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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[2]Magna International, Corporate R&D

BATTELLE **PNNL-SA-162430**

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

Solid Phase
PROCESSING

Overview

Timeline

- Start date: Jan. 2019
- End date: Mar. 2022
- % complete: 72% as of May 2021

Budget

- Total project funding
  - $2,000K (3 yr)
- $1,000K - DOE share
  - $668K spent through May 2021
- $1,000K - Industry share
  - $932K in-kind spent through March 2021

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

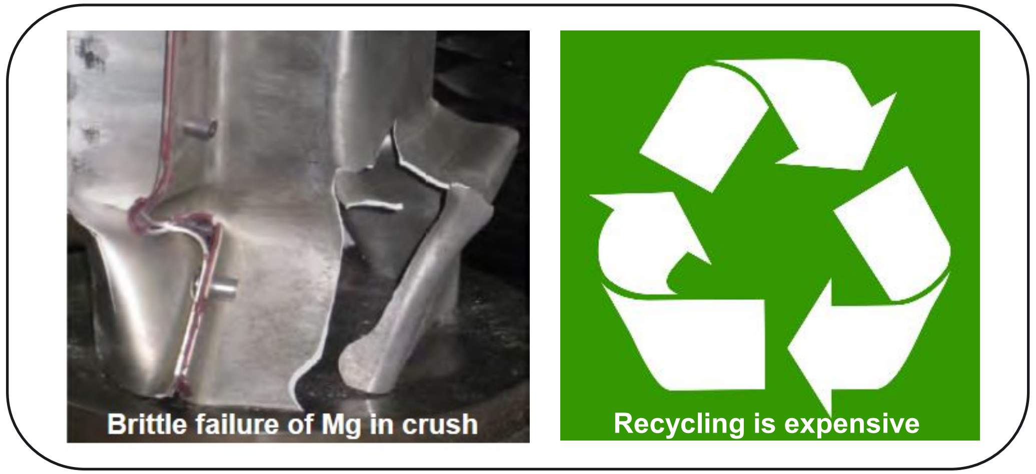
Partners

- Magna International
- Pacific Northwest National Laboratory (PNNL)

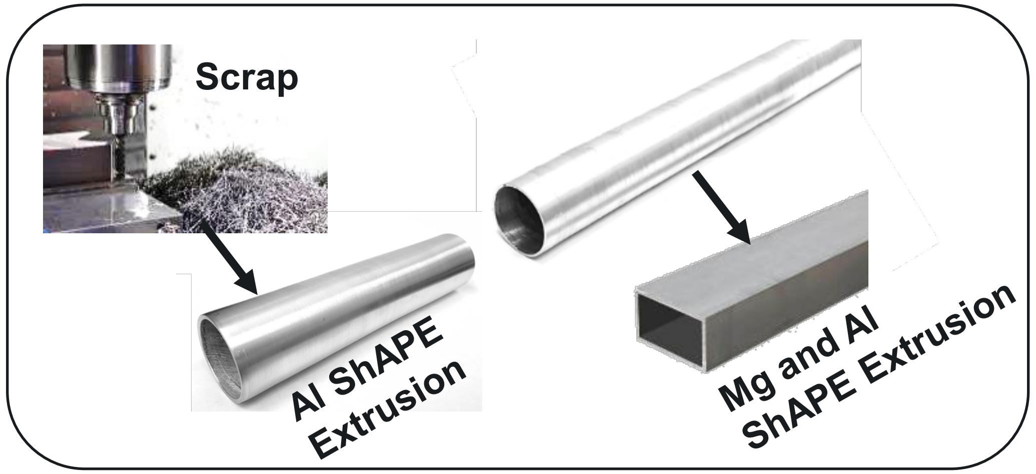
[1] Light-Duty Vehicle Technical Requirements and Gaps for Lightweight and Propulsion Materials: Final Report, Feb. 2013.

Relevance

- **Challenge**
  - Increase energy absorbtion for bumper applications
  - Utilize secondary scrap to reduce carbon footprint and manufacturing cost

