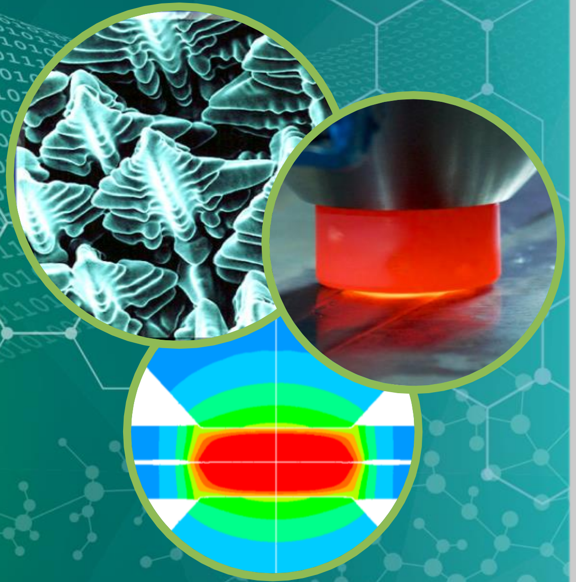
Oak Ridge National Laboratory

Project ID: Mat177

Lighter and Stronger Aluminum Matrix Composites for Powertrain Applications*

** Subtask 5C under the Powertrain Materials Core Program (PMCP)*

2020 DOE Vehicle Technology Office Annual Merit Review



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Project Overview: Lighter and Stronger Aluminum Matrix Composites for Powertrain Applications (PMCP Thrust 5, Subtask 5C, 1-year Exploratory Project)

Timeline/Budget

- Project start: April 2019
- Project end: May 2020
- Percent complete: 85%
- Total Project Budget: $100k
    - ORNL: $100k

Barriers

- Stronger and Lighter Materials for Next Generation Powertrain Applications
- Affordable processing routes for dispersion strengthened alloys

FY20 VTO Powertrain Materials Core Program **Research Thrusts**	FY20 Budget	Participating Labs
Thrust 1. Cost Effective LW High Temp Engine Alloys	$1.05M	ORNL
Thrust 2. Cost Effective Higher Temp Engine Alloys	$1.525M	ORNL, PNNL
Thrust 3. Additive Manufacturing of Powertrain Alloys	$1.075M	ORNL
Thrust 4A. Advanced Characterization & Computation	$1.625M	ORNL, PNNL, ANL
Thrust 5. Exploratory Research(1-year projects) **-Subtask 5C ($100K): Lighter and Stronger Aluminum ….** -Subtasks 5B, 5C & 5D ($450K)	$600k	ORNL, PNNL, ANL

Partners

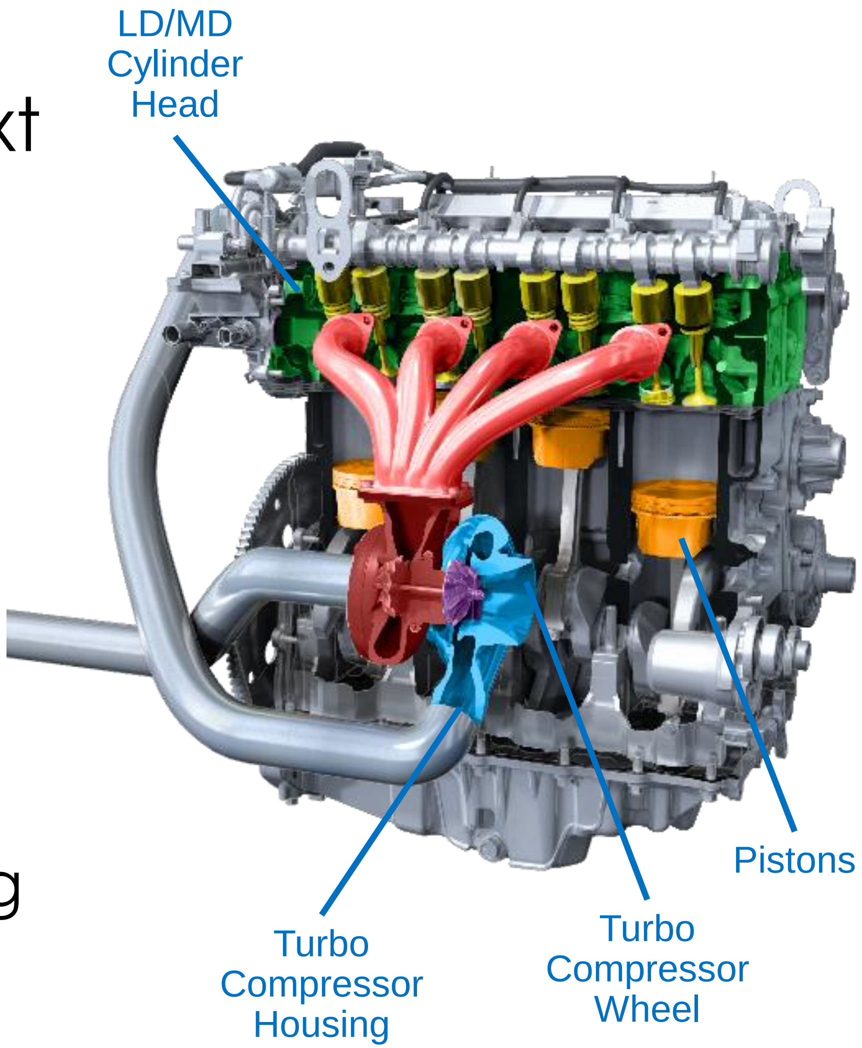
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory (parallel one-year effort with different dispersion additives funded at $100K also, with collaboration)

