Project ID: mat229

LightMat: Development of a Novel Magnesium Alloy For Thixomolding® of Automotive Components

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This presentation does not contain any proprietary, confidential, or otherwise restricted information. This project is a Cooperative Research and Development Agreement (CRADA), funded by Vehicle Technologies Office LightMAT Consortium. Certain data have been withheld and some data in this presentation have been sanitized for public release

Overview

Timeline/Budget

- Program start: Feb. 2020
- Program end: Sept. 2023

No-cost extension approved due to scheduling conflicts at Leggera Technologies

Barriers

- Mg alloys have insufficient ductility and energy absorption for crash protection
- Lack of low-cost, environmentally friendly magnesium production capability, atmospheres used for handling molten magnesium involve greenhouse gas subject to safety concerns
- Corrosion protection required for new alloys
- Long development time of advanced materials

Budget

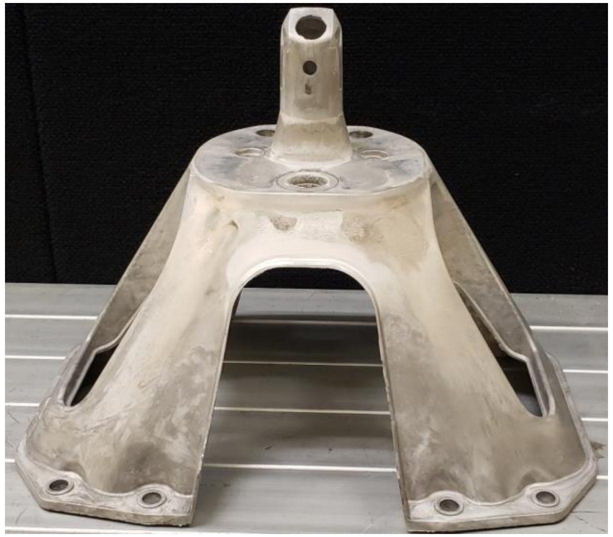
- Total Project Funding: $ 1 M
  - DOE: $500,000
  - Industrial cost share: $500,000
- Funding for FY22: $135,000
- Funding for FY23: $100,000

Partners

- **Lead National Laboratory**
  - Oak Ridge National Laboratory (ORNL)
- **Industrial Partners**
  - FCA US LLC
  - Leggera Technologies
  - Magnesium USA (Terves)

Relevance

- Reducing the weight of a conventional passenger car, battery electric and heavy-duty vehicles by 10% using lightweight Mg alloy components will result in a 6%–8% improvement in fuel economy
- Availability of Mg alloy components with improved energy absorption and ease of manufacturing will reduce barriers for use and accelerate automotive light-weighting
- Alloys with ease of processing, strength, and ductility are needed



Current Wrangler Spare Tire Carrier (Thixomolded® AM60B)

Objectives:

- Develop a Mg alloy with **ease of processing** in Thixomolding®
- New Mg alloy should achieve desired combination of strength and ductility in Thixomolded® components

Background: Thixomolding® Process

- Casting method where the alloy is
  - Heated to 560° to 600° C to the solid + liquid region and sheared until it reaches "dough-like" consistency
  - Injected into a mold
  - Duration of the injection process ~ 0.03 seconds
  - Cycle time - 20 to 45 seconds.
- **Advantages**
  - More uniform structure and lower porosity and/or cavity-free compared to die casting due to **laminar flow** front
  - Fast freezing/cooling rates of > 100°C/s for molded parts
  - Fine grain size and reduced eutectic size
  - Higher ductility and fatigue strength
  - Long die life, due to 80°C cooler metal temperatures than die casting
  - Environmental friendliness, with no open foundry, no SF_6 gas, no sludge or dross - with worker comfort and safety
  - Higher process yield, less scrap
  - Flexibility in part design, down to 0.7 mm thickness

Viscosity decreases with shear rate*

Viscosity Pa s	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}	10^{6}	10^{8}	10^{12}
Non-Metallic Materials		Acetone	Water	Olive Oil	Yogurt	Glycerin	Honey, Ketchup	Chocolate syrup	Molasses, Bitumen				Molten Glass
Metallic Alloys			Liquid Metals		Semi-solid alloys at fs=0.4: $\dot{\gamma} = 200 s^{-1}$					$\dot{\gamma} = 0.001 s^{-1}$			