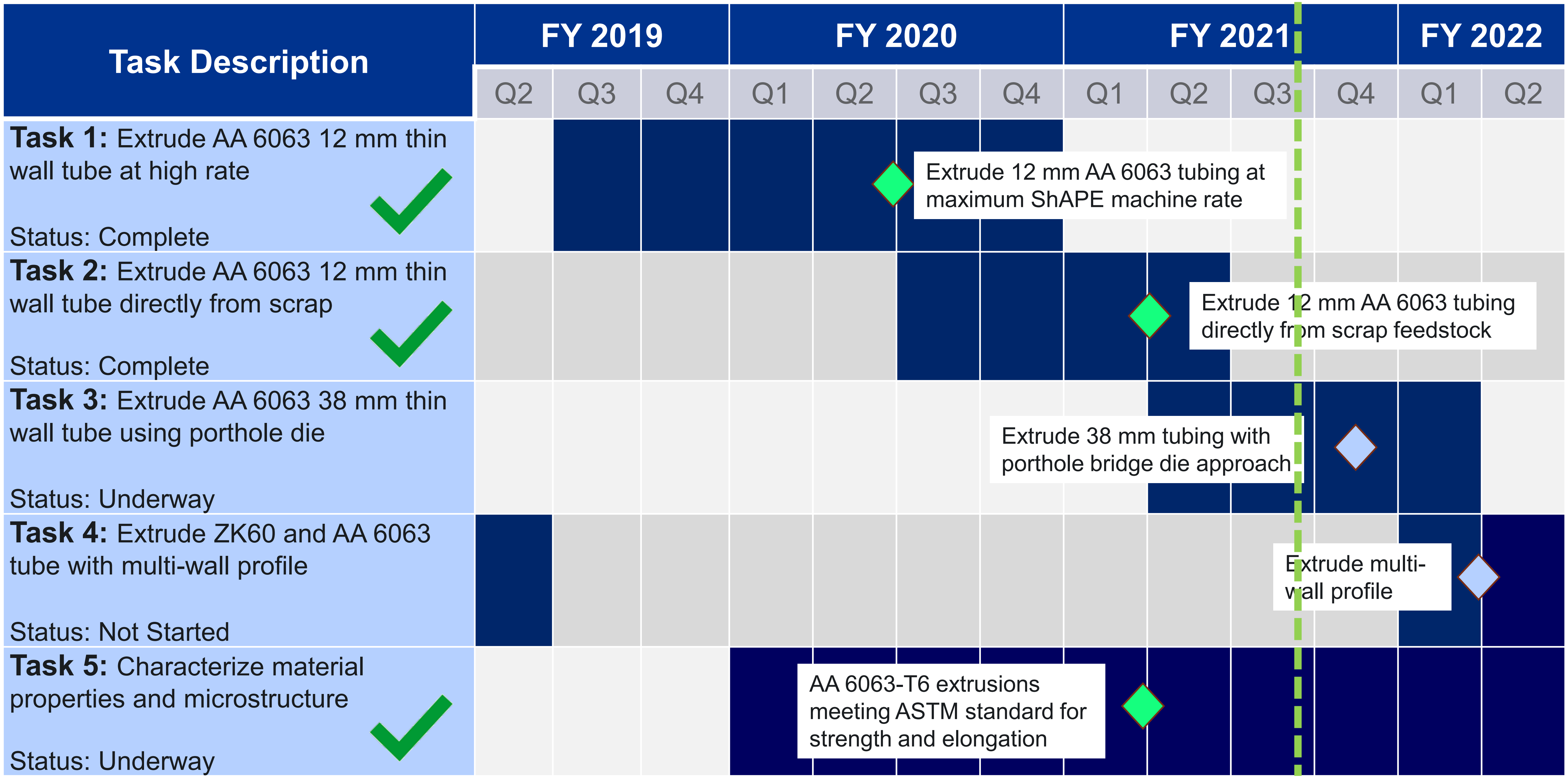


- **Objectives**
  - Convert Al secondary scrap directly into extrusions
  - Increase extrusion speed for commercialization
  - Exceed material property standards
  - Improve energy absorption of non-RE Mg
  - Demonstrate ShAPE for multi-wall profile



- **Benefits**
  - 30% weight reduction possible for Mg components compared to Al
  - Energy and cost reduction for 100% scrap vs. casting + primary

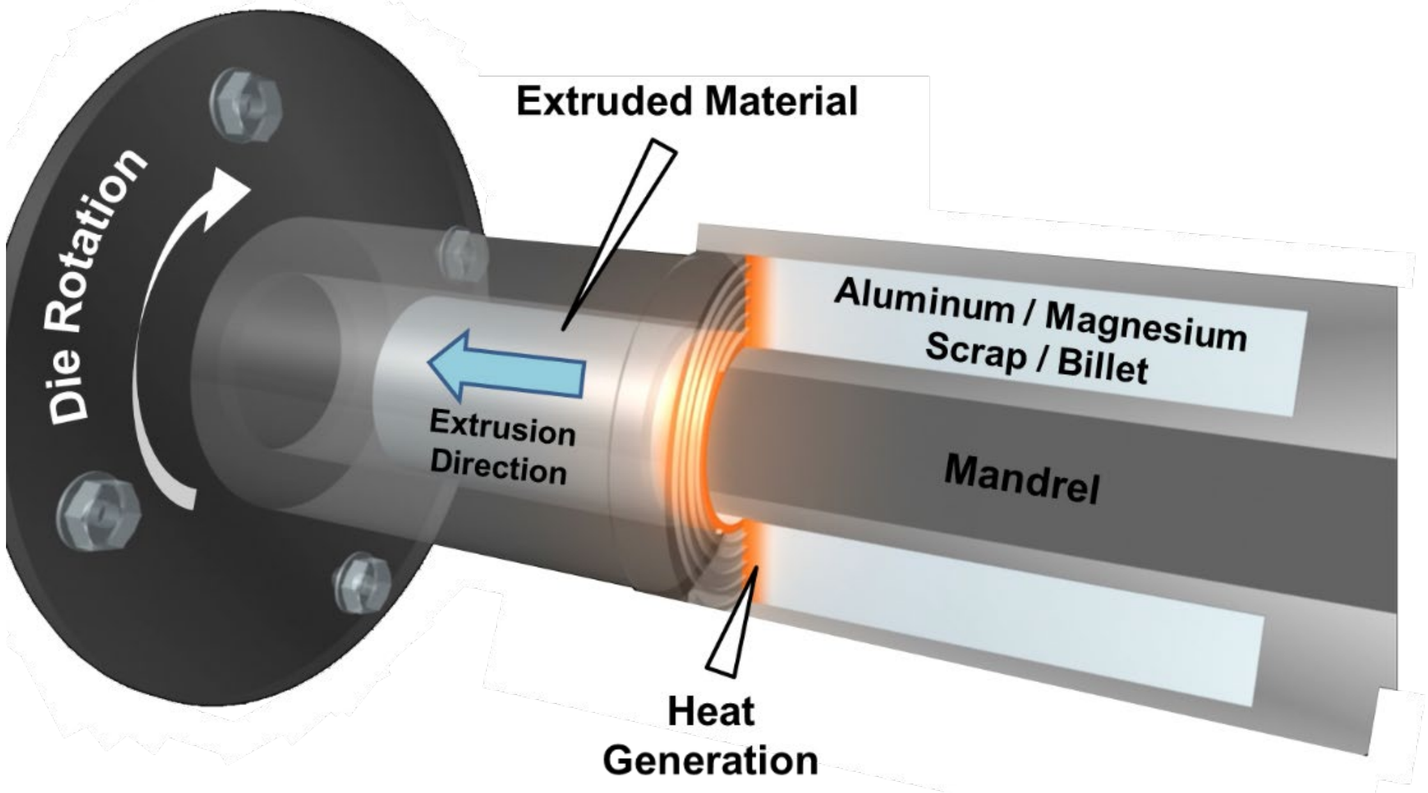
Milestones



Task Description	FY 2019			FY 2020				FY 2021				FY 2022	
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Task 1: Extrude AA 6063 12 mm thin wall tube at high rate ✓ Status: Complete		■	■	■	■ ◆ Extrude 12 mm AA 6063 tubing at maximum ShAPE machine rate	■	■						
Task 2: Extrude AA 6063 12 mm thin wall tube directly from scrap ✓ Status: Complete						■	■	■ ◆ Extrude 12 mm AA 6063 tubing directly from scrap feedstock	■				
Task 3: Extrude AA 6063 38 mm thin wall tube using porthole die Status: Underway									■	■	■ ◇ Extrude 38 mm tubing with porthole bridge die approach	■	
Task 4: Extrude ZK60 and AA 6063 tube with multi-wall profile Status: Not Started	■											■ ◇ Extrude multi-wall profile	■
Task 5: Characterize material properties and microstructure ✓ Status: Underway				■	■	■	■	■ ◆ AA 6063-T6 extrusions meeting ASTM standard for strength and elongation	■	■	■	■	■

