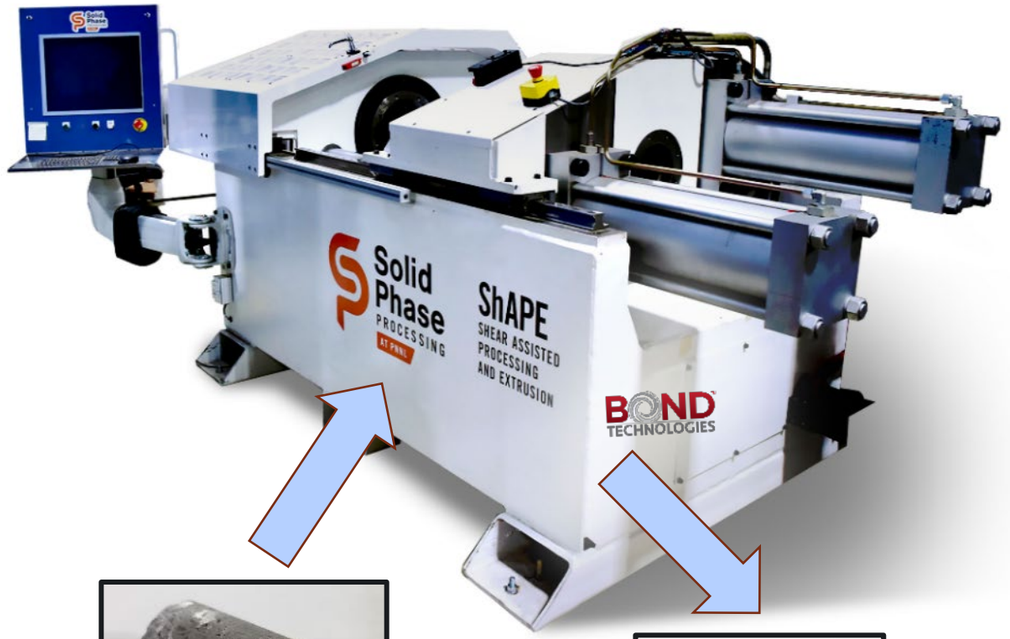


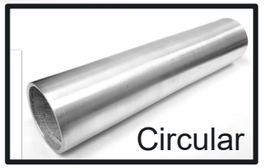
- **Hypotheses:**
  - Can we extrude Al scrap with good properties?
  - Can we extrude non-circular multi-cell profiles with ShAPE?

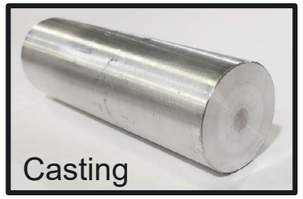
Approach

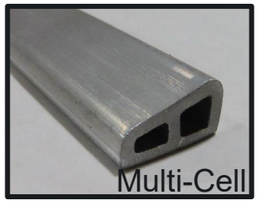
ShAPE of Al 6063 – Secondary Scrap

- Manufacture feedstock using 100% secondary Al
  - Cast billet
  - Chipped briquette
- Mandrel die configuration
  - Circular profile
- Porthole die configuration
  - Circular
  - Non-circular
  - Non-circular multi-cell





