Pacific Northwest NATIONAL LABORATORY

LightMAT Lightweight Materials Consortium

MAGNA

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

Project ID: **MAT149**
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Team: Magna International, Inc.
Md. Reza-E-Rabby[1]
Scott Taysom[1]

[1]**Pacific Northwest National Laboratory**

BATTELLE **PNNL-SA-172544**

PNNL is operated by Battelle for the U.S. Department of Energy

Solid Phase PROCESSING

Overview

Timeline

- Start date: Nov. 2018
- End date: Sept. 2022
- % complete: 91% as of June 2022

Barriers

- Magnesium (Mg)
  - Low-cost feedstock
  - Improved alloys for energy absorption
- Aluminum (Al)
  - Improved ductility and fatigue
  - Recycling of scrap directly into product

Budget

- Total project funding
  - $2,000K
- $1,000K - DOE share
  - $878K Costs incurred through Apr. 2022
- $1,000K - Industry share
  - $1,576K Costs incurred through Apr. 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

- Evaluate potential for ShAPE to improve energy absorption of non-RE Mg alloy ZK60
- 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


Higher Energy Absorption

Lower CO_2 100% Al Scrap

Benefits

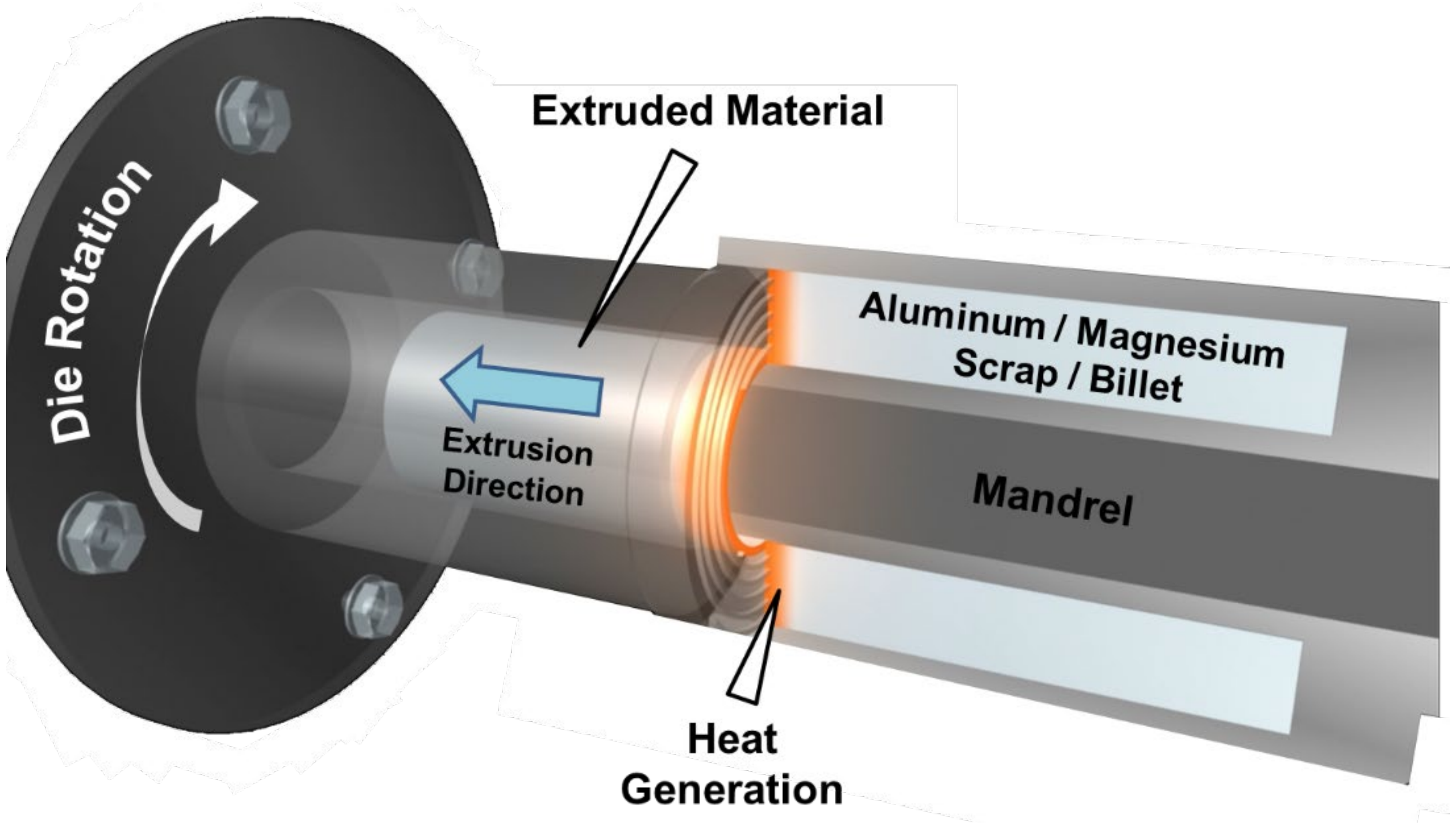
- Reduced vehicle weight, replacing aluminum extrusions with Mg extrusions
- Reduced cost, energy, and CO_2 footprint using 100% secondary Al scrap

Milestones

Task Description	Milestone (FY 2019 Q2 – FY 2022 Q4)
Task 1: Extrude Al 6063 tube at industry relevant rate using wrought billets ✓	Extruded 12 mm diameter Al 6063 tubing with 1 mm and 2 mm wall at the maximum ShAPE machine ram speed of 360 mm/min
Task 2: Extrude 100% secondary scrap Al 6063 with equivalent T5 and T6 properties ✓	Extruded 12 mm diameter Al 6063 tubing with 1 mm and 2 mm wall using briquettes made from 100% secondary Al scrap
Task 3: Extrude Al 6063 round profile using porthole die ✓	Extruded 12 mm diameter tubing with 2 mm wall using briquette and cast 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 non-circular profile from 100% secondary Al 6063 scrap ✓	Extruded 2-cell trapezoidal profile with 2 mm wall from 100% secondary Al 6063 scrap using cast billets
Task 6: Characterize material properties and microstructure ✓	Al 6063-T5 and T6 extrusions using cast and briquette billets meeting ASTM standard for strength and elongation