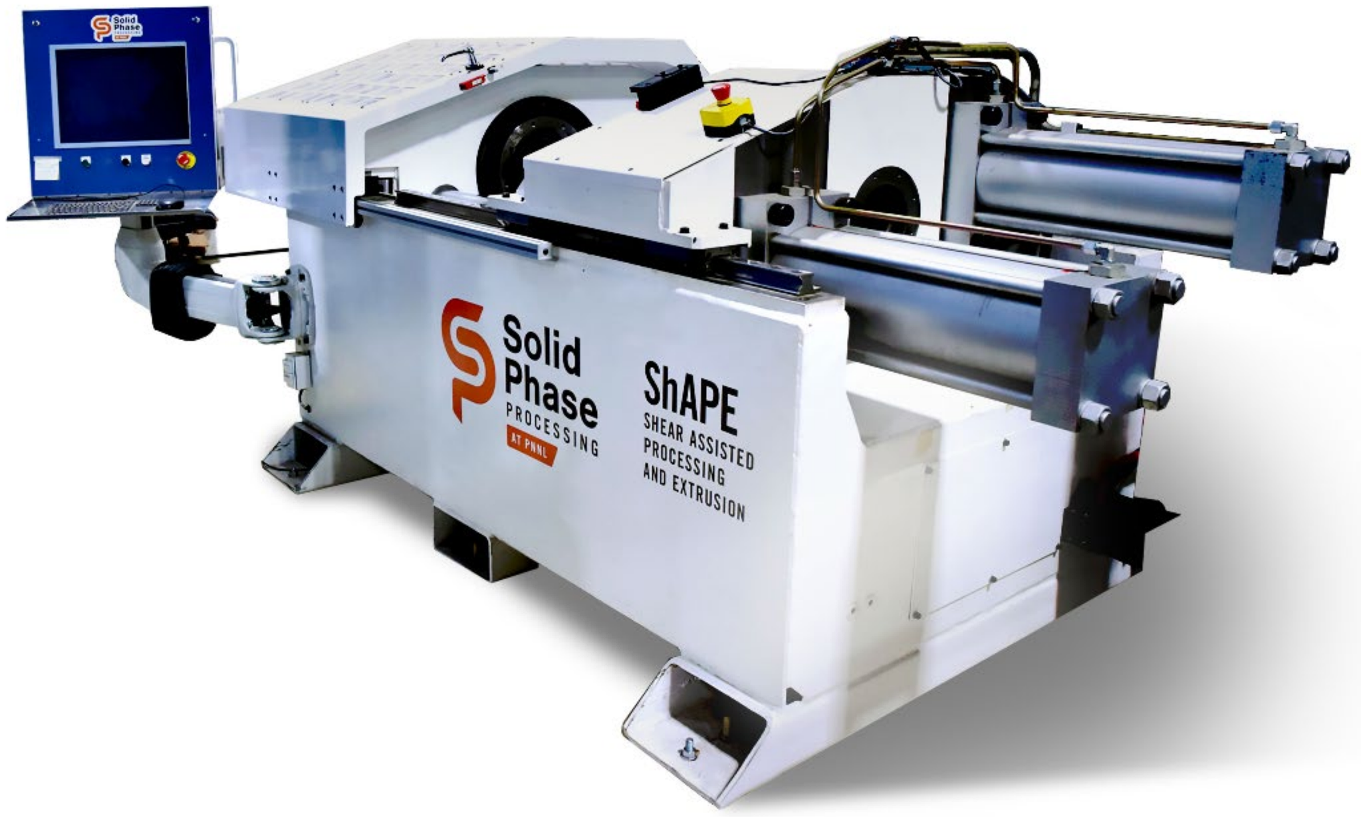
Approach

- **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 can reduce asymmetry in tensile/compressive strength ratio
  - Improved energy absorption
- **Benefit for Aluminum**
  - Consolidation of chips from low-cost secondary aluminum feedstock
  - Repurpose secondary scrap without re-melting and adding primary aluminum



Approach

- **ShAPE of AA 6063**
  - **Feedstock materials**
    - Wrought billet
    - Cast billet (Secondary scrap)
    - Briquette (Chipped secondary scrap)
  - **12 mm OD with 1 mm and 2 mm wall**
  - **Maximum speed and > ASTM properties**
  - **Develop porthole die approach**
    - Circular → non-circular → multi-wall



- **ShAPE of ZK60**
  - Cast billet
  - Porthole die for non-circular profile
  - Achieve maximum feed rate that gives improved energy absorption

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Technical Accomplishments: AA 6063-T5 Wrought Billet Speed and Properties

Solid Phase
PROCESSING

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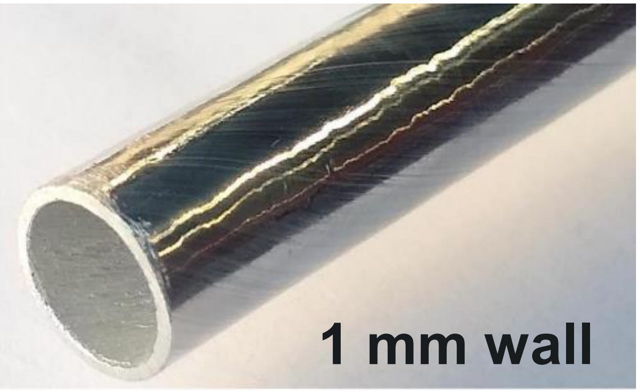
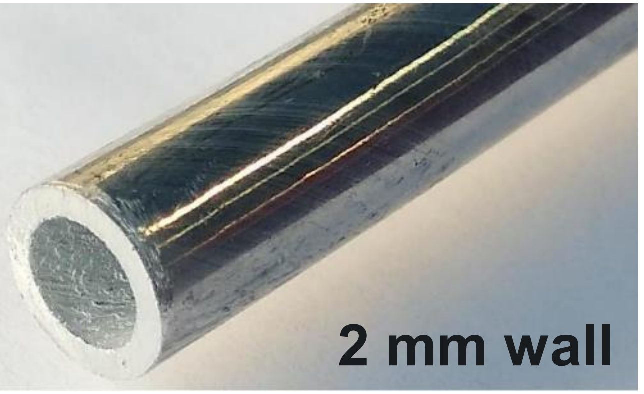
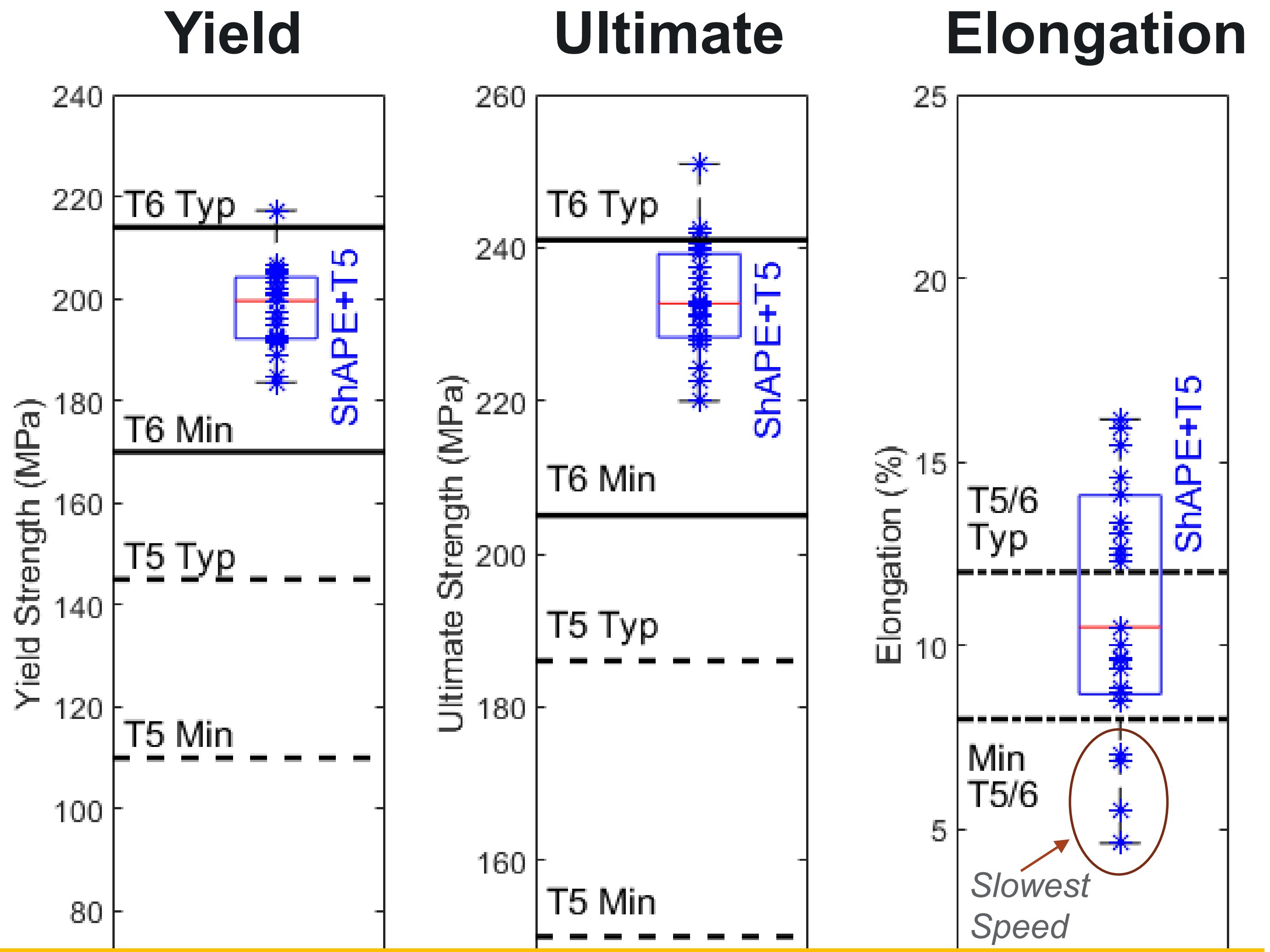




