Non-Rare Earth Magnesium Bumper Beams

Project ID: **MAT-149**
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BATTELLE PNNL-SA-152750

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Solid Phase PROCESSING

Overview

Timeline

- Start date: Jan. 2019
- Re-Scope: Jun. 2019
- End date: Mar. 2022
- % complete: 46%

Barriers

- Magnesium (Mg)[1]
  - Low cost feedstock
  - Improved alloys for energy absorption
- Aluminum (Al)[1]
  - Improved ductility and fatigue
  - Recycling of scrap directly into product

Budget

- Total project funding
  - $2,000K ($667K/yr)
- $1,000K - DOE share
- $1,000K - Industry share
- 50% spent

Partners

- Magna International
- Pacific Northwest National Laboratory (PNNL)

[1]Light-Duty Vehicle Technical Requirements and Gaps for Lightweight and Propulsion Materials: Final Report, Feb. 2013.

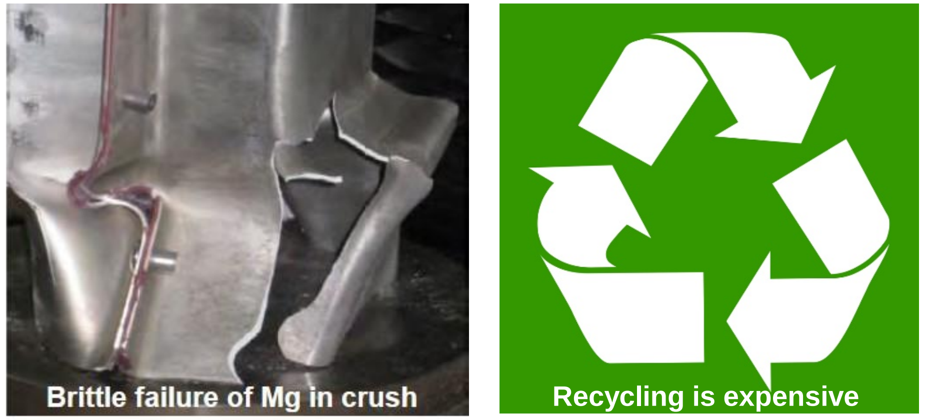
Project Scope

- **Project kicked-off in January 2019**
  - 2 year - $500K Industry / $500K DOE LightMAT
  - Objective was to develop ShAPE for a rectangular profile with non-RE Mg
  - Retain energy absorption properties measured for non-RE Mg round tubing

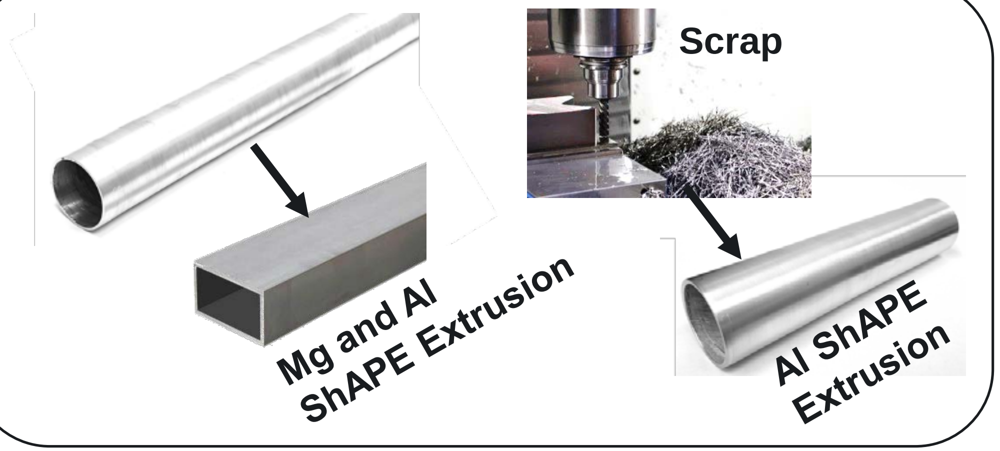
- **Project Augmented and Re-Scoped in June 2019**
  - 3 year - $1M Industry / $1M DOE LightMAT
  - Rectangular Mg profile retained and prioritized later in project
  - Added scope for Al and prioritize to beginning of project
  - Objective is to develop ShAPE for recycling Al scrap directly into extrusions

Relevance

- **Challenge**
  - Energy absorption of non-RE Mg is poor
  - Aluminum scrap recycling is expensive



- **Objective**
  - Develop ShAPE for non-circular profiles
  - Recycle Al scrap directly into extrusions



- **Benefits**
  - 30% weight reduction possible for magnesium components compared to aluminum
  - Energy and cost reduction for scrap + ShAPE route vs. re-melt + extrusion route