*Adapted from F. Czerwinski, Magnesium Injection Molding, Springer, 2008

Schematic of Thixomolding® process

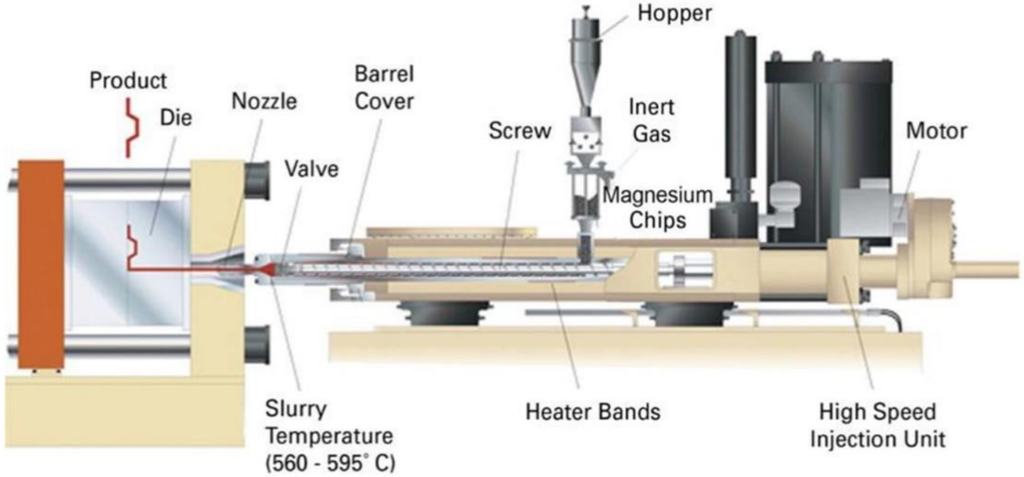


Figure courtesy Leggera Technologies

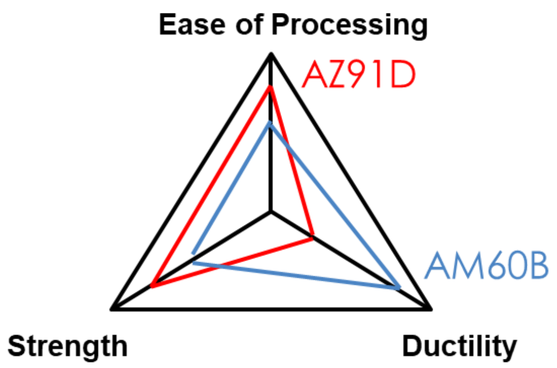
Existing Die Casting Alloys Trade Ease of Thixomolding® For Mechanical Properties

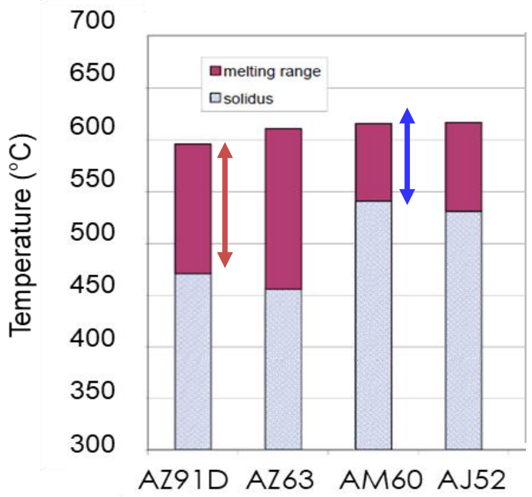
- Existing alloys have been primarily designed for injection molding in liquid state (for die casting)
- Components thixomolded® with die casting alloys do not have balanced properties
  - AZ91D has good processability, high strength, but poor ductility
  - AM60B has good ductility but needs improvement in strength and processing characteristics
- Need to design new alloys with balanced properties for thixomolded® components
  - Increase liquid + solid range to have good control on solid fraction at injection temperature
  - Increase ductility while maintaining or improving strength (e.g. achieve fine grain size)
  - Maintain/improve corrosion resistance

Composition and properties of thixomolded alloys

Alloy	Mg	Al	Zn	Mn	Yield Strength (MPa)	Elongation
AM60B	Bal	6	0.2	0.3	121	16
AZ91D	Bal	9	0.7	0.3	158	6

Melting range of AZ91D is wider and solidus is lower than AM60B*





Target Properties of Desired Alloy

Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Corrosion resistance	Processability
120	180	15-20%	Comparable to AM60B	Similar to AZ91D

*Adapted from F. Czerwinski, Die casting Engineer, Nov. 2004

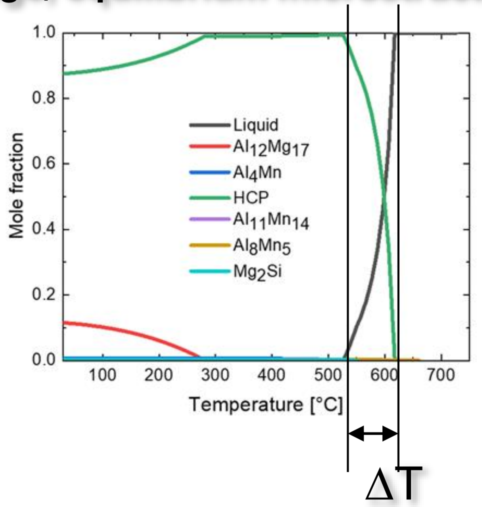
Approach

- Task 1 : Establish required/desired properties using study of baseline component
- Task 2: Alloy development using computational modeling
- Task 3: Alloy ingot and chip production
- Task 4: Produce component tooling
- Task 5: Component production
- Task 6: Material characterization and Computer-Aided Engineering (CAE)
- Task 7: Component evaluation

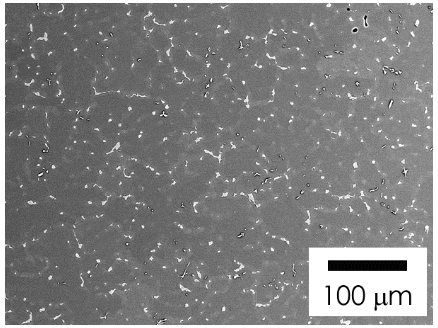
1. Evaluate AM60B component to define mechanical properties (Yield strength, ductility, and ease of processing
2. Use computational modeling to design alloys for target properties
3. Validate properties using laboratory scale heats
4. Evaluate ease of processing
5. Fabricate alloy Ingot and produce chips
6. Fabricate component
7. Evaluate component
8. Evaluate corrosion behavior

Alloy Design Balances Solidification Characteristics with Mechanical Properties

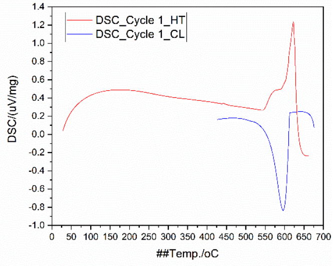
Alloy design using thermodynamic modeling
(Liquidus, solidus, solidification range, equilibrium microstructure)