	1 mm wall	2 mm wall
Extrusion Ratio	20.6	11.8
Length	2.1 m	1.2 m
Extrusion Speed	1.7 m/min	3.8 m/min
Process Temperature	440 - 510 C	

T5 = Artificial aging at 177 °C for 8 hr
T6 = ~~Solution heat treat at 520 °C for 1 hr + quench~~
+ artificial aging at 177 °C for 8 hr

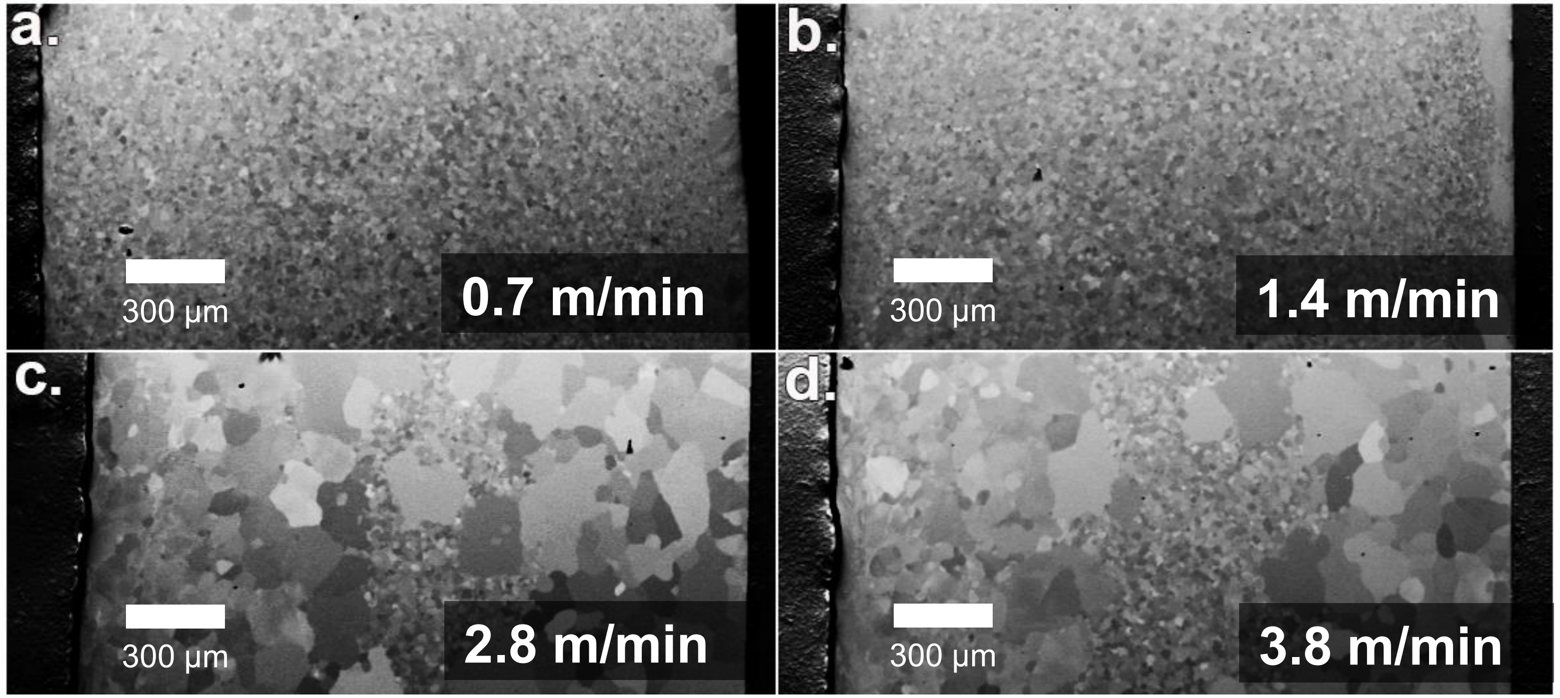
* T5/T6 Min, ASTM B221M-13, Table 2
* T5/T6 Typ, ASM Handbook, Vol 2b, Table 4-6



- ***Achieved T6 Properties with T5 Temper over a range of extrusion speeds and process temperatures***
- ***Energy and cost of solution heat treating is eliminated***