Milestones

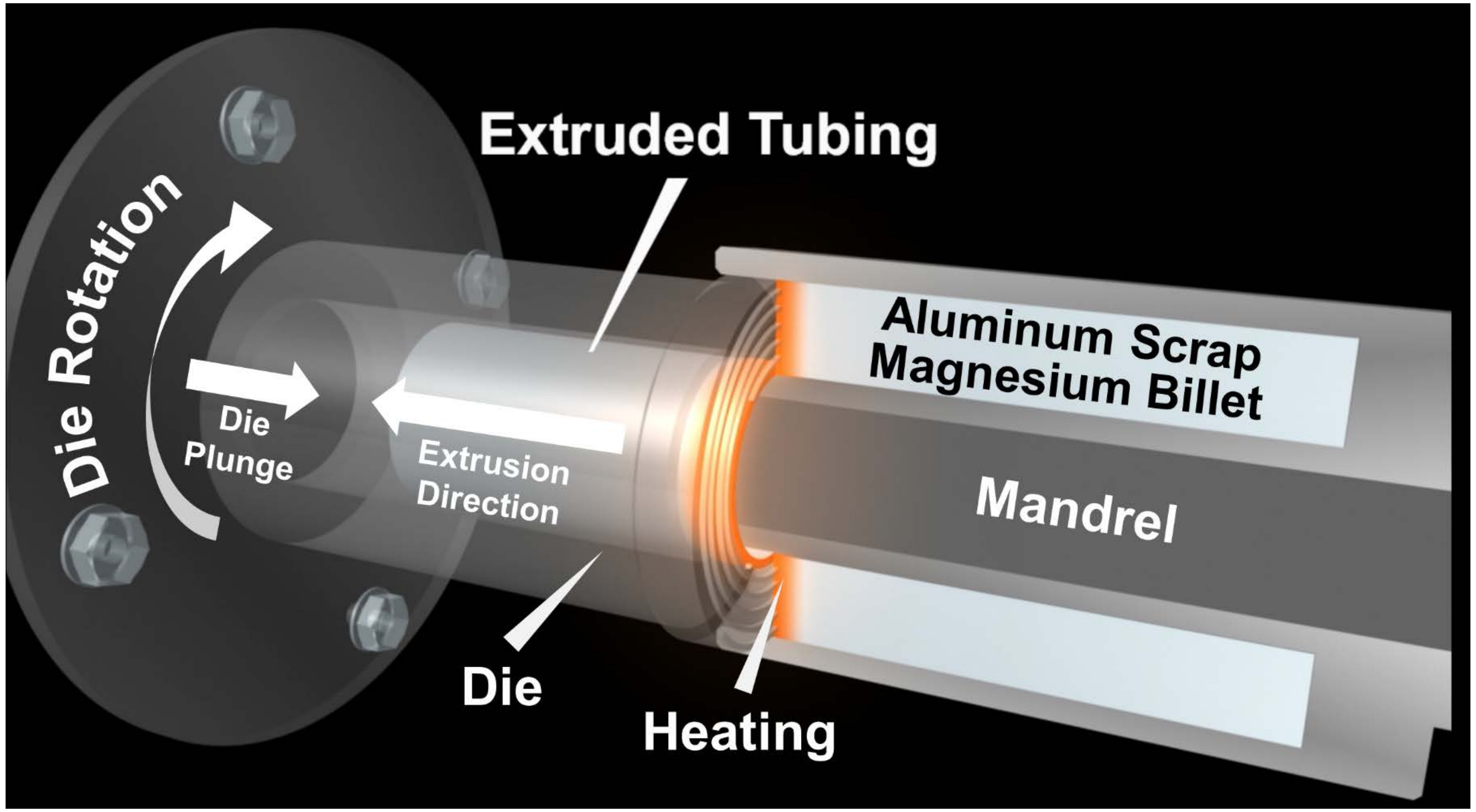
Task Description	FY 2019 Q2	FY 2019 Q3	FY 2019 Q4	FY 2020 Q1	FY 2020 Q2	FY 2020 Q3	FY 2020 Q4	FY 2021 Q1	FY 2021 Q2	FY 2021 Q3	FY 2021 Q4	FY 2022 Q1	FY 2022 Q2
Task 1: Extrude AA6063 12mm thin wall tube at high rate Status: Underway					Extrude 12mm AA6063 tubing at maximum ShAPE machine rate								
Task 2: Extrude AA6063 12mm thin wall tube directly from scrap Status: Underway							Extrude 12mm AA6063 tubing directly from scrap feedstock						
Task 3: Extrude AA6063 50mm thin wall tube using portal bridge die Status: Not Started									Extrude 50mm tubing with portal bridge die approach				
Task 4: Extrude ZK60 and AA6063 tube with non-circular profile Status: Not Started												Extrude non-circular profile	
Task 5: Characterize material properties and microstructure Status: Underway								AA6063-T6 extrusions 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 structural tubing with hollow cross section

- **Benefits for Magnesium**
  - Grain refinement and texture alignment eliminates asymmetry in tensile/compressive strength ratio
  - Improved energy absorption