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 Mg**
  - Grain refinement and texture alignment have potential to reduce asymmetry in tensile/compressive strength ratio
  - Improved energy absorption
- **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)



Approach

ShAPE of Al 6063 – Secondary Scrap

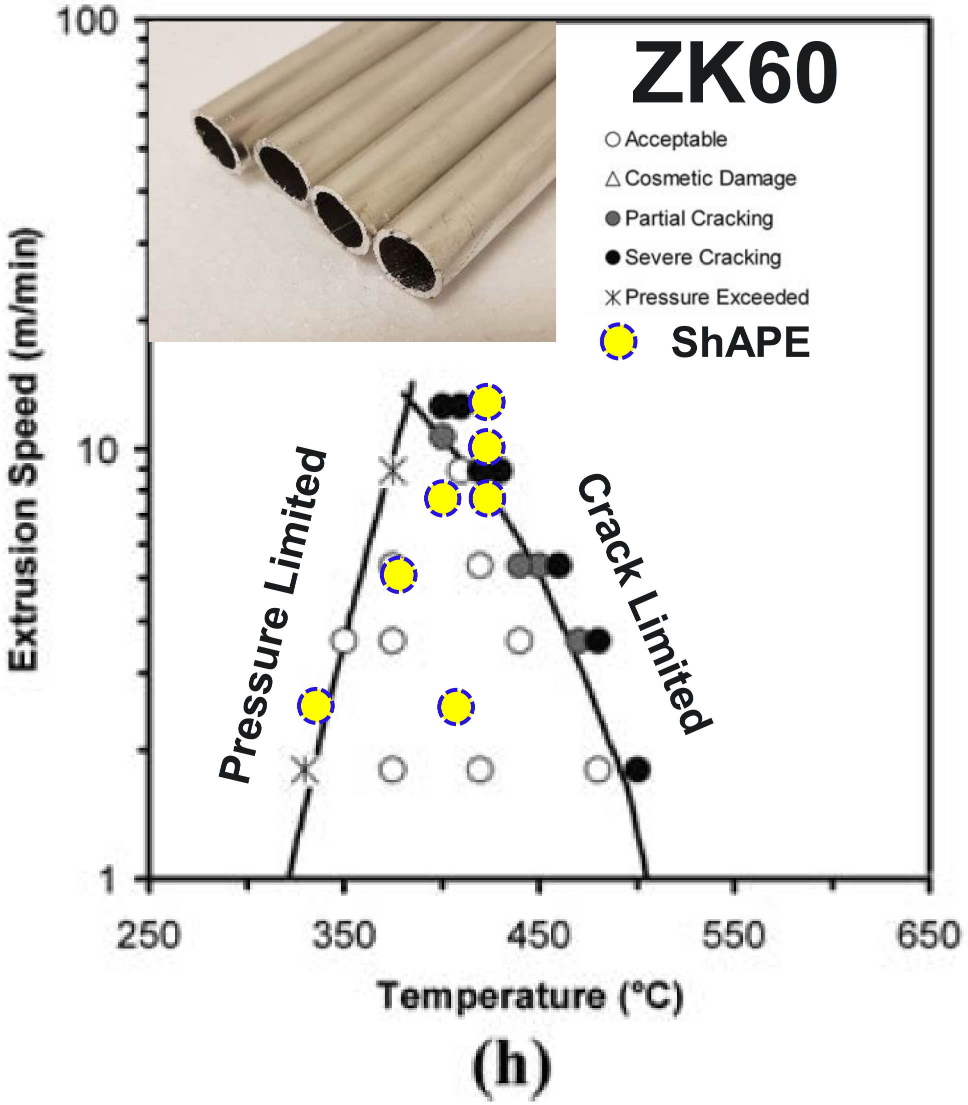
- Manufacture feedstock using 100% secondary Al
  - Cast Billet
  - Chipped Briquette
- Maximize ram speed, evaluate T5 & T6 properties
  - DOM (drawn over mandrel) die configuration
    - Circular profile
  - Porthole die
    - Circular
    - Non-circular
    - Non-circular multi-cell

ShAPE of ZK60 – Energy Absorption

- Feedstock typical cast billet
- Evaluate energy profile

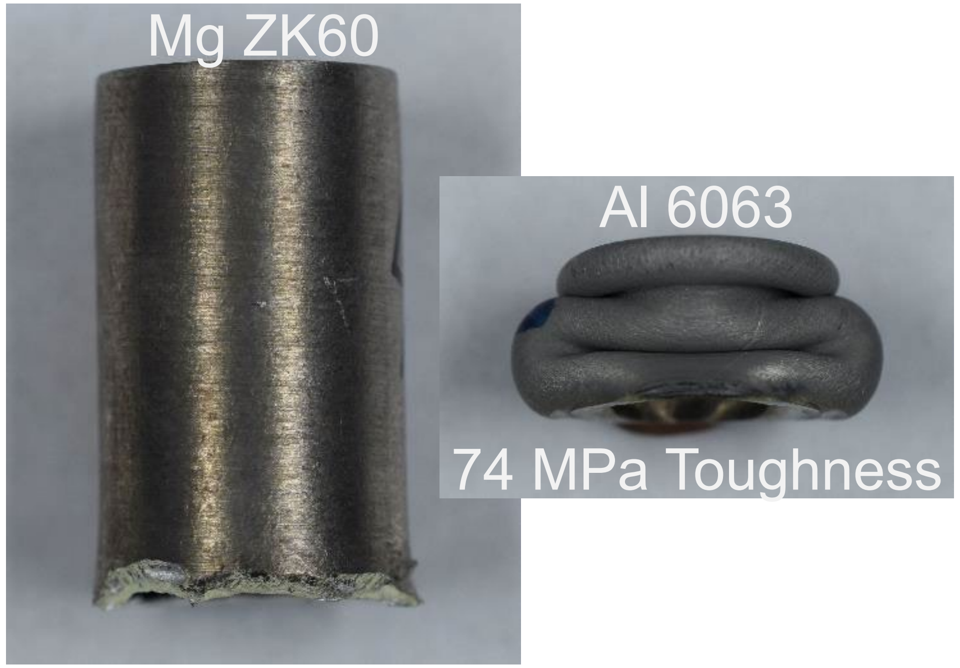
Technical Accomplishments:

Extrusion and toughness of Mg ZK60



D. Atwell, M. Barnett, "Extrusion Limits of Magnesium Alloys," Metallurgical and Materials Transactions A, 38A, 3032-3041.