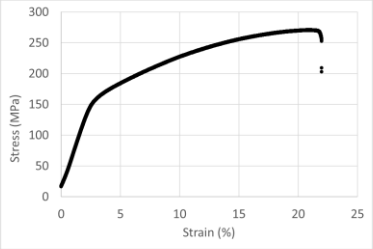


Laboratory Scale Heats
Microstructural Evaluation



Differential Scanning Calorimetry, Mechanical Properties



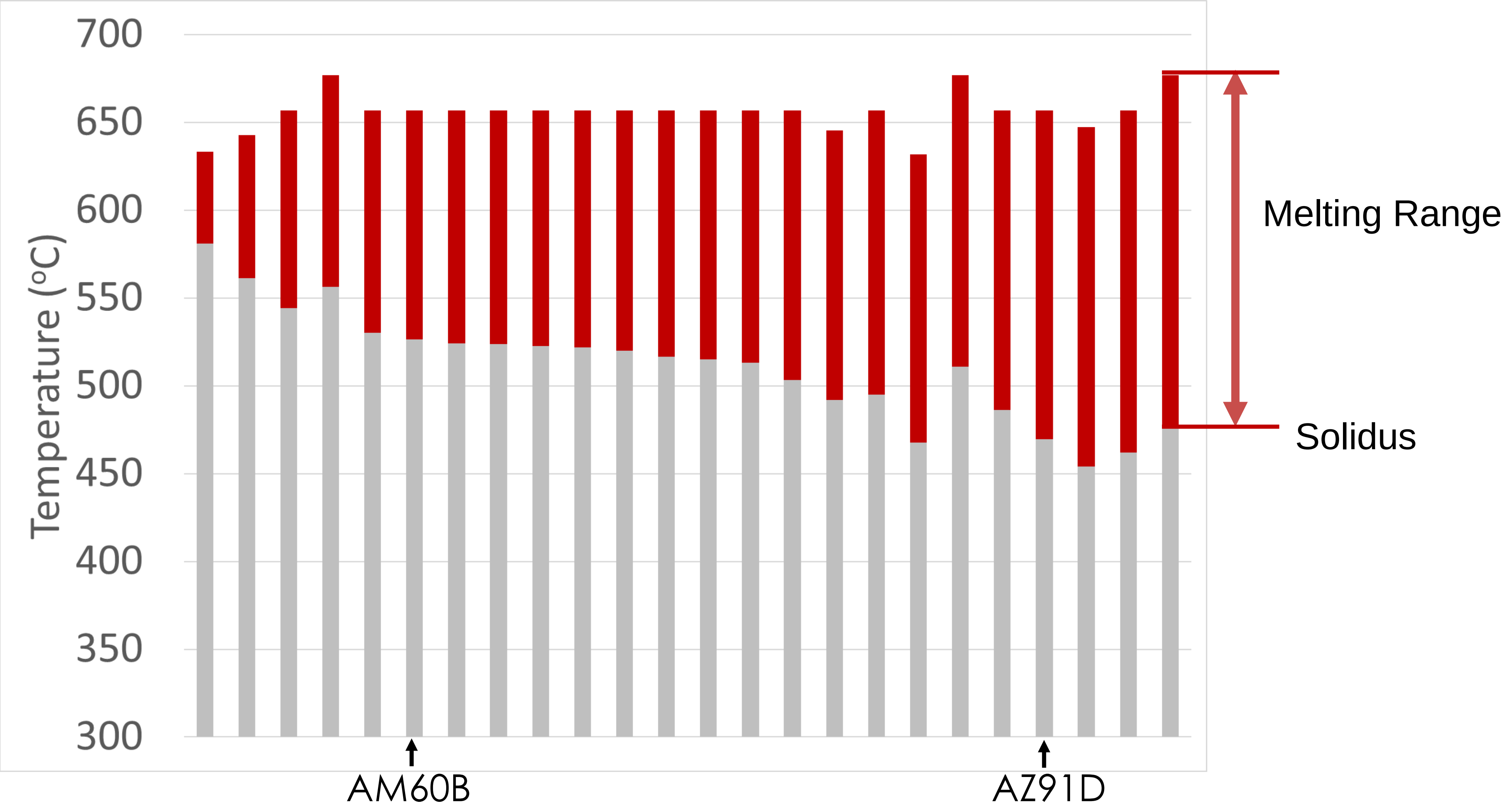


Iterate

FY23 Milestones

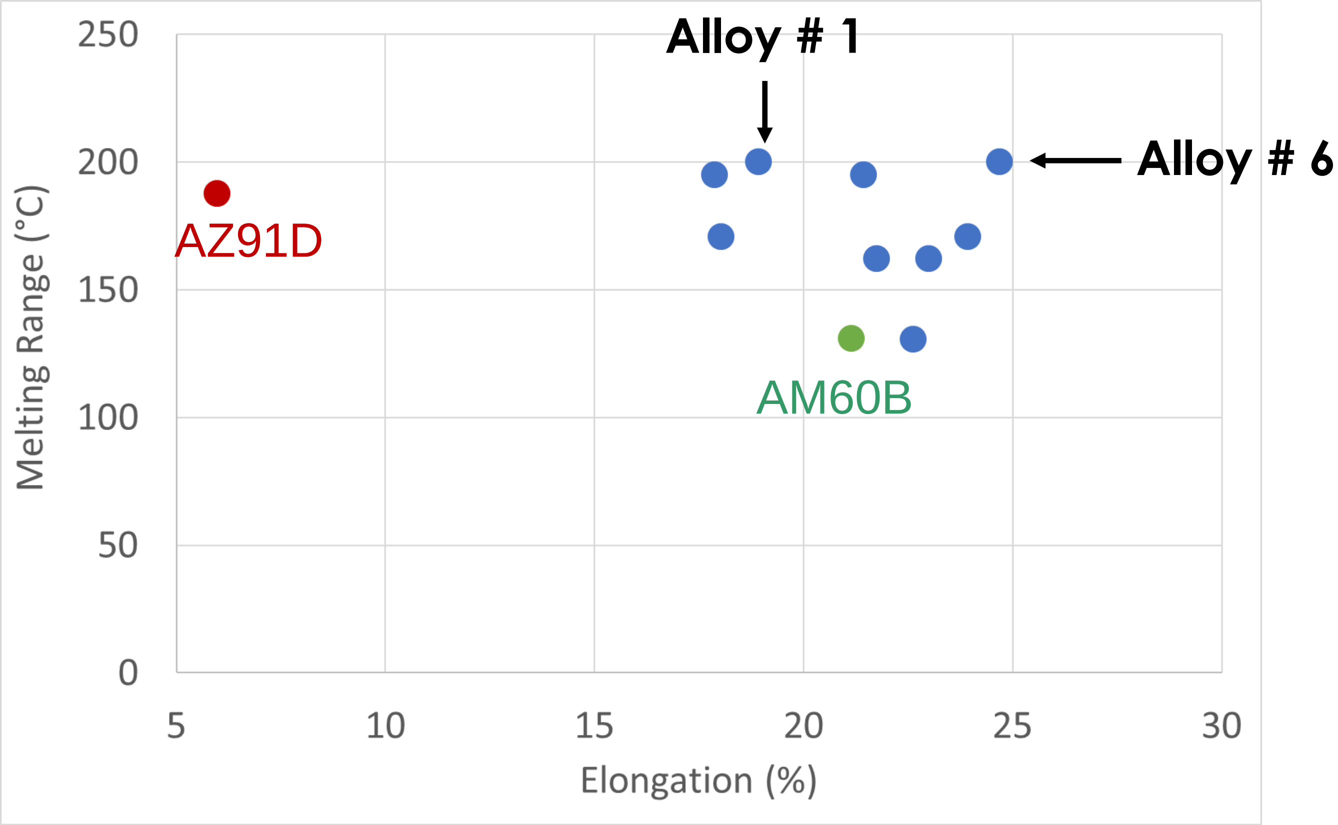
Month/ Year	Milestone Description	Status
March 2022	Complete scale-up of alloy/s	**Completed**
June 2023	Produce component using down-selected alloy/s	**Completed**
Sept. 2023	Evaluate properties of materials from component	**On-Track**

Computational Modeling Used to Identify New Alloys with Melting Range Comparable to AZ91D