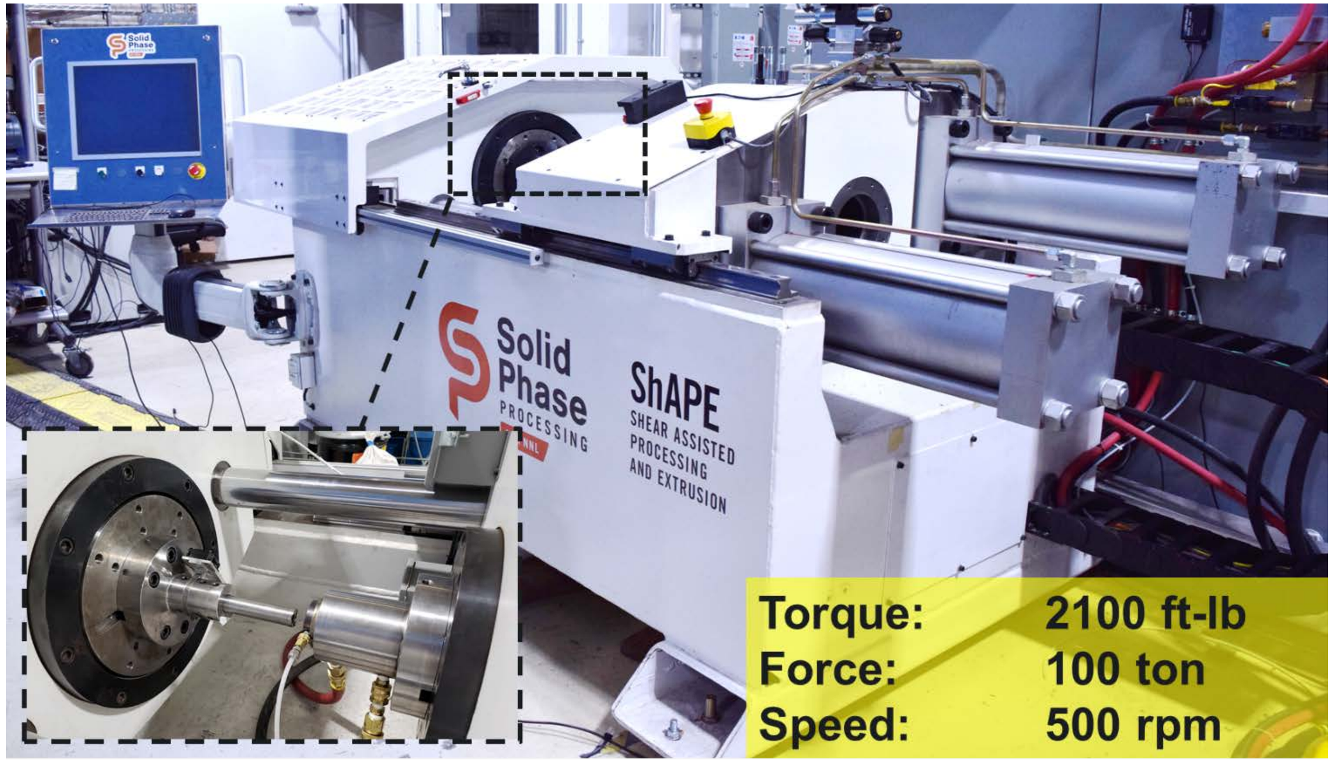
- **Benefit for Aluminum**
  - Breakdown of surface oxides on scrap enables consolidation
  - Recycling without re-melting



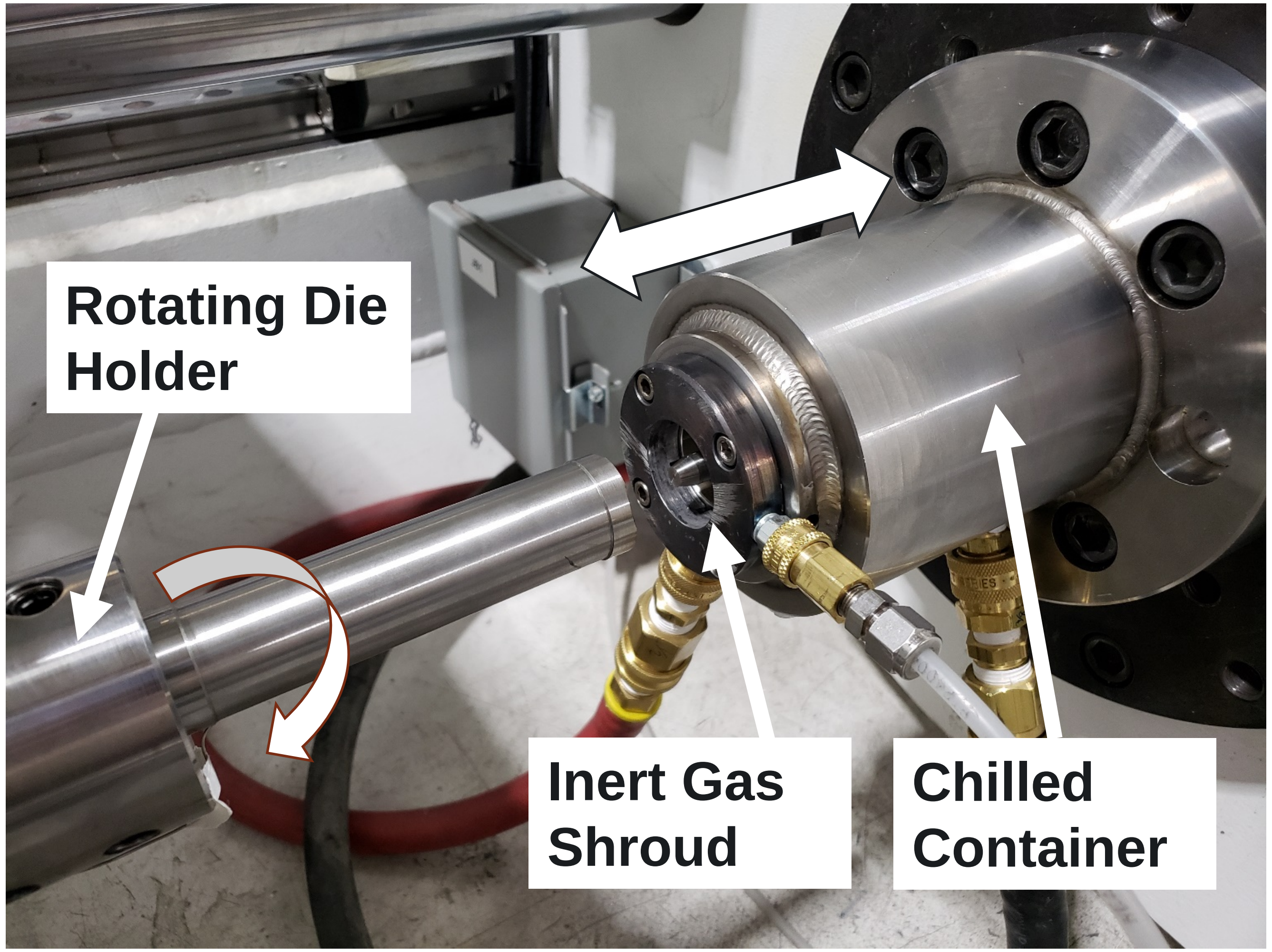
Approach

- **ShAPE of AA6063-T5**
  - Extrude billet and scrap into tubing with 12mm OD and 1-2 mm wall thickness
    - Develop tooling and process parameters
    - Extrude at maximum machine press velocity
    - Achieve mechanical properties above ASTM minimum limit
  - Develop portal die approach for 50 mm round tubing with 1-2 mm wall thickness