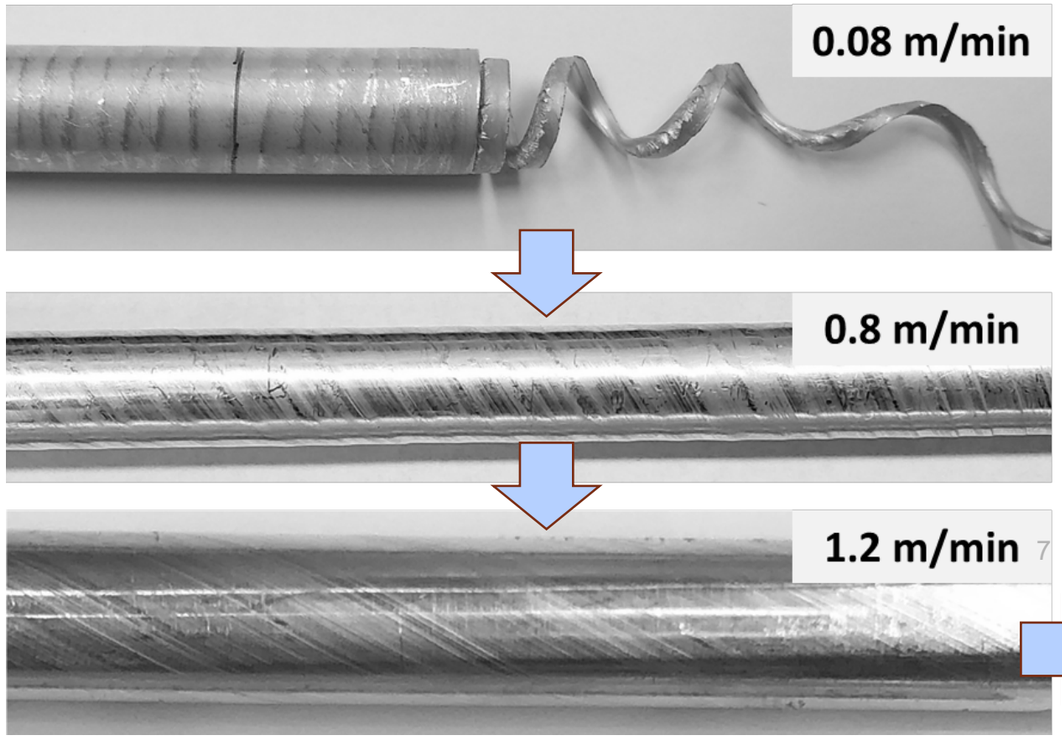


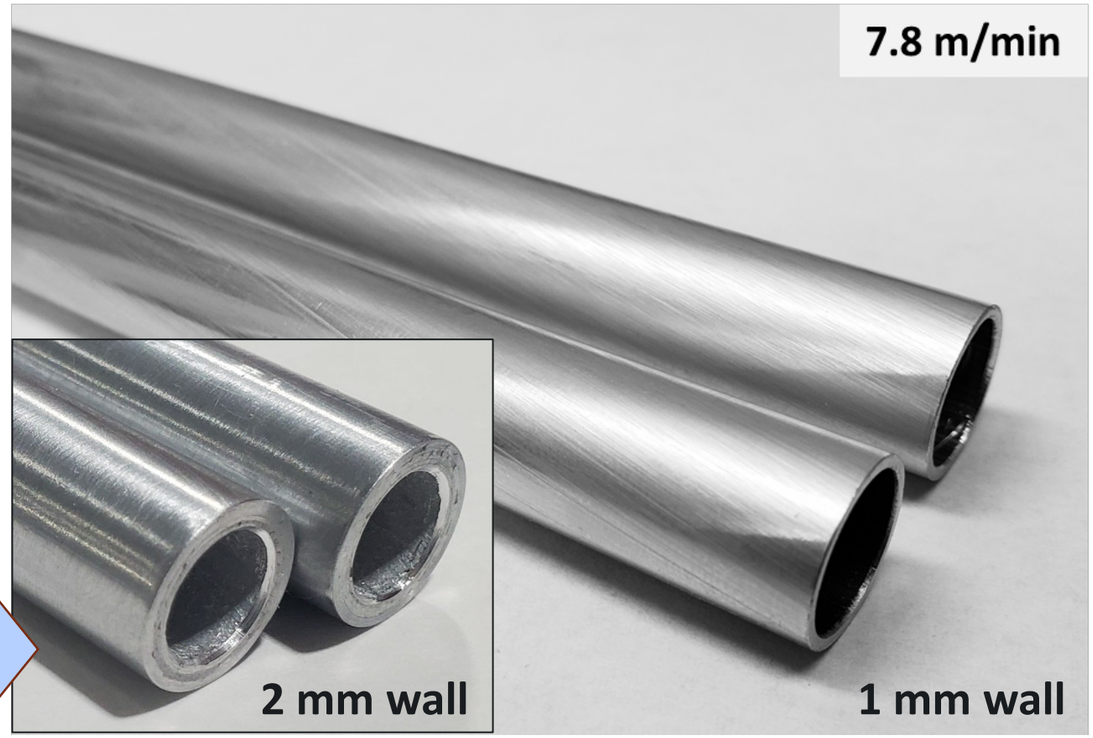


Technical Accomplishments:

Extrusion Speed and Quality

Extensive tooling and process development to achieve relevant speeds with 100% secondary Al Scrap





B.S. Taysom, N. Overman, M. Olszta. Md. Reza-E-Rabby, T. Skszek, M. DiCiano, S. Whalen, "Shear Assisted Processing and Extrusion of High-Strength Aluminum Alloy 6063 Tubing," International Journal of Machine Tools and Manufacture, 169, 103798, 2021.

Technical Accomplishments:

Billets from 100% Secondary Al 6063 Scrap

Unhomogenized Cast billets

0% primary Al gives 86% CO_2 savings

6063-T6	YS (MPa)	UTS (MPa)	El. (%)
Industry	214	241	12
ShAPE .21% Fe	228	251	15
ShAPE .34% Fe	206	238	16

S. Whalen, N. Overman, B.S. Taysom, M. Bowden, Md. Reza-E-Rabby, T. Skszek, M. DiCiano, "Effect of High Iron Content on Direct Recycling of Unhomogenized Aluminum 6063 by Shear Assisted Processing and Extrusion," Journal of Manufacturing Processes, Under Review, 2023.

Compacted briquettes

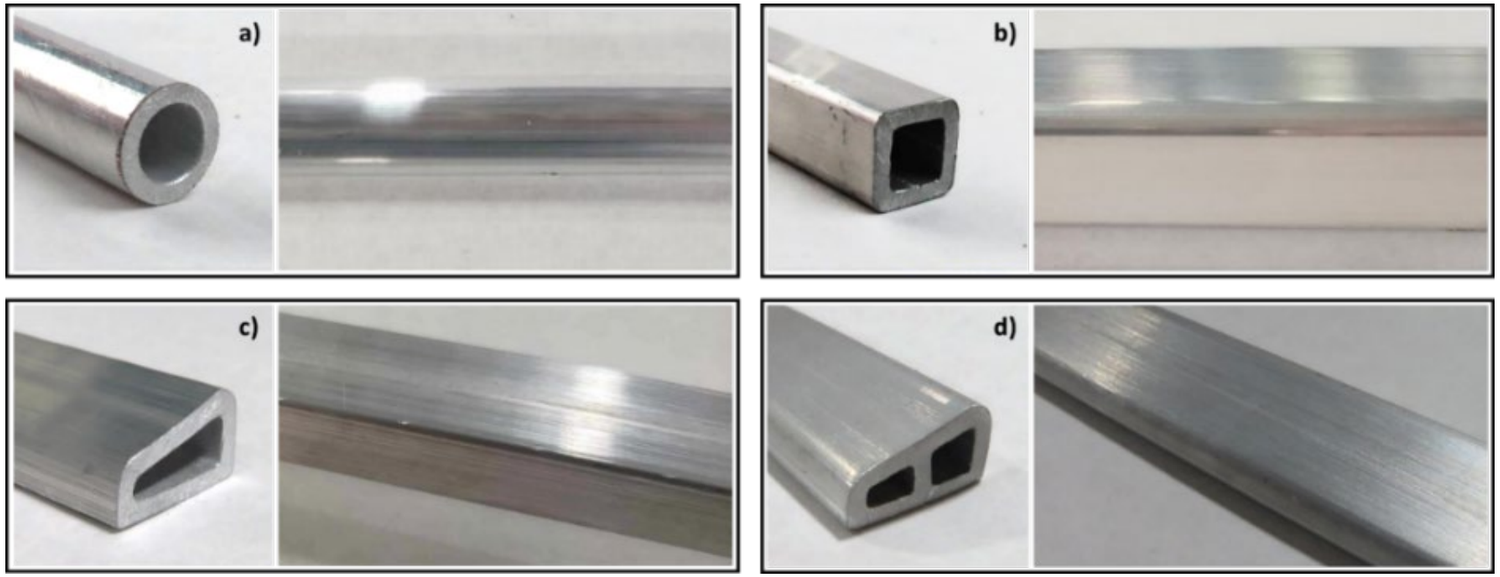
0% primary Al gives 92% CO_2 savings

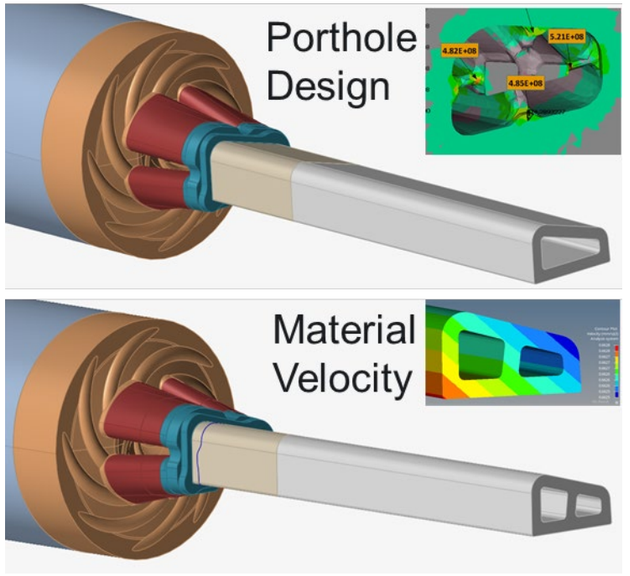
6063-T6	YS (MPa)	UTS (MPa)	El. (%)
Industry	214	241	12
ShAPE	204	231	17

B.S. Taysom, Md. Reza-E-Rabby, X. Ma, M. DiCiano, T. Skszek, S. Whalen, "Fabrication of Aluminum Alloy 6063 Tubing from Secondary Scrap with Shear Assisted Processing and Extrusion," Light Metals, pg. 294-300, 2022.

Technical Accomplishments:

Porthole Die Development





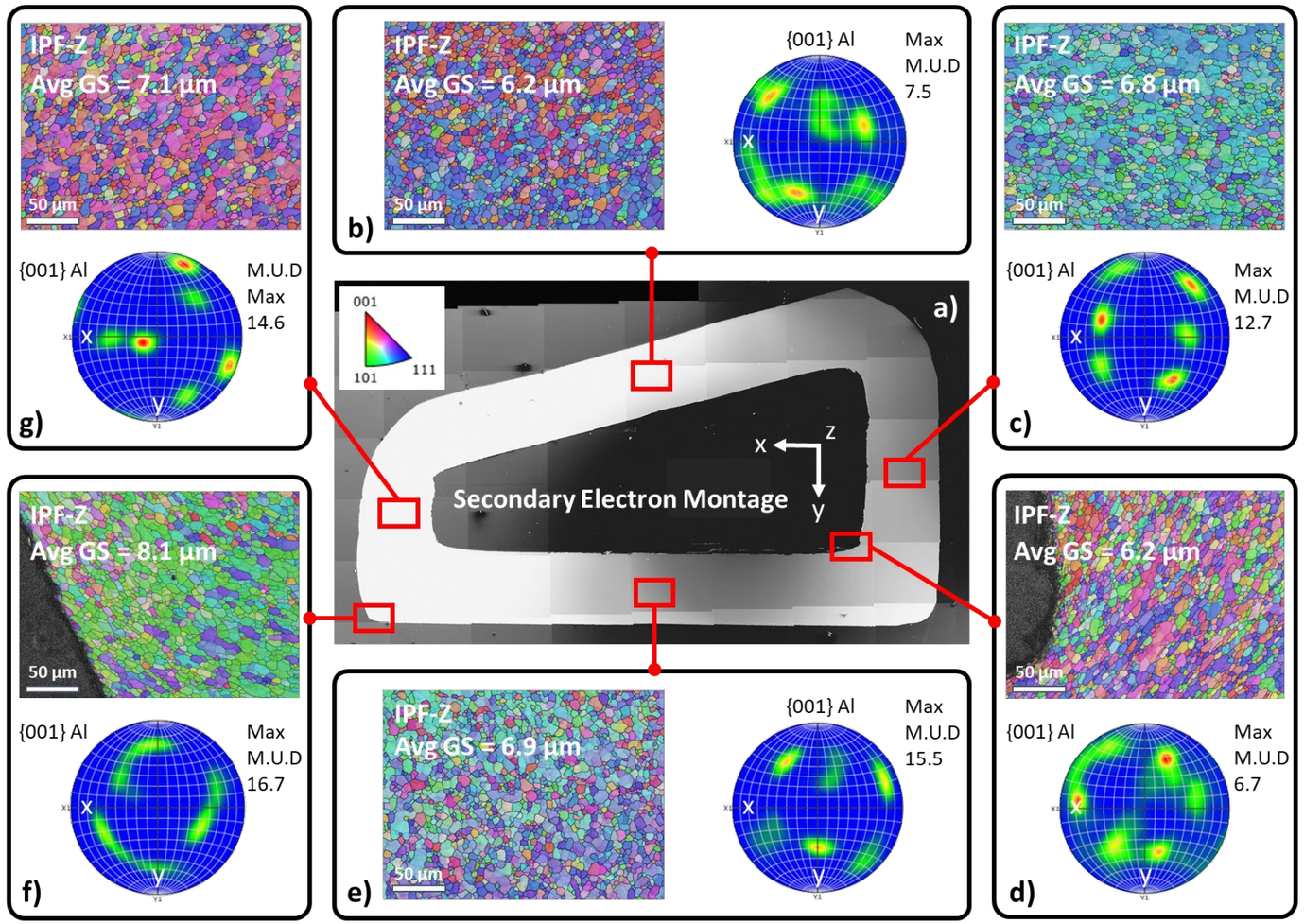
6063-T6	YS (MPa)	UTS (MPa)	El. (%)
Industry	214	241	12
ShAPE (Round)	247	271	17
ShAPE (Trapezoid)	211	239	14

Achieved non-circular asymmetric multi-cell profile from unhomogenized 100% secondary scrap

S. Whalen, B.S. Taysom, N. Overman, Md. Reza-E-Rabby, Y. Qiao, T. Richter, T. Skszek, M. DiCiano, "Porthole