Two Alloys (#1 and #6) Were Down-Selected Based Upon Mechanical Properties from Small Laboratory Scale Heats

½” X1” X5” ingots cast at ORNL



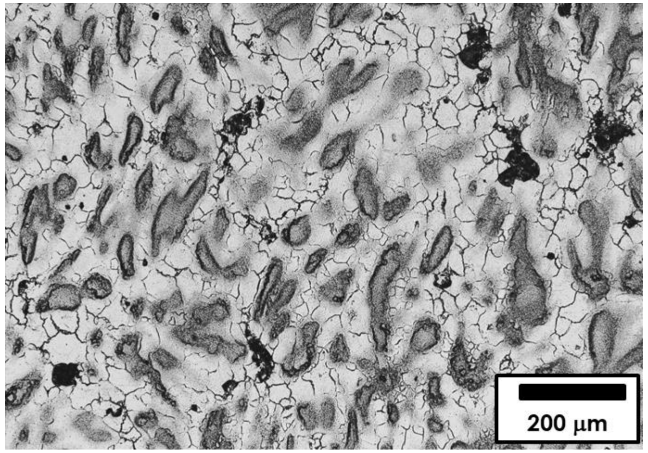
- **Alloy #1** **has calculated melting range similar to AZ91D** BUT **higher elongation to failure than AZ91D**
- **Alloy #6** has **calculated melting range similar to AZ91D** BUT **higher elongation to failure and yield strength than Alloy #1**

Spare Tire Carriers Were Thixomolded® Using Patent-Pending Alloys by Leggera Technologies

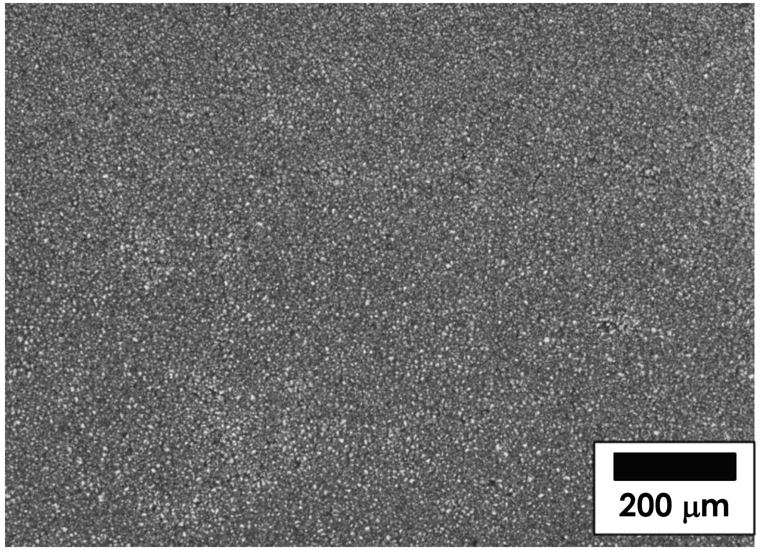
- Process window successfully achieved with **Alloy #1**
- Additional trials will be needed for Alloy #6