- **ShAPE of ZK60 (not yet started)**
  - Adapt portal die for non-circular profile
  - Extrude square 50 mm x 50 mm x 1-2 mm



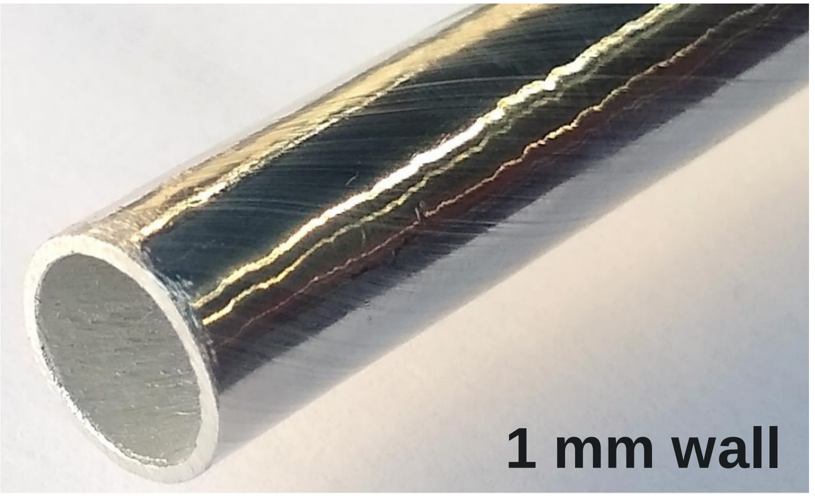
Technical Accomplishments: AA6063 ShAPE Tooling Development