Technical Accomplishments: AA 6063-T5 Wrought Billet Microstructure

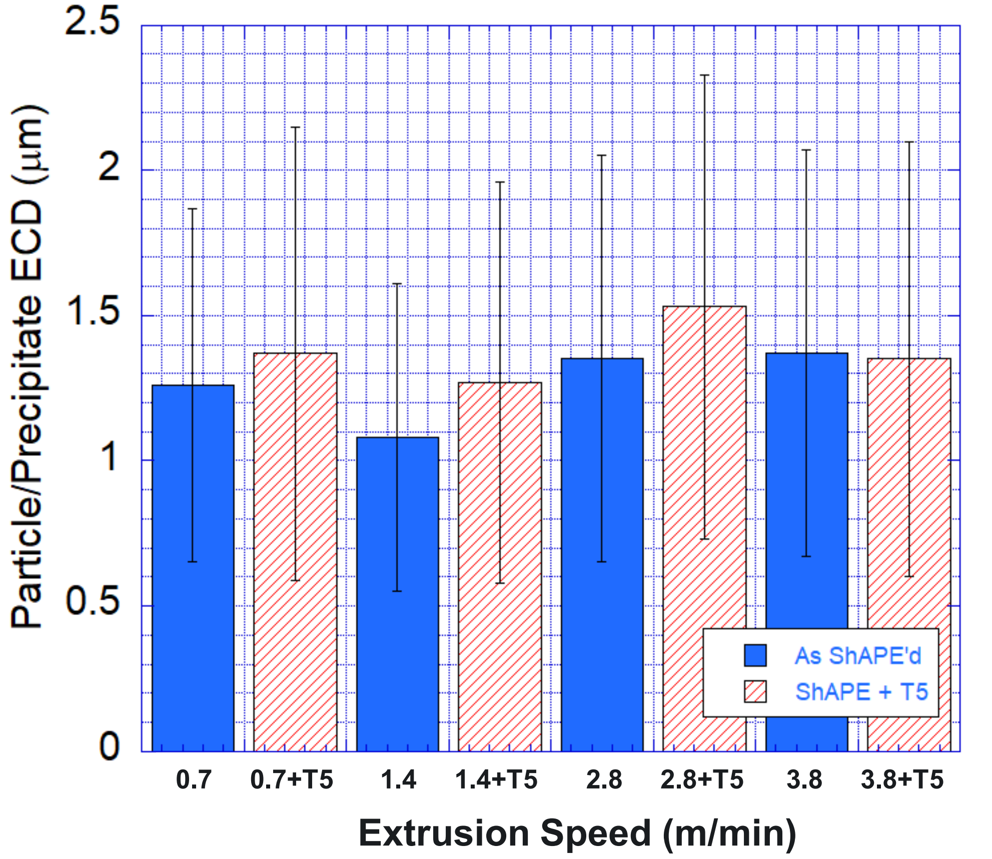
ShAPE As-Extruded Grain Structure



- Considerable growth in the as-extruded, high-speed conditions

- *UTS and YS independent of extrusion speed from 0.7-3.8 m/min*
- *Potential for even higher extrusion speeds with 7.8 m/min having been achieved*

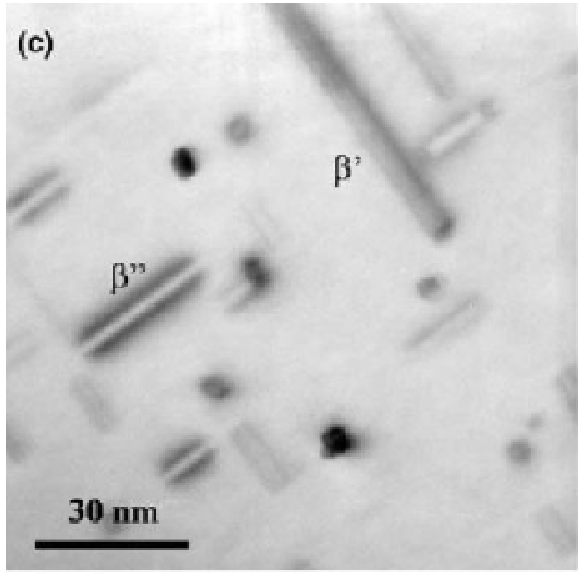
Particle/Precipitate Size vs. Processing Condition



No difference in precipitate size between as-ShAPE and ShaPE + T5 at the SEM scale suggests finer scale precipitates are responsible for strengthening

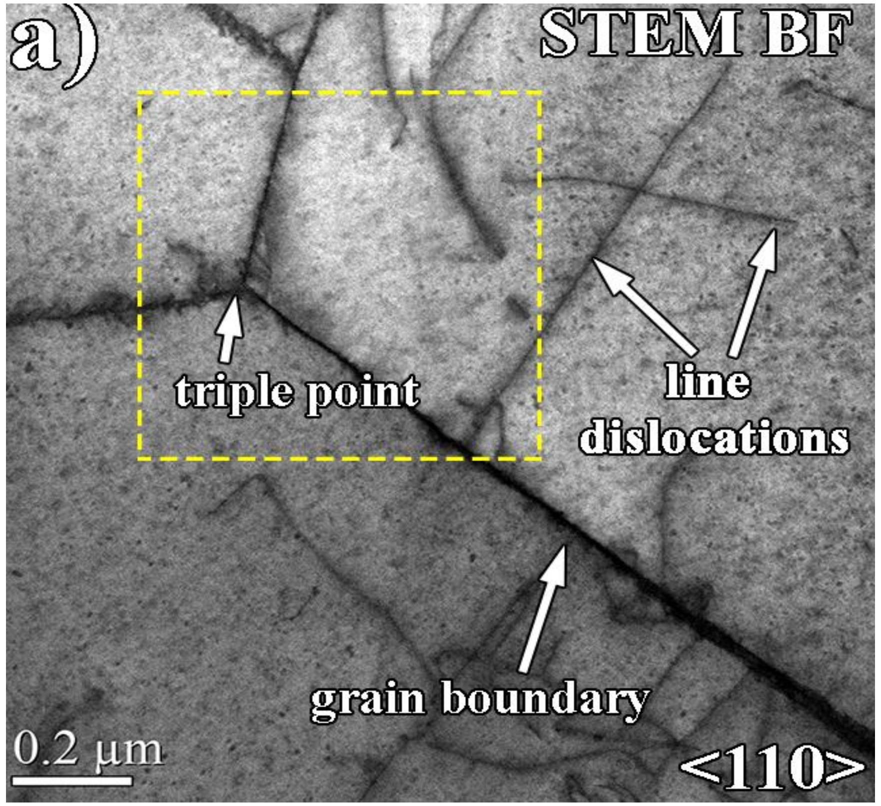
Technical Accomplishments: AA 6063-T5 Wrought Billet Microstructure