Speed (m/min)	Toughness (MPa)
7.4	18
4.9	22
2.4	16
1.2	2



Off-axis basal plane alignment discovered at slower speeds, 0.15 m/min* was not observed at higher extrusion rates.

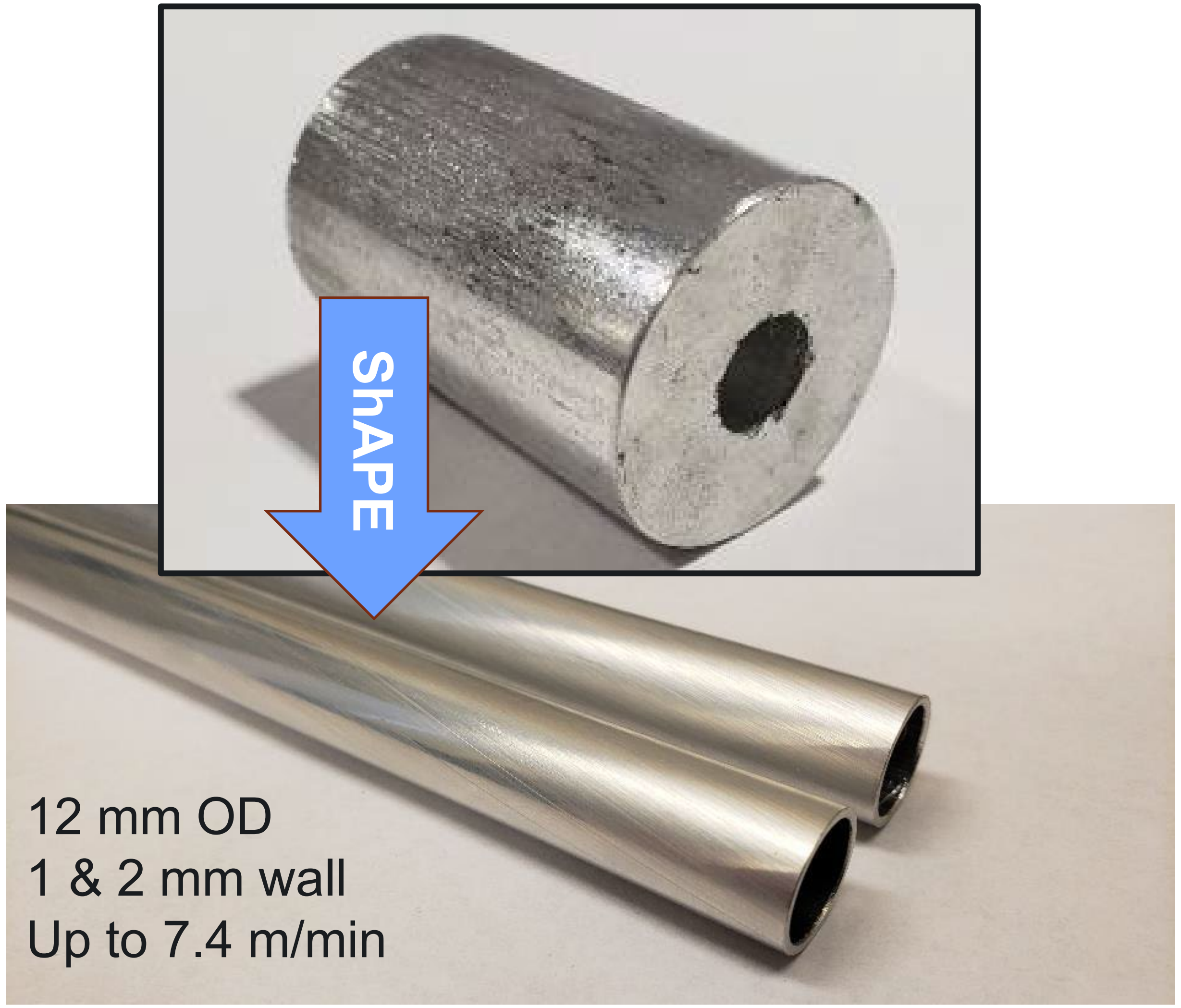
Limits potential for commercial application

*Joshi, et. Al., "The Processing-Structure-Properties Relationship for Mg Alloys during Shear Assisted Indirect Extrusion," TMS 2016.

Technical Accomplishments:

Briquettes from 100% Secondary Al 6063 Chips

Compacted briquette from 100% secondary Al 6063 scrap chips developed by Magna



* T5/T6 Min, ASTM B221M-13, Table 2
* T5/T6 Typ, ASM Handbook, Vol 2b, Table 4-6

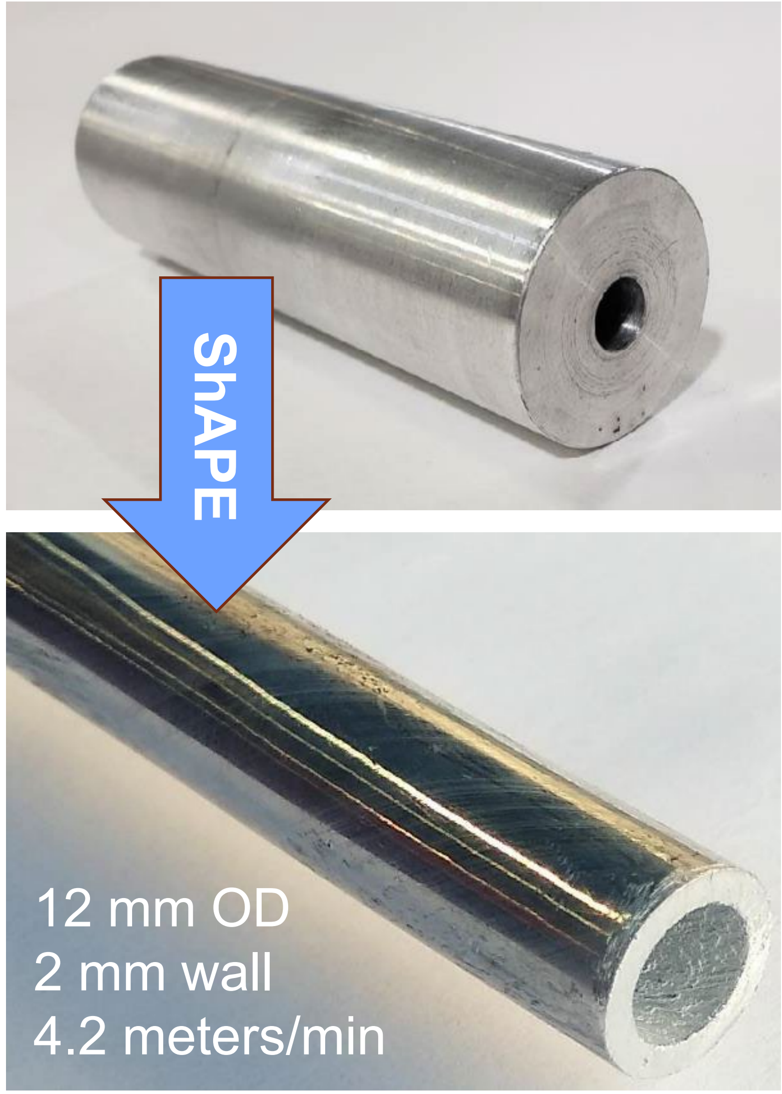
Al 6063	Yield Stress (MPa)	Ultimate Stress (MPa)	Elongation at Break (%)
ASTM Min (T5)	110	150	8
ASM Typ (T5)	145	186	12
ShAPE (T5)	**172**	**210**	**22**
ASTM Min (T6)	170	205	8
ASM Typ (T6)	214	241	12
ShAPE (T6)	**204**	**231**	**17**

- ***Briquettes from 100% secondary scrap Al are a low-cost, low CO_2 footprint feedstock***
- ***0% primary Al addition results in 92% CO_2 savings***

Technical Accomplishments:

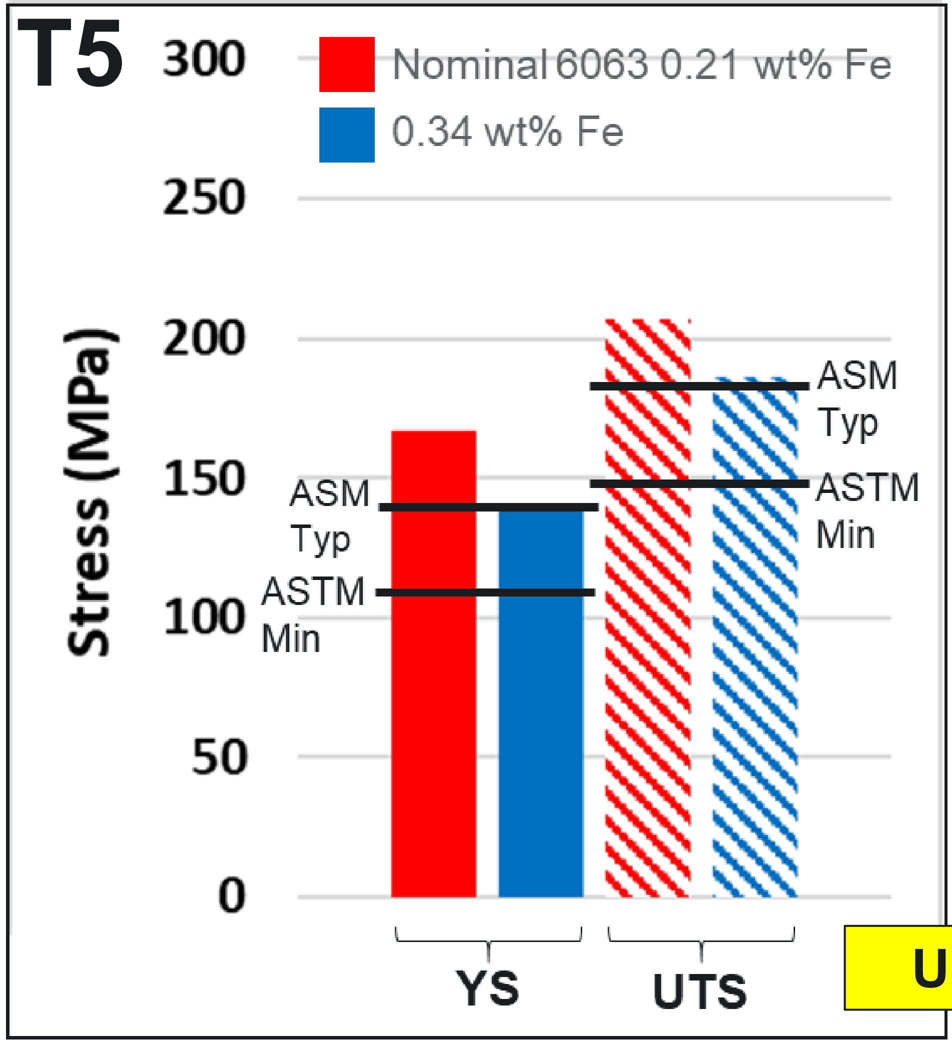
Cast Billet from 100% Secondary Al 6063 Scrap