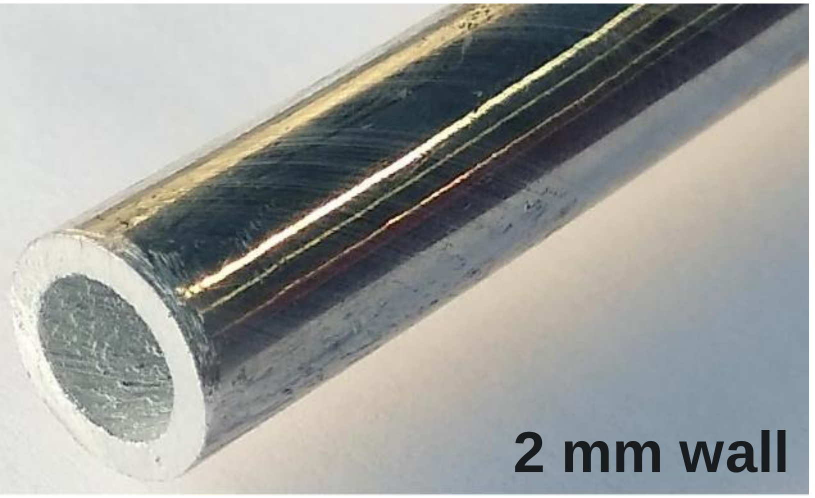


Tooling designed by PNNL and fabricated by Magna

Fixtures, integration, and processing performed by PNNL

Technical Accomplishments: AA6063 ShAPE Extrusion

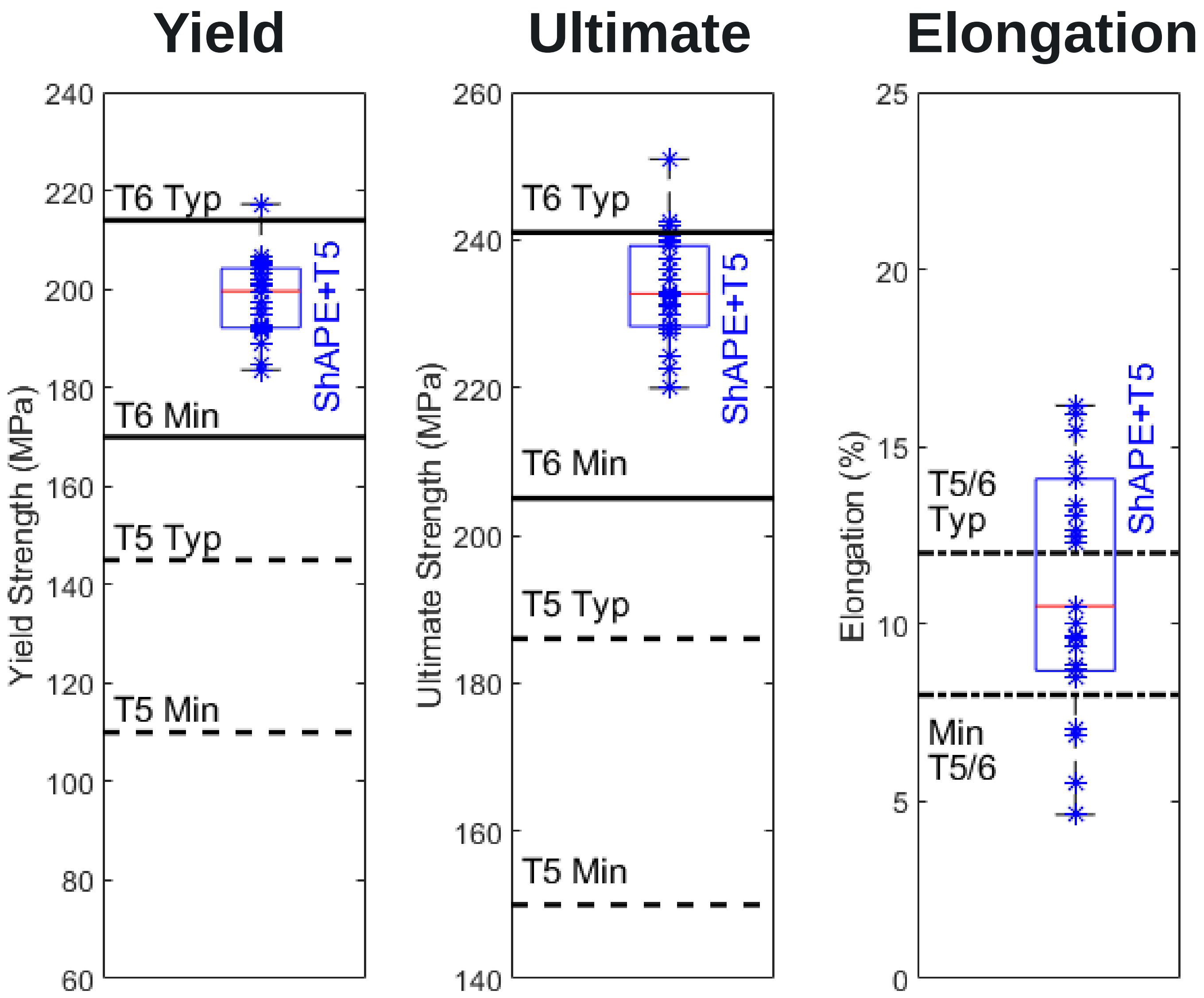


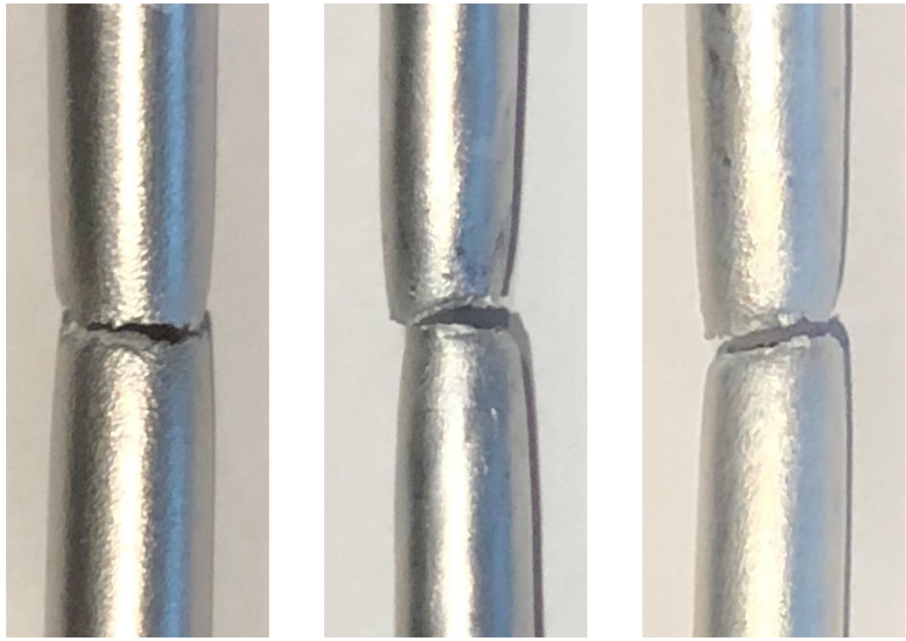


	1 mm wall	2 mm wall
Extrusion Ratio	20.6	11.8
Length	2.1 m	1.2 m
Force	518 kN	381 kN
Temperature	450 ^{o}C	440 ^{o}C
Speed*	7.8 meters/min	4.5 meters/min
Mass Rate*	0.76 kg/min	0.73 kg/min

*Performed at maximum machine press speed of 0.38 meters/min

Technical Accomplishments: AA6063 Mechanical Properties





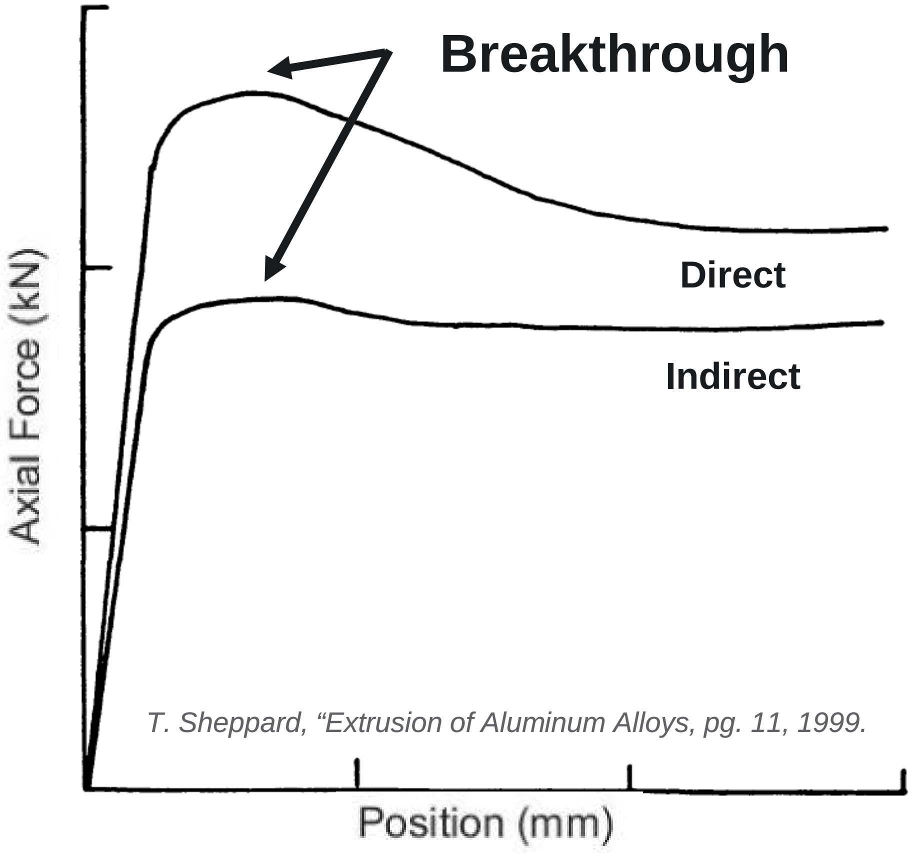
Classic ductile failure mode unaffected by slight twisting of extrusion