β’’needles are the Primary Strengthening Mechanism



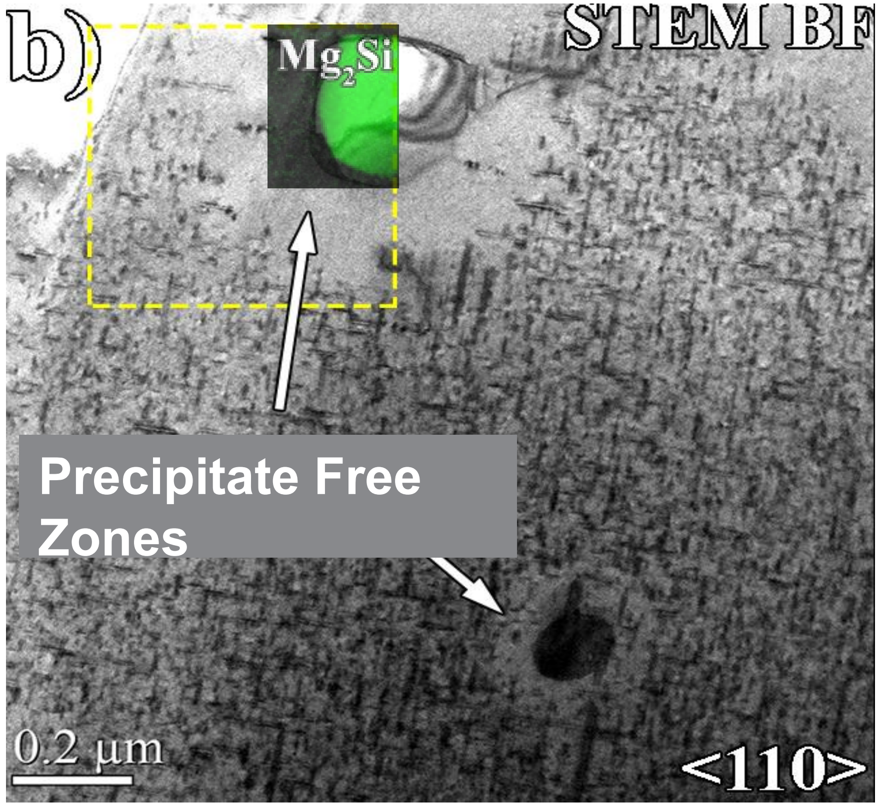
REFERENCE:
R.R. Ambriz and D. Jaramillo (June 11th 2014). Mechanical Behavior of Precipitation Hardened Aluminum Alloys Welds, Light Metal Alloys Applications, Waldemar A. Monteiro, IntechOpen, DOI: 10.5772/58418.

As-ShAPE



- No β-type precipitation is visible
- Solutionizing occurs during ShAPE

ShAPE + T5

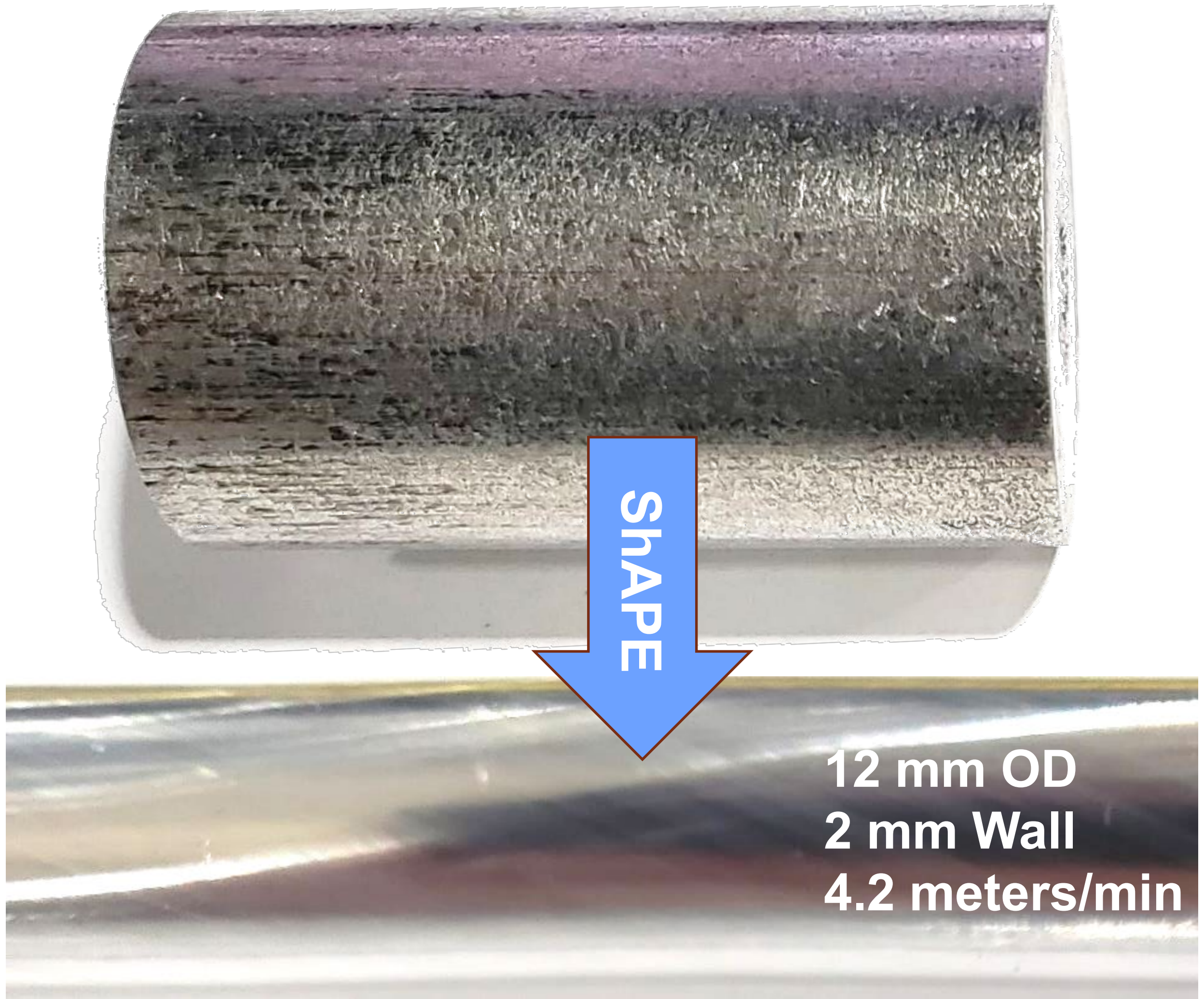


- Significant β’ and β’’ precipitation is observed

- ***ShAPE performs solutionizing in situ due to combination of temperature and extreme shear***
- ***ShAPE + T5 reponds with a mostly peak-aged condition***

Technical Accomplishments: AA 6063 Briquette from Chipped Scrap

Cold compacted AA 6063 briquette from 100% secondary chipped scrap developed by Magna (98% density)