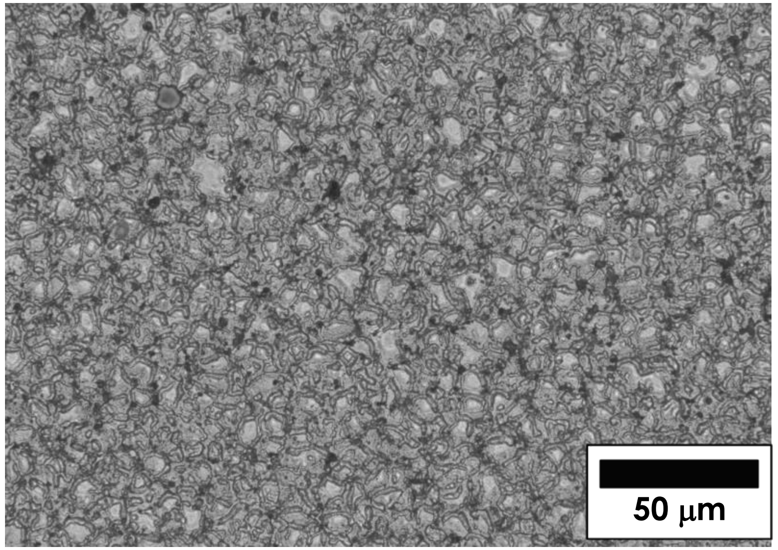
Rapid Cooling During Thixomolding® Results in Fine Grain Structure