Near T6 Properties with T5 Heat Treatment

* ASTM B221M-13, Standard Specification for Aluminum and Aluminum – Alloy Extruded Bars, Rods, Wires, Profiles, and Tubes (Metric) , Table 2
**ASM Handbook, Vol 2b, Properties and Selection of Aluminum Alloys, Typical Mechanical Properties (2011), Table 4-6, pg. 395

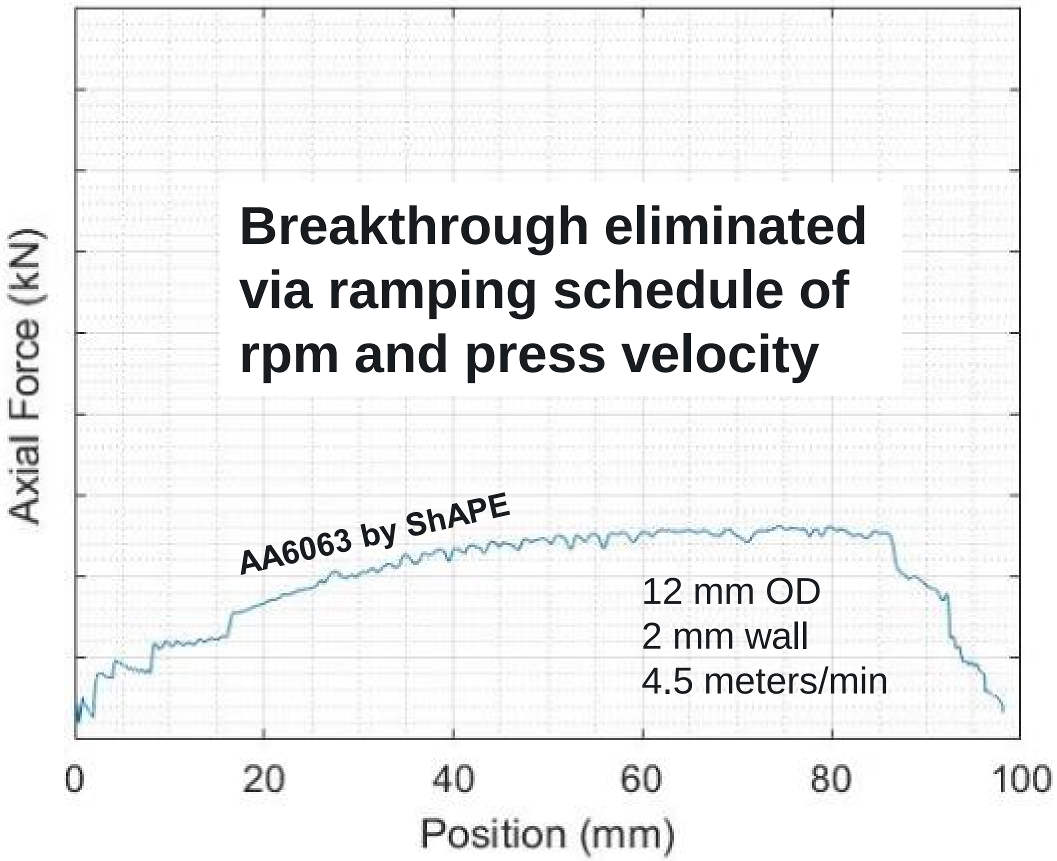
Technical Accomplishments: AA6063 Breakthrough Eliminated