12 mm OD
2 mm Wall
4.2 meters/min

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

AA 6063	Process Temp (°C)	Ultimate Stress (MPa)	Yield Stress (MPa)	Elongation at Break (%)
ASTM/ASM T5	-	150/186	110/145	8/12
ShAPE T5	500	200	156	22
ShAPE T5	510	**210**	**172**	**22**
ShAPE T5	520	184	144	19
ASTM/ASM T6	-	205/241	170/214	8/12
ShAPE T6	510	**231**	**204**	**17**

Briquettes from 100% secondary chipped scrap are a low-cost feedstock and give excellent properties when ShAPE extruded

Technical Accomplishments: AA 6063 Cast Billet from Scrap

- **26 extrusions performed using cast billet made from AA 6063 secondary scrap**
  - Castings made with 0% primary aluminum and various levels of Mg and Fe at Canmet

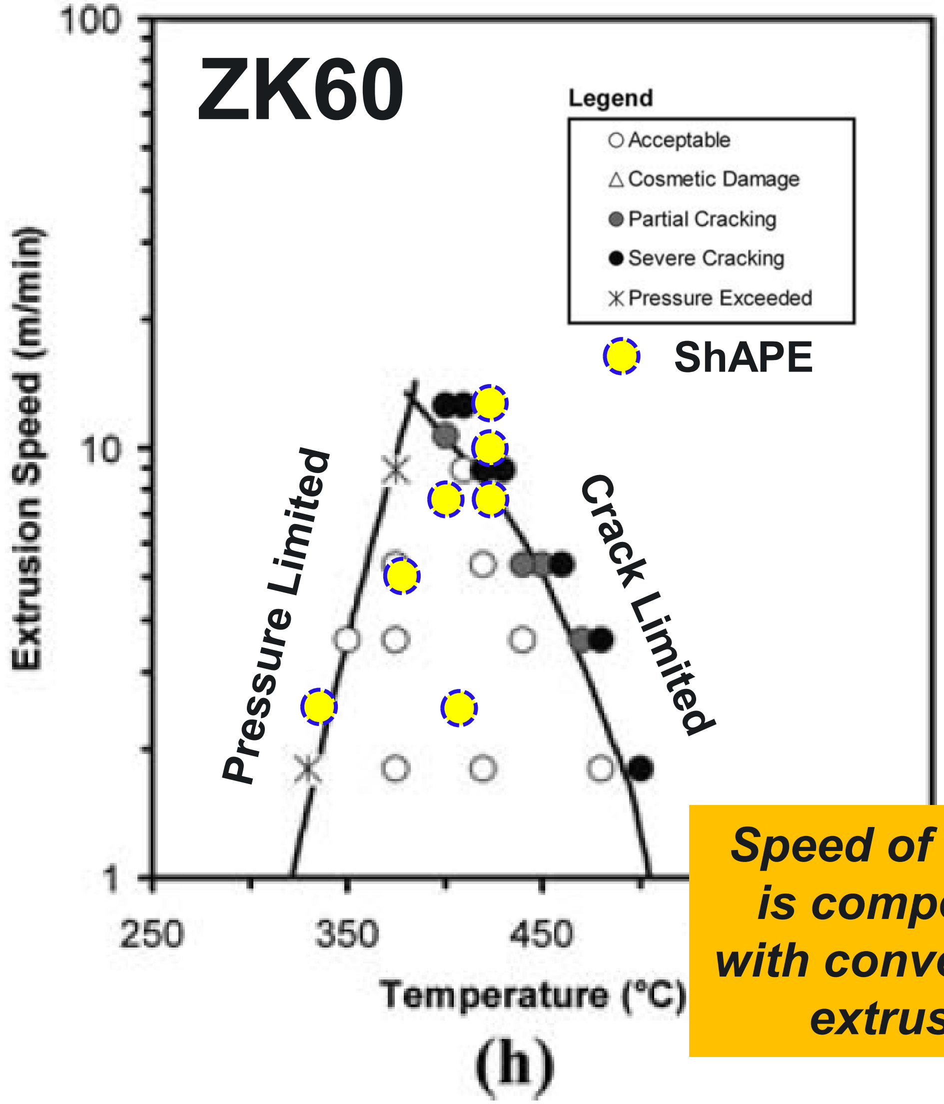
- **Status: Awaiting mechanical test results**

Extruding castings from 100% secondary scrap would:

- *Eliminate the need for primary aluminum*
- *Save 20% energy*
- *Reduce feedstock cost*

Technical Accomplishments: Magnesium ZK60 Castings

Extruded ZK60
2.5-12.2 m/min
2 meters long
330-430 °C die temperature

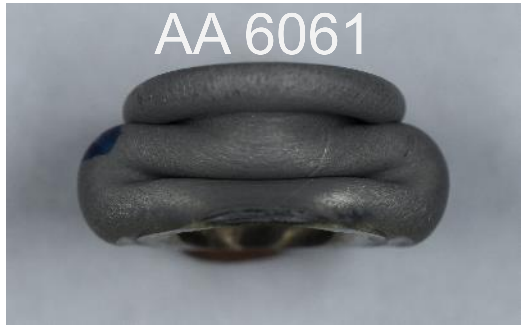


Speed of ShAPE is competitive with conventional extrusion

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

Technical Accomplishments: Magnesium ZK60 and Aluminum 6061 and 6063 Made From Cast Billet by ShAPE

		0.2% YS (MPa)	UTS (MPa)	Elongation (%)	Energy (Joule)	Extrusion Speed (m/min)
Tension	ZK60-T6	271	336	14	-	7.4
	AA 6061-T6	228	313	24	-	7.4
	AA 6063-T6	161	236	23	-	7.4
Compression	ZK60-T6	-	-	-	18	7.4
	AA 6061-T6	-	-	-	56	7.4
	AA 6063-T6	-	-	-	74	7.4