Relevance

- Need to *further* increase high temperature strength of the best-in-class lightweight powertrain and body structure Al alloys
  - Solid solution strengthening
  - Precipitation/aging hardening: today's high strength Al alloys
  - **Dispersion strengthening via mechanical alloying**: add thermally stable, nearly insoluble and very low diffusivity oxides and other dispersoids

Relevance

- Utilize **mechanical alloying** to create next generation lightweight powertrain alloys with even higher strength than today's best-in-class high-strength Al alloys
  - **Milestone:** >20% increase in strength at room temperature and 300°C, when compared to baseline 7xxx series alloys or the cast ACMZ family alloys (May, 2020)
- Targeted applications:
  - Cylinder liners, pistons, driveshaft, connecting rods.
  - Feedstock materials for additive manufacturing

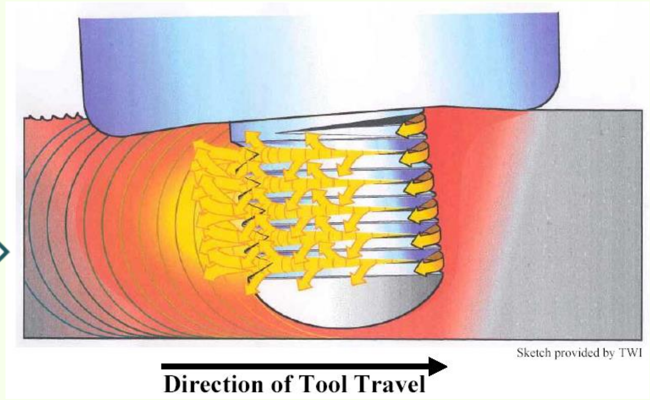


Approach

- Build on solid-state process innovations in friction stir processing (**FSP**) and friction stir extrusion (**FSE**) technologies at ORNL
  - ***multi-component additives***
    - graphene/carbon
    - nano-sized additives: carbide, oxide particles, and intermetallics
- Produce approximately 3-4” long, 1.5-2” wide, and ¼” thick AMC material blocks sufficient for mechanical property testing and evaluation.

Feedstock:
machined chips/powders mixed with additives

Solid state processing (FSP/FSE)