Die Extrusion of Aluminum 6063 Industrial Scrap by Shear Assisted Processing and Extrusion," Manufacturing Letters, Accepted In-Press, 2023.

Technical Accomplishments:

Porthole Die Development



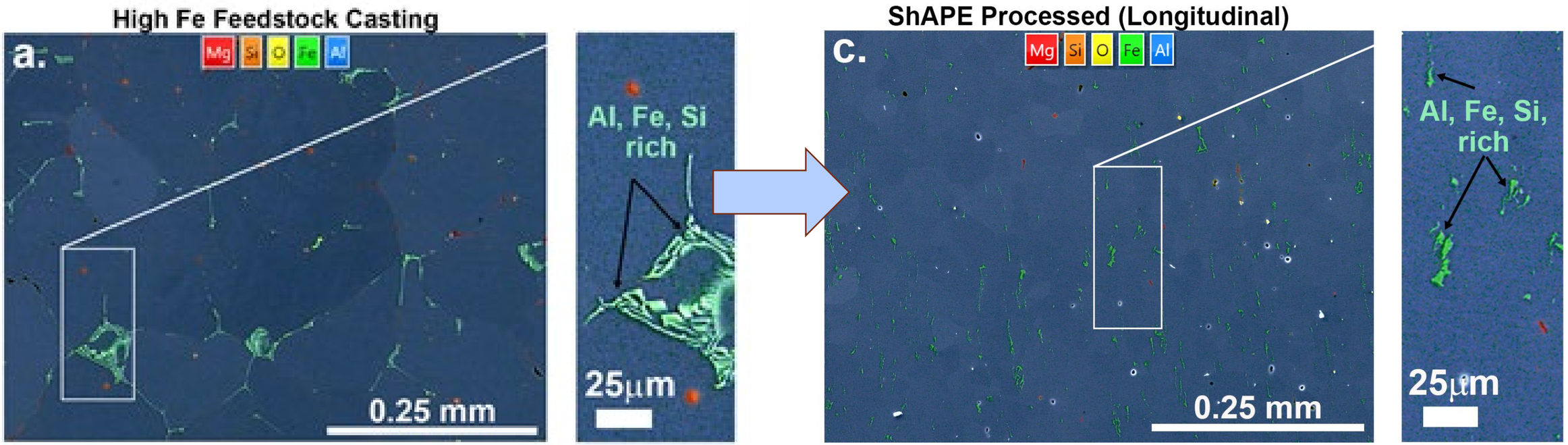
- **Highly refined microstructure**
- **No detectable weld seams**