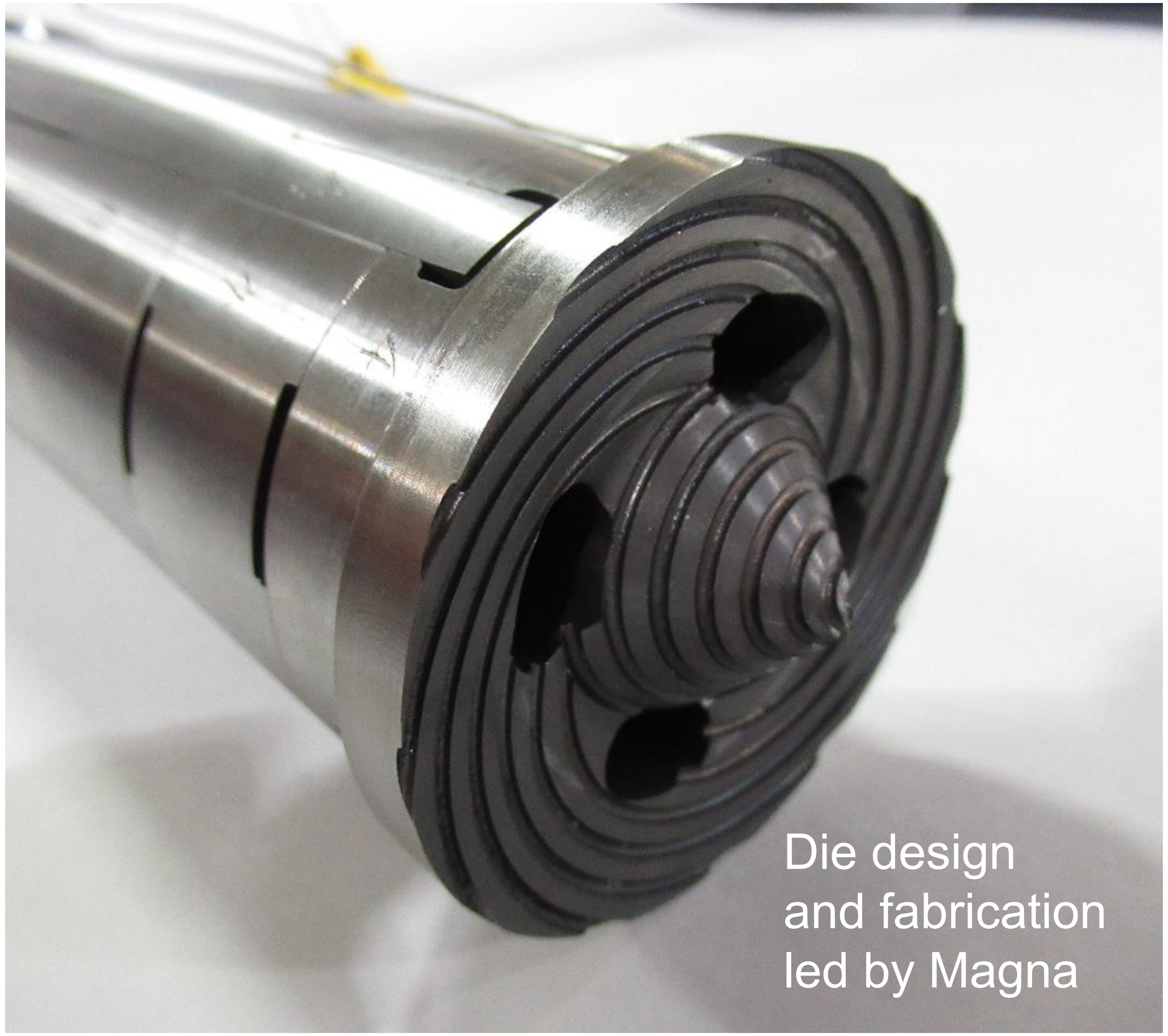
- ***Extrusion speed was too fast to realize energy absorption improvements that were discovered at slow speed** (0.15 m/min)***
- ***We need to determine maximum speed where energy absorption of ZK60 is improved compared to conventional extrusion***

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

Technical Accomplishments: Porthole Die Development

- **Developing porthole dies to enable non-circular multi-wall profile**
  - Collaboration between Magna, PNNL, and Exco
  - First die sets delivered to PNNL for 38 mm OD and 3 mm wall
- **Modeling and simulation tool being developed by Magna to help guide die design**

Porthole die will enable ShAPE extrusions with complex profiles using solid billets rather than just round tubing using hollow/pierced billets



Die design and fabrication led by Magna

Response to Previous Year Reviewers' Comments

Reviewer Comment	Response
Focus is lacking slightly in the omission of typical Al bumper alloys such as AA 6061, AA 6082, of 7XXX alloy.	The industry partners has specific applications for AA 6063 and ZK60. As a result, the project is focused on these two alloys.
There may be a significant risk to the program in shifting from circular AA 6063 extrusions to non-circular ZK60 extrusions without first investigating non-circular AA 6063. Non-circular AA 6063 would be a good addition.	Circular AA 6063 and ZK60 have been now investigated using identical tooling and extrusion process parameters. Non-circular AA 6063 will now also be investigated before ZK60.
There is no technical cost modeling to build a case for a successful result. A technical cost model would strengthen the project.	A robust business case has been developed by the industry partner using detailed technoeconomic analysis using secondary scrap feedstock.
Adding a commercial extruder to the project would expedite development.	A commercial extruder is not consistent with the commercialization plan. However, a commercial die designer is now integrated with the industry partner.
AA 6063 in not relevant to automotive needs.	This industry partner has specific automotive applications for AA 6063.

Collaboration

- **Pacific Northwest National Laboratory**

Scott Whalen	PM/PI
Md. Reza-E-Rabby	Process
Scott Taysom	Tooling
Nicole Overman	Characterization

- **Magna International**

Tim Skszek	PM
Aldo Van Gelder	PI
Massimo DiCiano	Process
Michael Miranda	Tooling
Cangji Shi	Simulation

EXCO
Process Simulation

CanmetMATERIALS
Secondary Cast Billet

Magna has acquired a research use license for ShAPE IP to facilitate commercialization of technology at scale

Remaining Challenges and Barriers

- **AA 6063**
  - Extrudability and material properties are sensitive to Mg and Fe content with conventional extrusion and need to be understood for ShAPE
  - Manufacturing process for cold compacting chips is not fully optimized for density and contamination

- **ZK60**
  - Improved energy absorption must be achieved for ShAPE extrusions at a speed that is cost effective for industry

- **Porthole Die**
  - Integration of a porthole die with the ShAPE process combines many challenges such as die pre-heating, higher machine toque, complex die configuration, and process parameter development

Proposed Future Research

- **FY21 (Q3-Q4)**
  - Optimize AA 6063 briquette and cast billet using 100% secondary feedstock
  - Develop extrusion parameters for higher energy absorption in ZK60
  - Manufacture circular profiles using porthole die approach
    - Extrude AA 6063 and ZK60 with circular profile
    - Round profiles, 38 mm diameter and 2-3 mm wall thickness
- **FY22 (Q1-Q2)**
  - Demonstrate capability to manufacture non-circular multi-wall profiles using porthole bridge die tooling

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

Summary

- **AA 6063 extrusions having T6 properties with only a T5 heat treatment**
  - Eliminates cost and energy of solution heat treating
- **AA 6063 briquette made from 100% secondary scrap chips have been extruded with T5 and T6 properties exceeding ASTM standard**
  - Reduces feedstock cost and in turn cost of extruded components
  - Saves 20% energy compared to casting scrap with added primary Al
- **AA 6063 cast billet made from 100% secondary scrap**
  - Reduces feedstock cost and in turn cost of extruded components, but less so than chip
- **In the process of demonstrating capability to manufacture non-circular multi-wall profiles using porthole die approach**
- **Magna has acquired a research use license for ShAPE IP**