Cast billets from 100% secondary scrap Al 6063

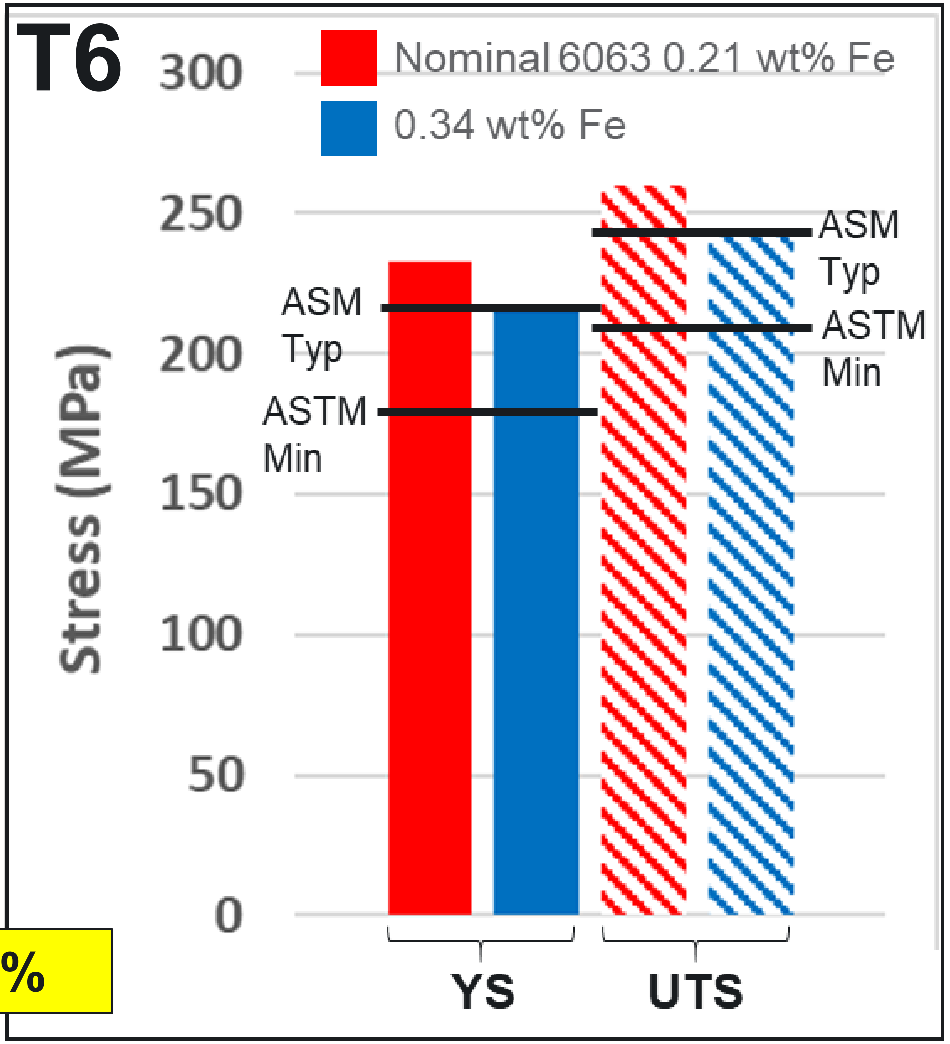


Technical Accomplishments:

Billets from 100% Secondary Al 6063 Scrap



U.E >15%



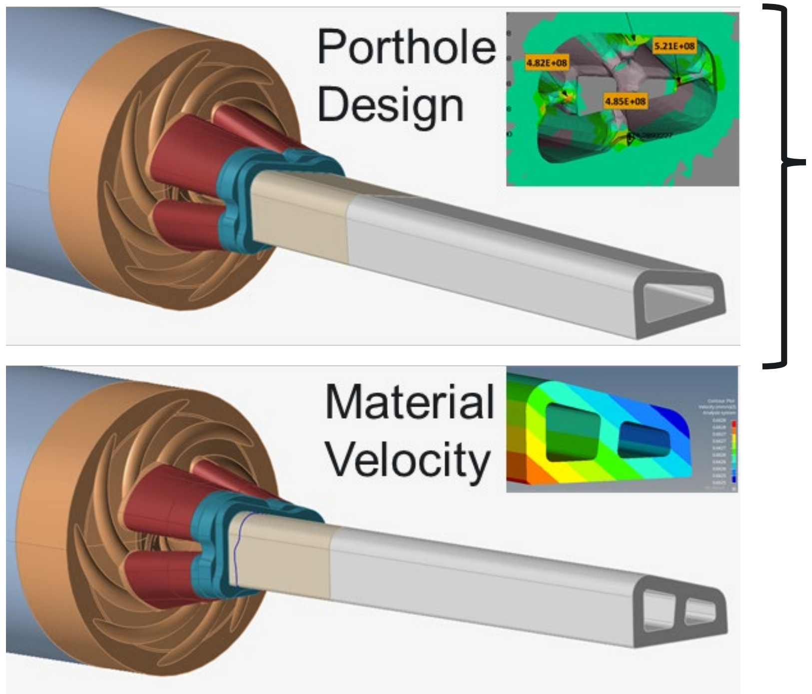
- *Billet feedstock comprised of 100% secondary Al scrap are low-cost and have a reduced CO_2 footprint*
- *0% primary Al addition results in 86% CO_2 savings*
- *Increased Fe content resulted in lowered tensile properties, but within ASM_{typ} and ATM_{min} standards*