Alloy #1
Cast + Warm Deformed



Alloy #1
Thixomolded®

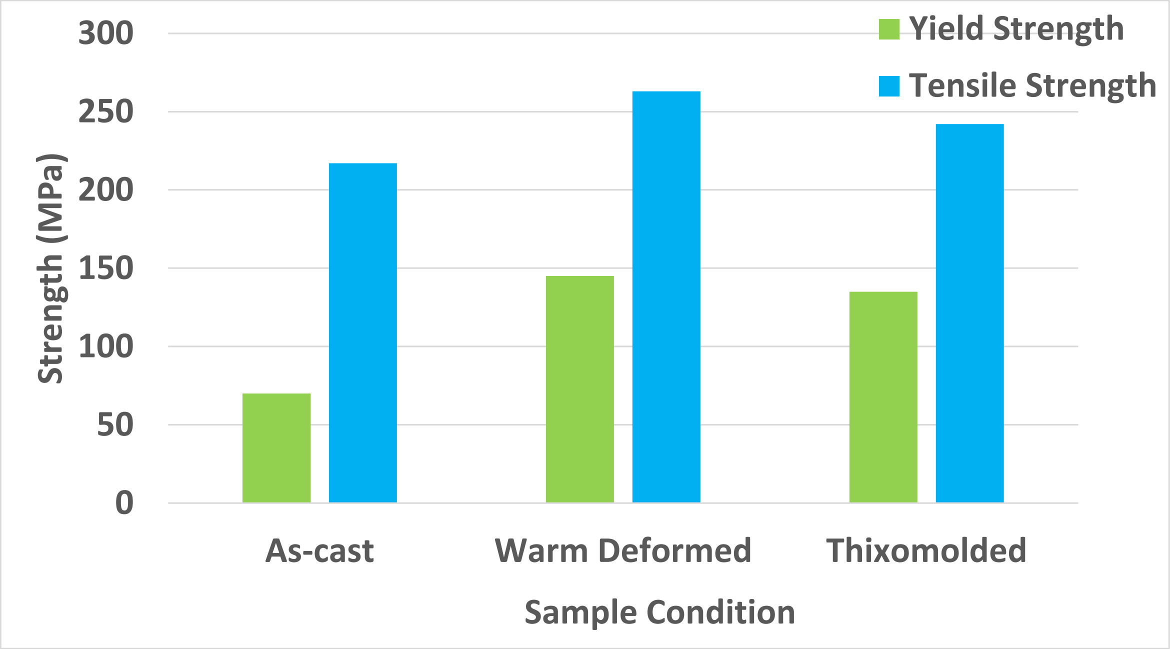




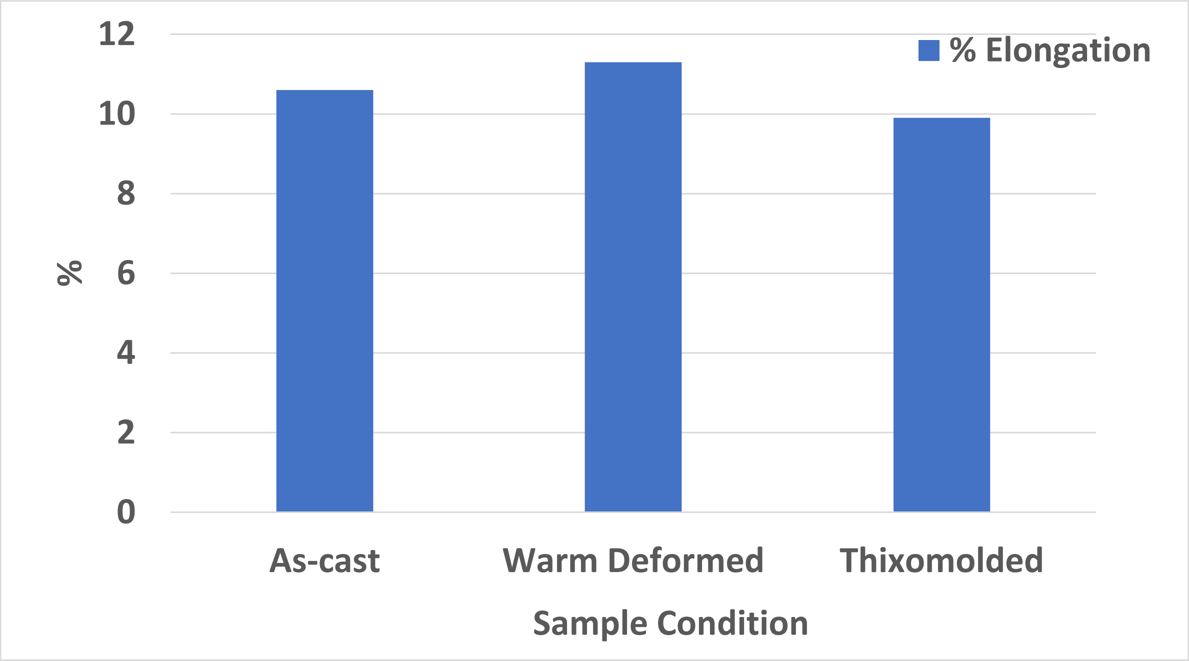
~80% decrease

Thixomolded® Alloy #1 Shows Good Strength and Ductility

Yield and Tensile Strengths

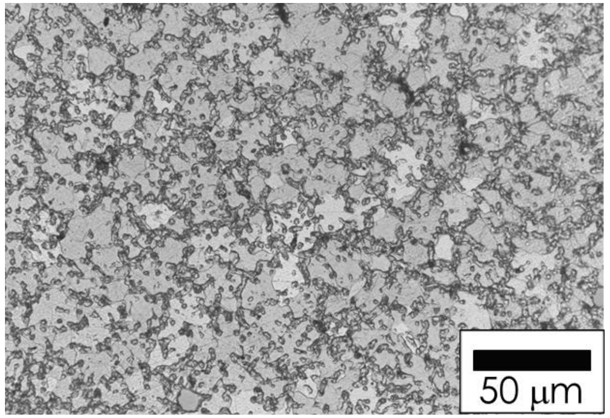


% Elongation

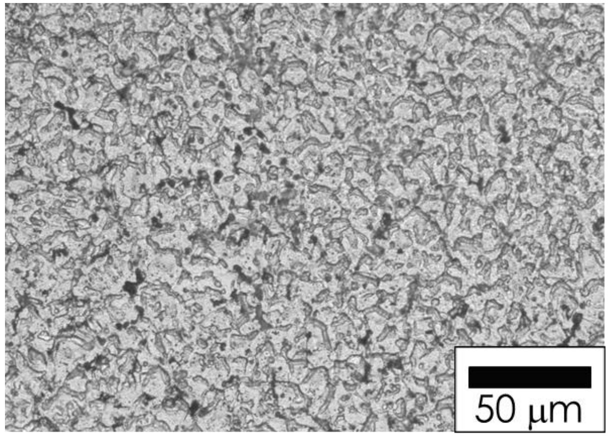


Alloy #1 Shows Finer Grain Structure, Increased Strength, AND Elongation in Thixomolded® Condition Over AM60B