Conventional Extrusion



Breakthrough force is typical and dictates the press capacity

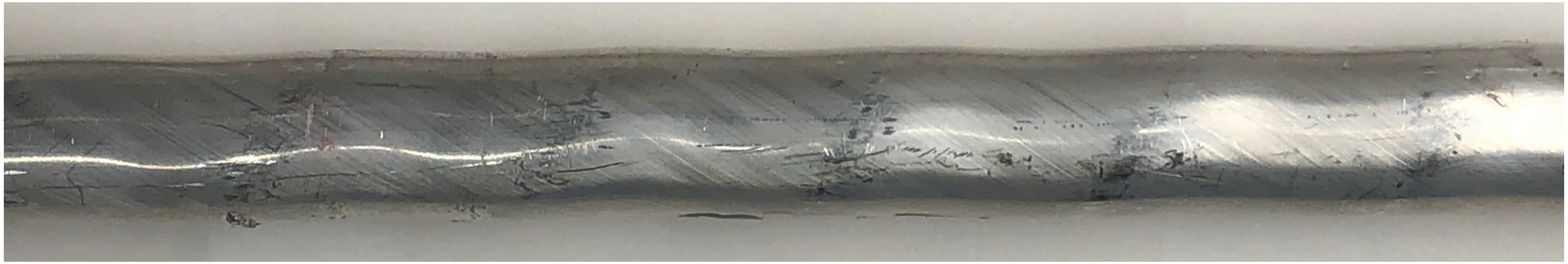
ShAPE Extrusion



Elimination of breakthrough can greatly reduce press capacity

Technical Accomplishments: AA6063 Tool Effect on Surface Finish

Baseline Tool: Twisted with rough surface

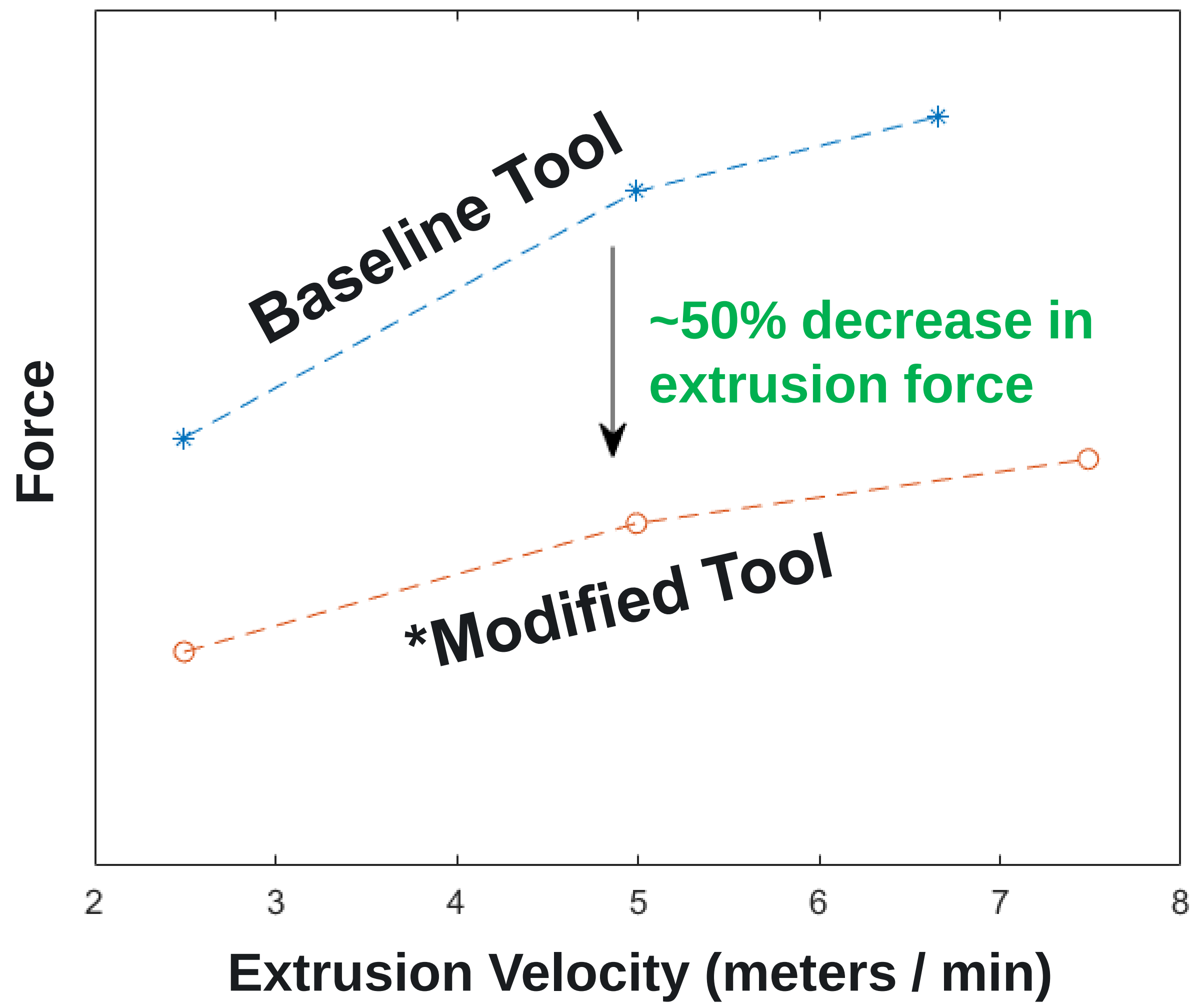


Modified Tool*: Straight with smooth surface

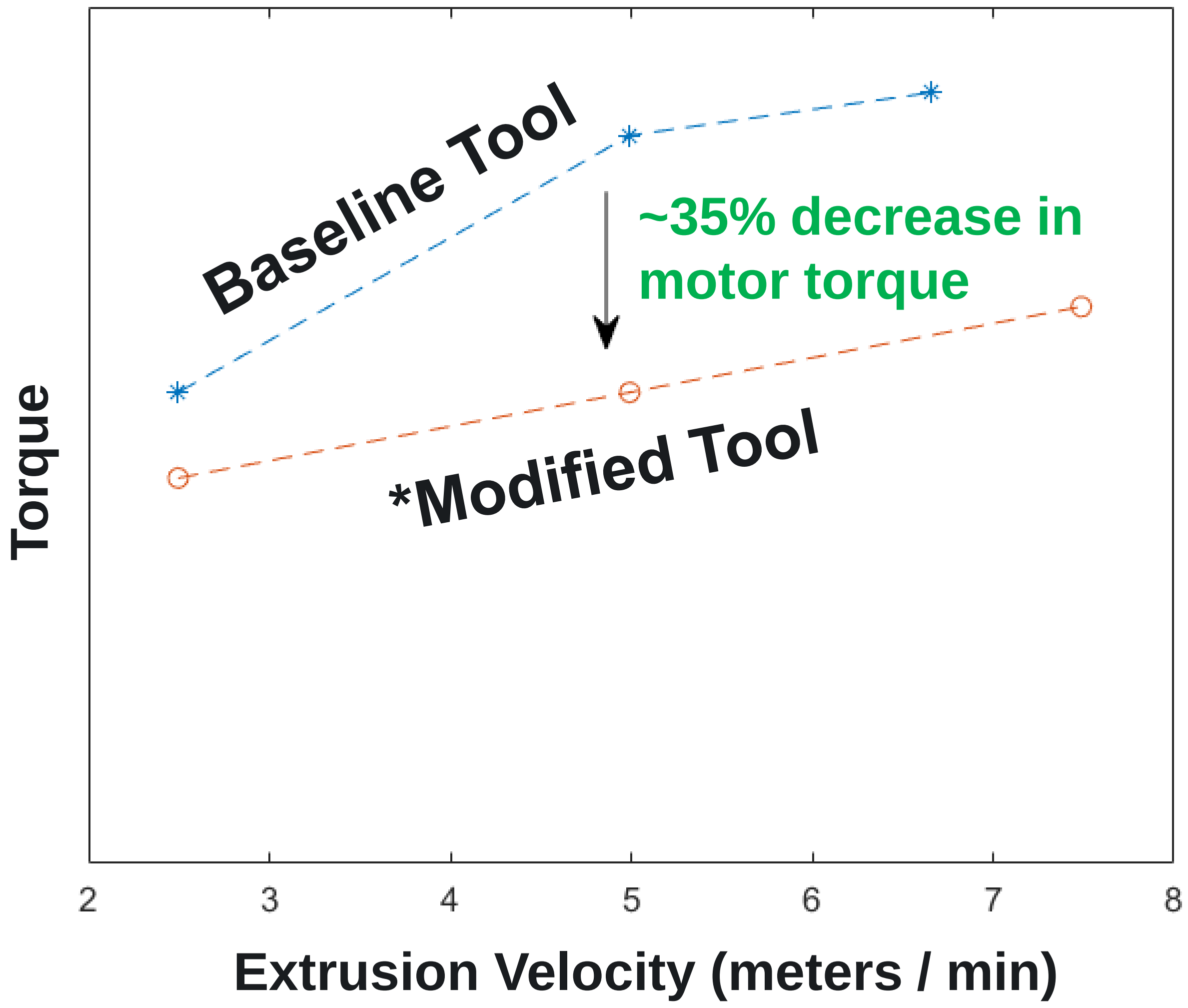
*Specific tooling features not shown due to ongoing intellectual property development

Technical Accomplishments: AA6063 Tool Effect on Process

Extrusion Force



Motor Torque



*Specific tooling features not shown due to ongoing intellectual property development

Response to Previous Year Reviewers' Comments

Reviewer Comment	Response
In order to realize reduction in weight with use of Mg alloys, texture engineering of the Mg is needed to meet energy absorption targets	ShAPE is effective at advantageously aligning basal texture in Mg alloy. Energy absorption of ShAPE extruded ZK60 is equivalent to conventionally extruded AA6061-T6
The design of the port hole die for extrusion is not an easy task and the team is not mentioning how they plan to approach this. The team needs to approach an extruder or engineering firm who are experts on this	Magna is undertaking the portal bridge die design and has the required expertise. A commercial portal die design/fabrication firm will be involved as needed to assist Magna in-house tool & die engineering expertise
It is not clear how the lower cost will be assessed in this project, nor how significant the cost reduction can be	Non-rare earth bearing magnesium alloys, such as ZK60, are over an order of magnitude less expensive than RE bearing WE43
The technology is relevant; however, it would be far more interesting and relevant for automotive if this was an Al alloy project.	The project has been re-scoped to include aluminum