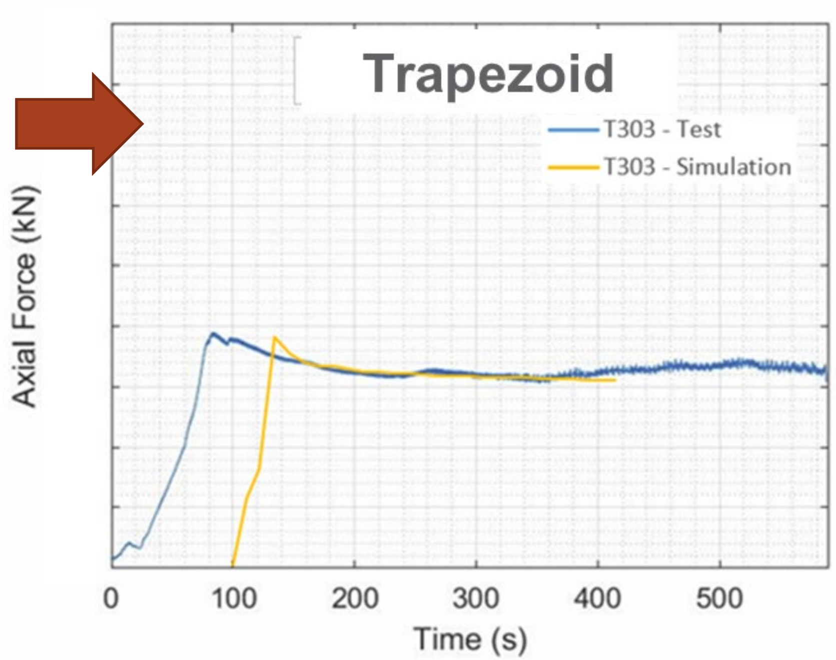
Technical Accomplishments:

Porthole Die Development

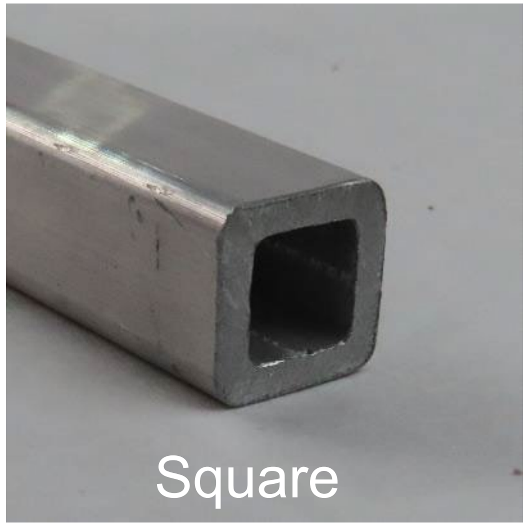
Cast billets from 100% secondary scrap Al 6063