S. Whalen, B.S. Taysom, N. Overman, Md. Reza-E-Rabby, Y. Qiao, T. Richter, T. Skszek, M. DiCiano, "Porthole Die Extrusion of Aluminum 6063 Industrial Scrap by Shear Assisted Processing and Extrusion," Manufacturing Letters, Accepted In-Press, 2023.

Technical Accomplishments:

Porthole Die Development

Extensive refinement of FeAlSi intermetallic phases



S. Whalen, N. Overman, B.S. Taysom, M. Bowden, Md. Reza-E-Rabby, T. Skszek, M. DiCiano, "Effect of High Iron Content on Direct Recycling of Unhomogenized Aluminum 6063 by Shear Assisted Processing and Extrusion," Journal of Manufacturing Processes, Under Review, 2023.

Response to Previous Year Reviewers' Comments

Reviewer Comment	Response
Comments from FY 22 AMR agreed that project was successful with all milestones and deliverables met	No actions taken

Collaboration

- **Pacific Northwest National Laboratory**
  - Scott Whalen — PM/PI
  - Md. Reza-E-Rabby — Process
  - Scott Taysom — Tooling & Mechatronics
  - Nicole Overman — Characterization

- **Magna International**
  - Tim Skszek — PM
  - Aldo Van Gelder — PI
  - Massimo DiCiano — Process
  - Thomas Richter — Simulation
  - Michael Miranda — Tooling
  - Cangji Shi — Commercialization

Remaining Challenges and Barriers

- **All objectives and milestones have been achieved**

Proposed Future Research

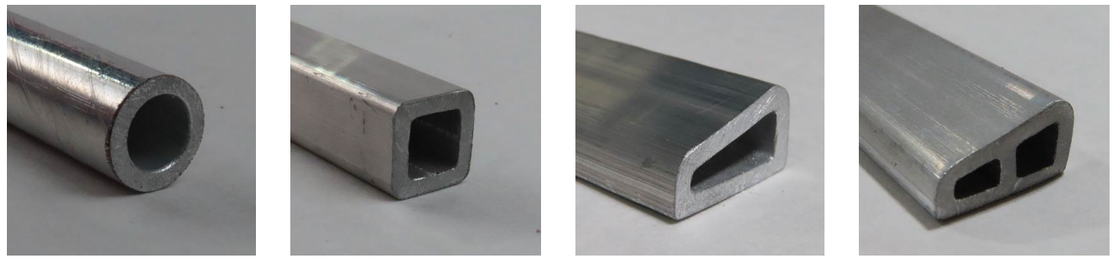
- **New LightMAT project awarded to Magna-Vehma/PNNL**
  - Semi-continuous extrusion
  - AA 6082 and AA 7075 scrap

Any proposed future work is subject to change based on funding levels

Summary

- **Extruded 100% secondary Al 6063 scrap**
  - Achieves T6 properties meeting requirements
  - Saves GHG compared to billets made with primary aluminum
  - Reduces cost of extruded components

- **Demonstrated porthole extrusion from 100% secondary Al 6063 scrap**
  - Round
  - Square
  - Trapezoid
  - Multi-Cell



- **Magna and PNNL are negotiating commercial use license for ShAPE IP**