AM60B

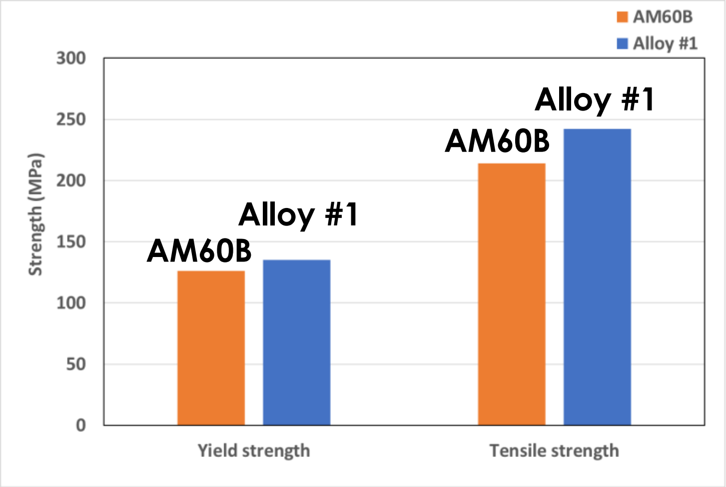


Alloy #1

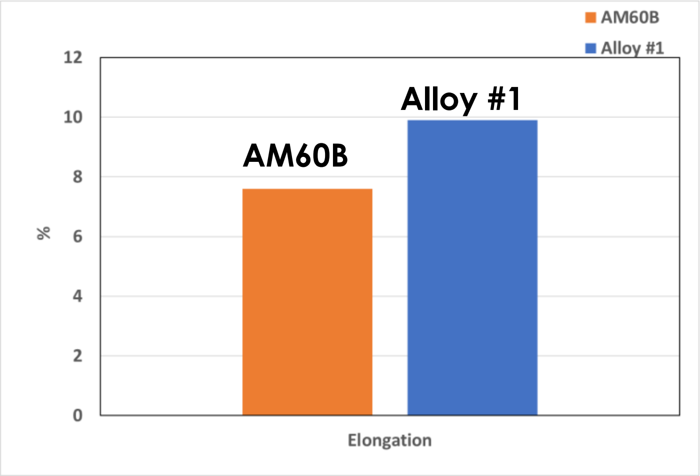


~25% finer

Yield and Tensile Strengths



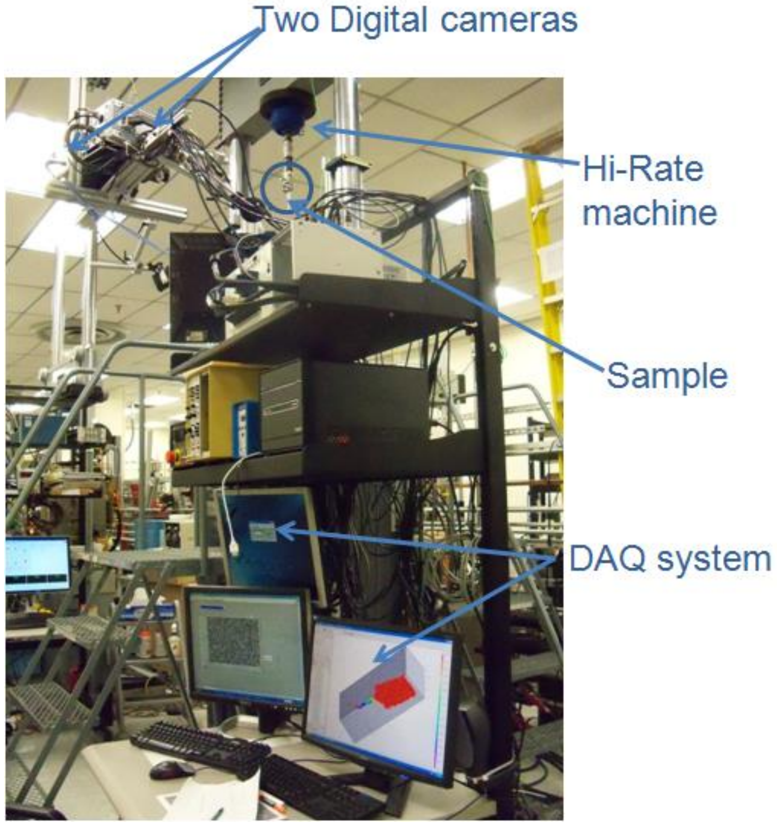
% Elongation



OAK RIDGE National Laboratory

Initial High Strain Rate Measurements Were Completed with Servo-Hydraulic Tensile Machine

High speed digital imaging system
Max. Frame rate: 1,000,000 fps
3D imaging capability for full field-displacement map



Custom Designed Hydraulic System

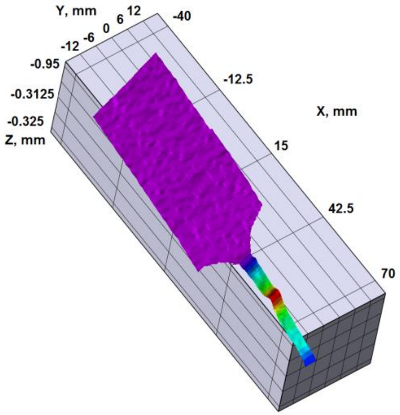
Max Velocity=700 in/s (18.5 m/sec) over approx. 4 in (100 mm) Range

Load Capacity : 9000 lbs (40 kN) static, 5500 lbs (25 kN) dynamic

Total Stroke: 15.5 in (400mm)

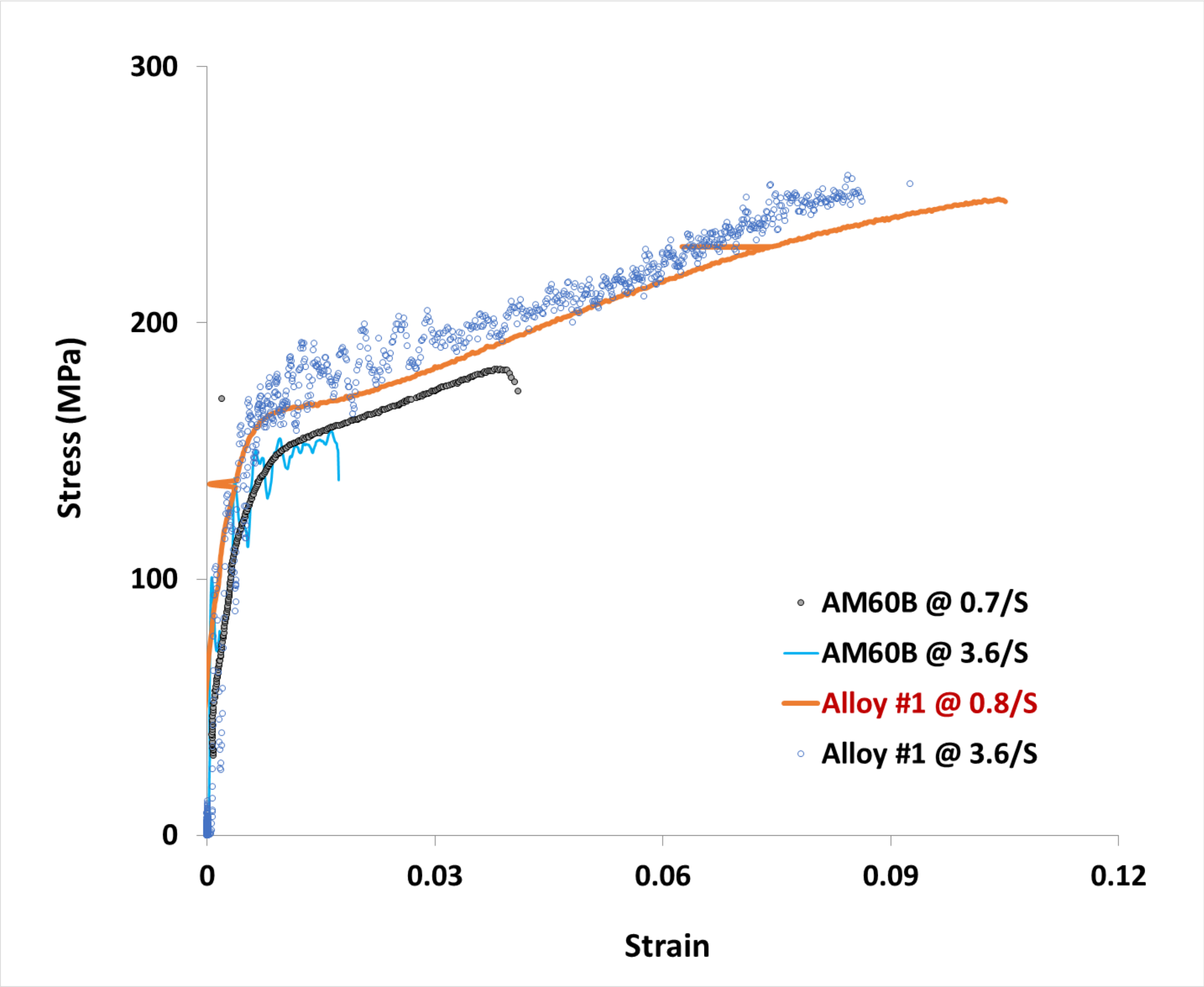
Working Stroke: approx. 7.0 in (175 mm) with slack adapter in the load train

Control: MTS 407 servo - hydraulic controllers, with external command signal (drive file). In-house developed synchronization and DAQ systems.