Porthole Tooling

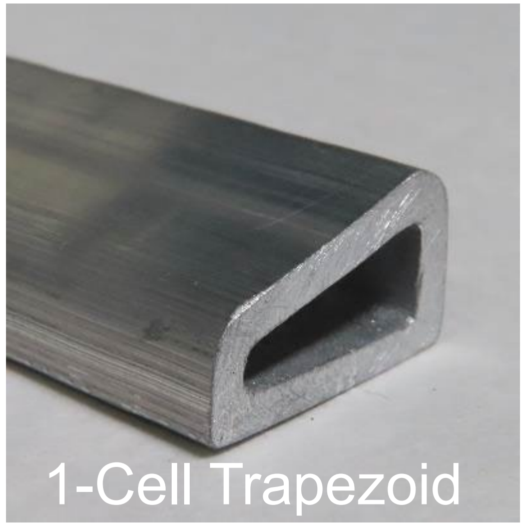




Circular



Square

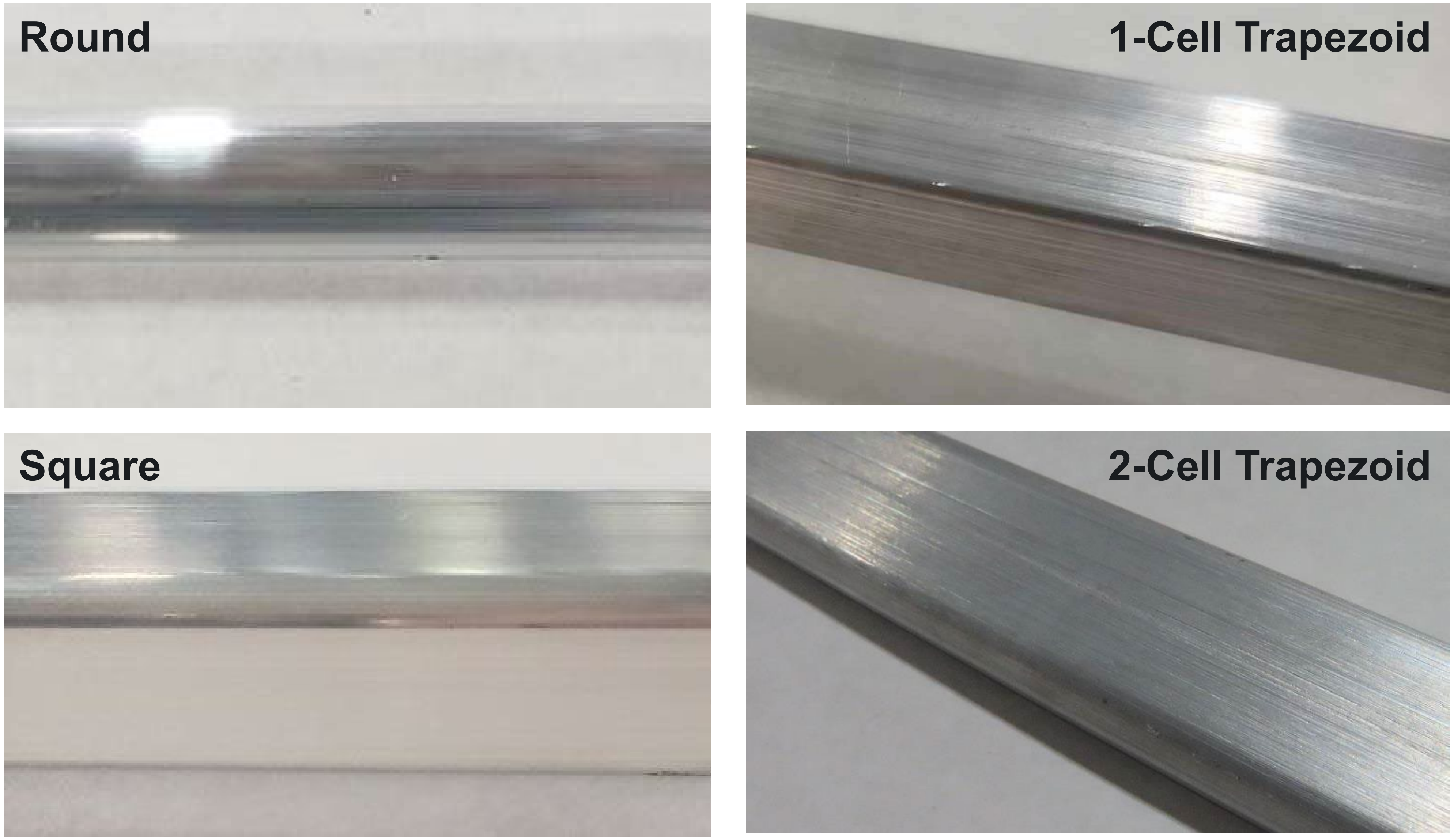


1-Cell Trapezoid

2-Cell Trapezoid

Technical Accomplishments:

Porthole Extrusion Quality



Surface quality meets or exceeds application requirements

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Technical Accomplishments:

Porthole Extrusion Quality

Solid Phase PROCESSING

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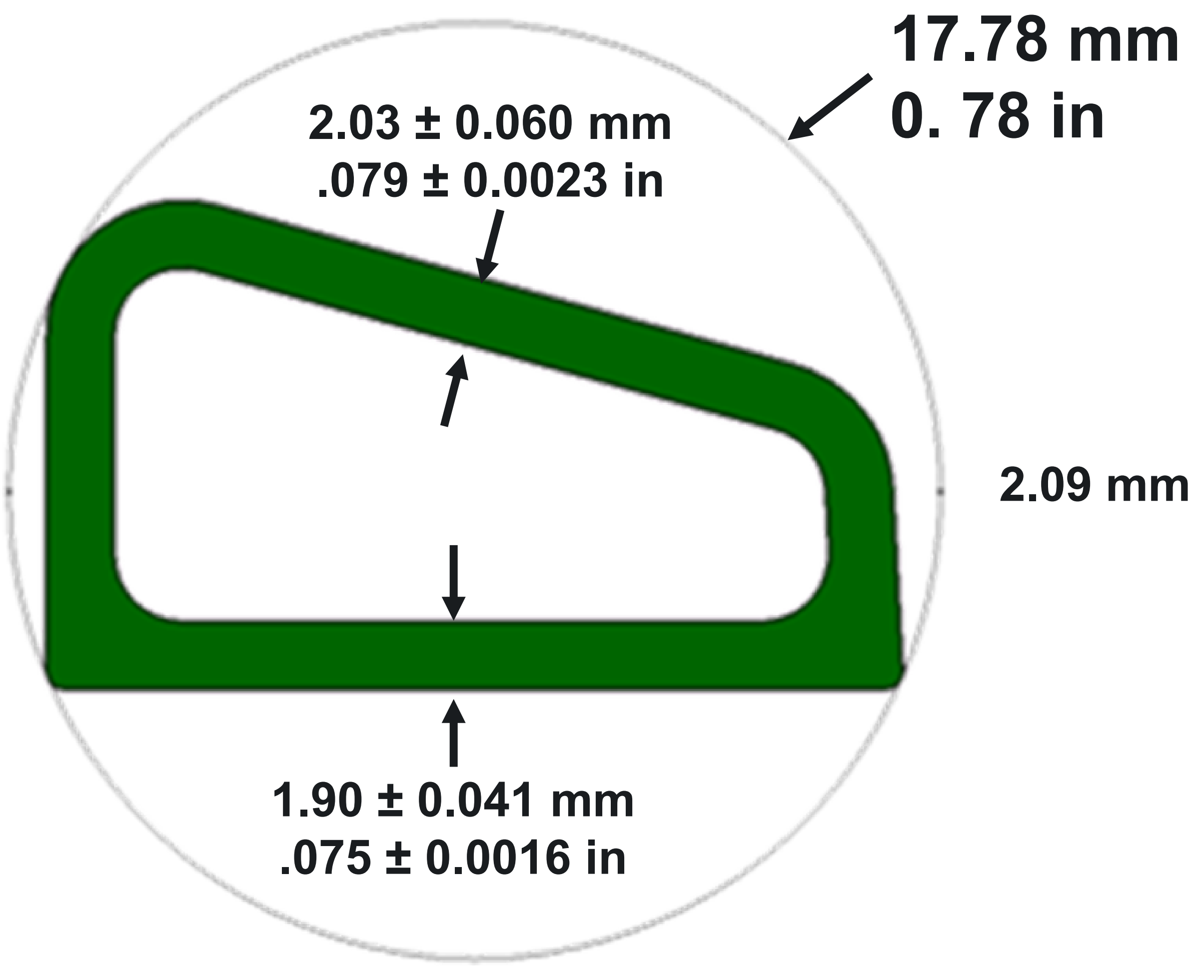
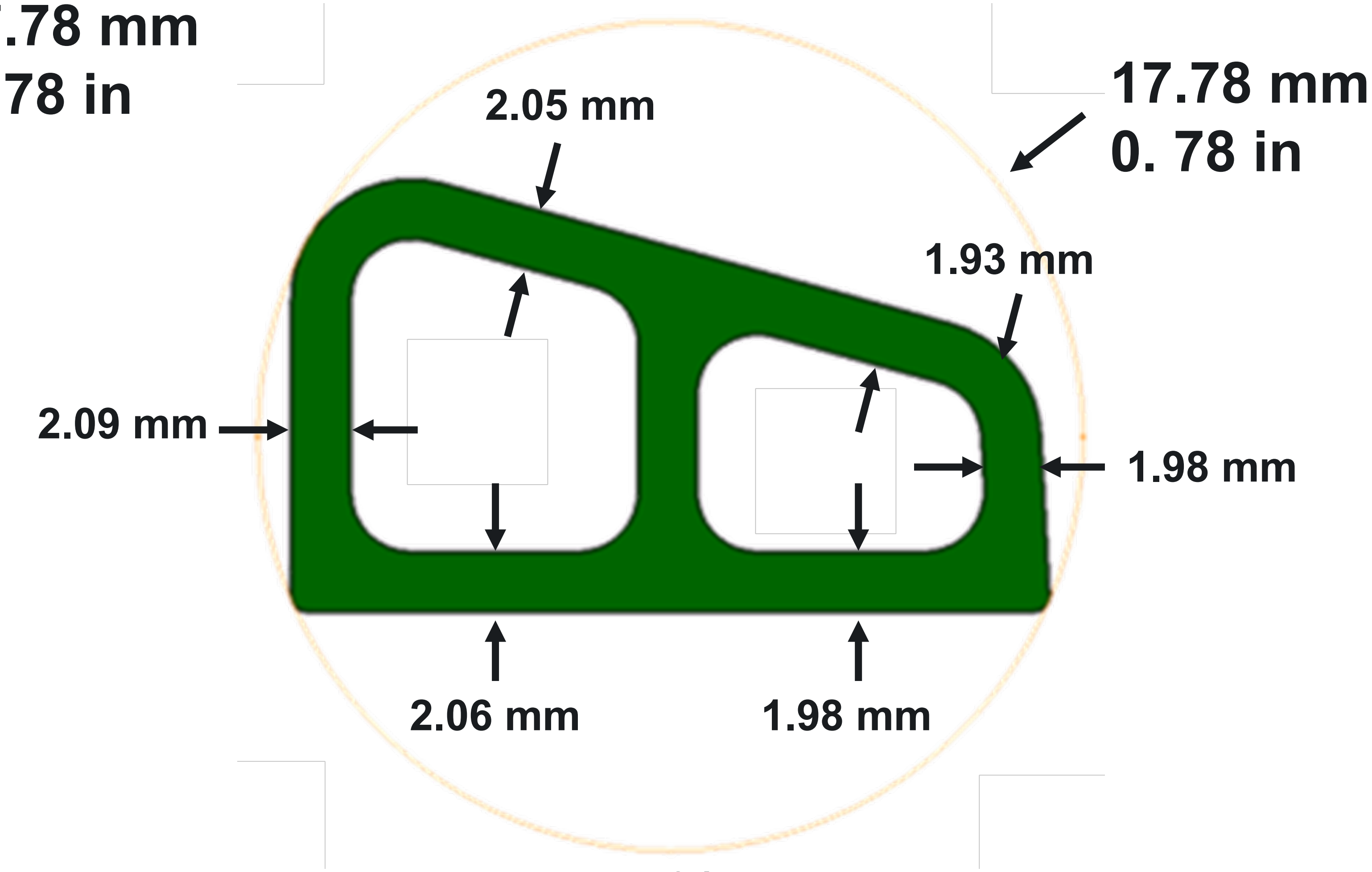
1-Cell Trapezoid