Collaboration

- **Pacific Northwest National Laboratory**
  - Scott Whalen — PM/PI
  - Md. Reza-E-Rabby — Process development
  - Scott Taysom — Tooling and die design
  - Joshua Silverstein — Materials characterization

- **Magna International**
  - Tim Skszek — PM
  - Aldo Van Gelder — PI
  - Massimo DiCiano — Testing and characterization
  - Michael Miranda — Tooling and die fabrication
  - Ketan Choudhari — Extrusion simulation
  - Cangji Shi — Extrusion simulation

Use of Resources

- Utilizing existing infrastructure and knowledge-base associated with ShAPE at PNNL, previously funded by VTO
- Project meetings precede scheduled monthly trials to ensure that experimental objectives align with overall project goals
- Magna present on site at PNNL during monthly experimental trials where 10-15 extrusions are fabricated
- Magna is fabricating all tooling which has greatly accelerated the project

Remaining Challenges and Barriers

- Develop process parameters for extruding AA6063-T5 scrap
- Surface finish acceptable for product applications
- Design and integrate portal bridge die approach with ShAPE

Proposed Future Research

- **FY20**
  - Extrude AA6063-T5 scrap with properties exceeding ASTM standard
  - Optimize heat treat schedule for ShAPE extruded AA6063
  - Design tooling and fixtures for portal bridge die approach

- **FY21**
  - Refine process for extruding AA6063-T5 scrap
  - Implement a portal bridge die approach
    - Extrude AA6063 round tubing with 50mm diameter and <2mm wall thickness
    - Extrude non-RE magnesium alloy with a square/rectangular cross section

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

Summary

- ShAPE tooling and process parameters developed for extruding AA6063-T5 at maximum machine velocity
- ShAPE of AA6063-T5 gave near T6 properties with T5 heat treatment
- ShAPE of AA6063-T5 scrap is next, and offers cost savings compared to typical recycling