Control and synchronization of multiple data sources are achieved and it is essential for accuracy at high speeds.

Results from High Strain Rate Testing Show Improved Properties of Thixomolded® Alloy # 1 Over AM60B



AM60B Alloy #1

Response to Reviewers Comments

Comment: According to this reviewer, while the approach to designing the new alloys seems to be clear, the project leaders reasons for choosing extrusion over Thixomolding® to confirm the benefits of the new alloy compositions are not. It is clear that extrusion will yield different results to Thixomolding®
Response: Extrusion was not chosen to confirm the benefits of the alloy. Extrusion was utilized to warm reduce cast billets to an appropriate cross-section to run through a commercial chipping machine. It is not part of the planned production process.

Comment: This reviewer said that the collaboration between ORNL and FCA (corrosion testing) was evident. Less evident are the synergies with Magnesium USA and Leggera.
Response: FCA US LLC and Magnesium USA featured more strongly in the first half of the project centered around alloy requirements, chemistry, and material production. Leggera featured more strongly in the second half of the project centered around Thixomolding® process parameter development, component fabrication, and industrialization.

Comment: A quantitative analysis of the Thixomolding® process parameters impact on part properties such as surface quality, defects, filling, etc. would be an important output as well.
Response: Analysis of process parameters would be of significant interest. Due to raw material on this project being limited to 500 kg per alloy, a comprehensive development of process parameters was not feasible. Such a development would be of interest for future projects.

Comment: This reviewer thought that corrosion testing on prototypical specimens, as opposed to just coupons, will be prudent.
Response: Corrosion testing on prototype parts is included in the project scope and timeline and is currently underway

Collaborations and Coordination with Other Institutions

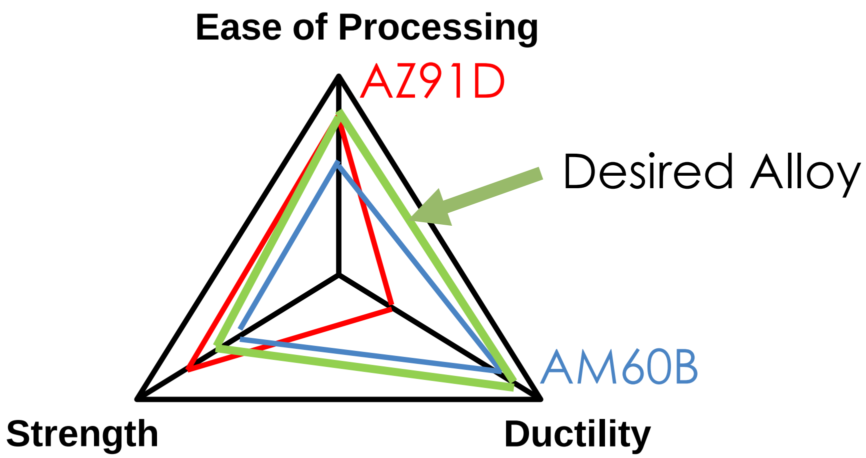
COLLABORATIONS

- **Oak Ridge National laboratory: National Laboratory partner**
  - Evaluate microstructure and properties of base alloy obtained from component
  - Computational development of new alloys
  - Alloy property data development
  - Evaluate properties of new alloy obtained from prototype component
- **FCA US LLC: Project Lead**
  - Provide guidance on property requirements
  - Lead down-selection of alloy, ingot and chip production
  - Corrosion testing
  - CAE card development
  - Prototype component design and evaluation
- **Magnesium USA**
  - **Magnesium alloy scale-up (casting and extrusion)**
- **Leggera Technologies**:
  - Provide guidance on values of important process variables
  - Provide baseline component for evaluation
  - Supply baseline material for evaluation and alloy development
  - Supply tooling and develop process for manufacturing prototype component using novel alloy
  - **Manufacture prototype component**

Remaining Challenges and Barriers

- Improvements in strength and ductility have been achieved with the new alloy.
  - Additional improvements can be achieved by optimizing process parameters that enable a greater solid fraction during the Thixomolding® process.

- Further process development is necessary to produce prototype parts using Alloy #6.



Proposed Future Research

- Complete ASTM G85 Annex 2, cyclic acidified salt spray test of samples removed from the Thixomolded® part at FCA US LLC

- Complete additional high strain rate testing of materials obtained from the Thixomolded® part at ORNL

- Complete electrochemical evaluation of Alloy #1 at ORNL

Prototype Wrangler Spare Tire Carrier (Thixomolded ® New Alloy)

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

Summary

- **Relevance:**
  - Reducing the weight of a conventional passenger car, battery electric and heavy-duty vehicles by 10% using lightweight Mg alloy components will result in a 6%–8% improvement in fuel economy
  - Thixomolded® components have finer grain size, higher ductility, and lower porosity than die cast components
- **Approach/Strategy**:
  - Existing die cast alloys are not ideally suited for Thixomolding® process
  - Alloys with optimum combination of ease of processing, strength, and ductility are needed
- **Accomplishments:**
  - Tire carrier was successfully Thixomolded ® using a patent pending alloy
  - Strength and ductility of new alloy **without rare earth elements** exceeds current baseline alloy
- **Collaborations:**
  - This work is a CRADA between Oak Ridge National Laboratory, FCA US LLC, and Legerra Technologies
- **Proposed Future Work:**
  - Property testing of materials removed from Thixomolded® part will be completed