2-Cell Trapezoid



Measured variation in wall thickness was ≈ ±5%, within the specification "not to exceed 10% of nominal thickness"

Response to Previous Year

Reviewers' Comments

Reviewer Comment	Response
Modeling and simulation should be performed to optimize die configurations and process parameters	Magna performed extensive modeling of porthole die design and ShAPE extrusion process simulation
Resources may be insufficient to demonstrate the porthole approach	Significant resources were needed to demonstrate round, square, trapezoidal, and multi-cell profiles with porthole dies. Multi-cell is the key to enabling commercialization
The project could address more on chemistry as part of using castings 100% Al scrap as feedstock	Magna agrees with the importance of understanding the effect of scrap feedstock chemistry. This will be addressed in future work focusing on Al 6061, 6063, and 6082.
Extrusion quality metrics such as dimensional accuracy, surface quality, texture, etc… are important considerations	Preliminary dimensions and surface quality are promising and will require further investigation. Appears to be equivalent to conventional extrusion
The full supply chain, from scrap to extruder, is not involved in the project	Manga has engaged the secondary scrap Al supply chain and industrial machine manufactures to build commercial scale ShAPE extrusion machines

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

- ***Fully integrated multi-disciplinary team across 4 site locations***
- ***Frequent virtual meetings and collaboration***

- ***Research Use License has been acquired by Magna for ShAPE IP***
- ***Negotiations between PNNL and Magna are in-process for Commercial Use License***

Remaining Challenges and Barriers

- **All objectives and milestones have been achieved**
- **No challenges or barriers remain for LightMAT scope**
- **Magna is now pursuing commercialization**
  - Expand alloys to 6061 and 6082
  - Understand sensitivity of 100% scrap Al feedstock for Mg and Fe content
  - Optimize cleaning and compaction process for manufacturing briquettes
  - Investigate scaling of ShAPE process

Proposed Future Research

- **FY22 (Q3-Q4)**
  - Continue to build mechanical property statistics for porthole extrusion of 100% secondary Al 6063 scrap feedstock
  - Mature ShAPE process parameters for port hole extrusion of non-circular multi-cell profiles
  - Prepare final report

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

Summary

- **Determined that ShAPE of Mg ZK60 at production extrusion speeds does not offer improved toughness**

- **Extruded briquettes and cast billets made from 100% secondary Al 6063 scrap**
  - T5 and T6 properties exceed ASTM standard and ASM typical values
  - Reduces feedstock cost and in-turn cost of extruded components
  - Eliminates need for adding primary Al during recycling
  - Saves 86-92% CO_2 compared to conventional extrusion of standard billets

- **Demonstrated porthole extrusion of ZK60 and 100% secondary Al 6063 scrap**
  - Round ZK60 and 100% secondary Al scrap
  - Square ZK60 and 100% secondary Al scrap
  - Trapezoid 100% secondary Al scrap
  - Multi-Cell 100% secondary Al scrap

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