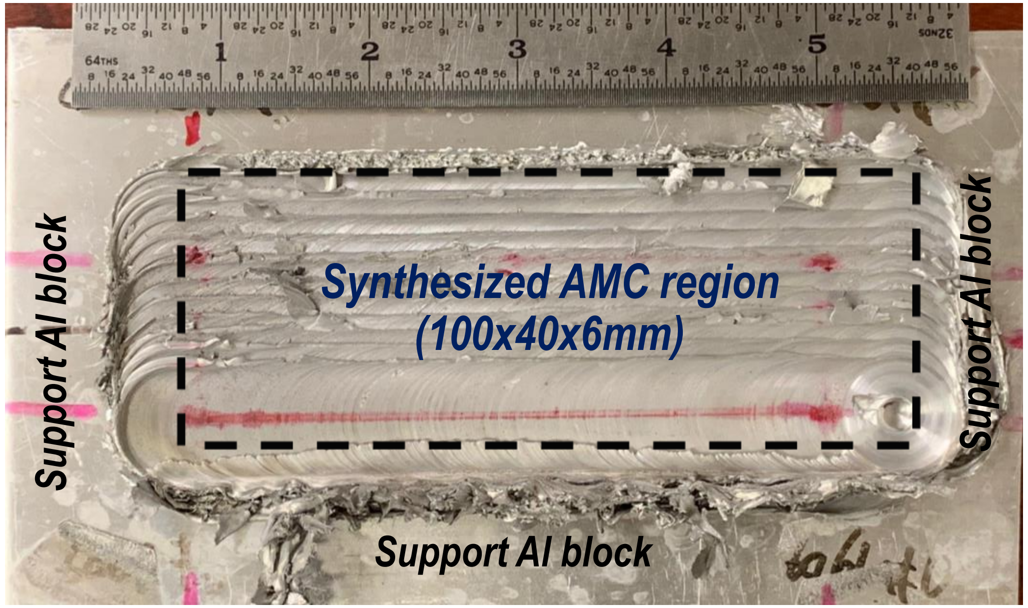
Mechanically alloyed Al metal composite material

- *Feng, Z, David, SA, Frederick, DA. (2011) Friction Stir Method for Forming Structures and Materials. USA Patent 8061579 B2.*
- *Manchiraju, VK, Feng, Z, David, A, Yu, Z. (2011) Providing Plastic Zone Extrusion. USA Patent US 9,616,497 B2.*

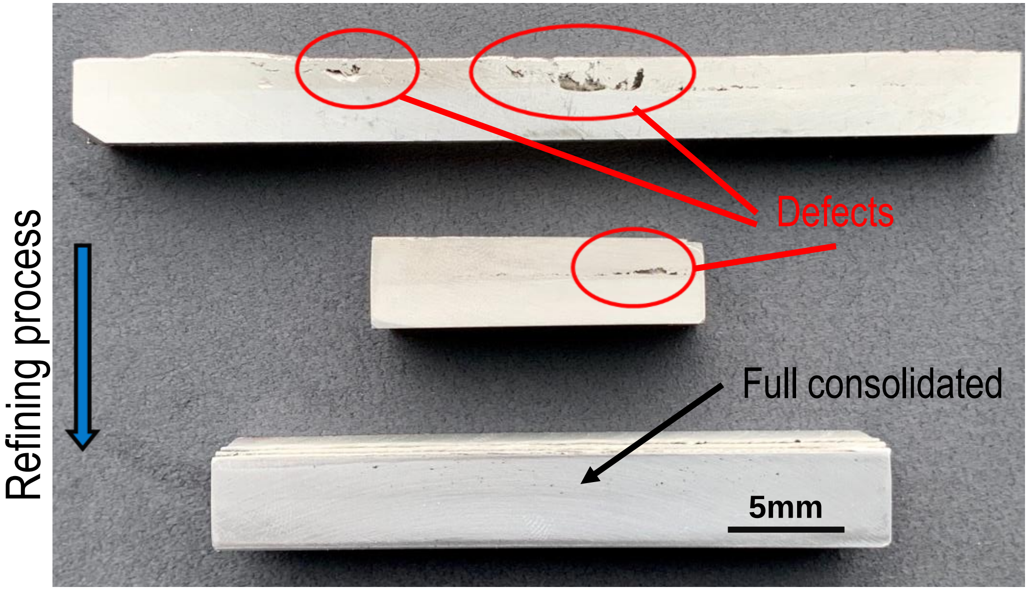
Technical Accomplishments & Progress: Process development

- Process development:
- Matrix and additive material placed in resevior in aluminum support block
  - Matrix materials: Machined ships of AA6061 and AA7075
  - Additives: Carbon, intermetallics, SiC (3% to 10% wt)

AA6061 with nano additives synthesized by FSP.
A 100x40x6mm region for property property testing



Process development to achieve fully dense consolidated material blocks from machined chips/powders

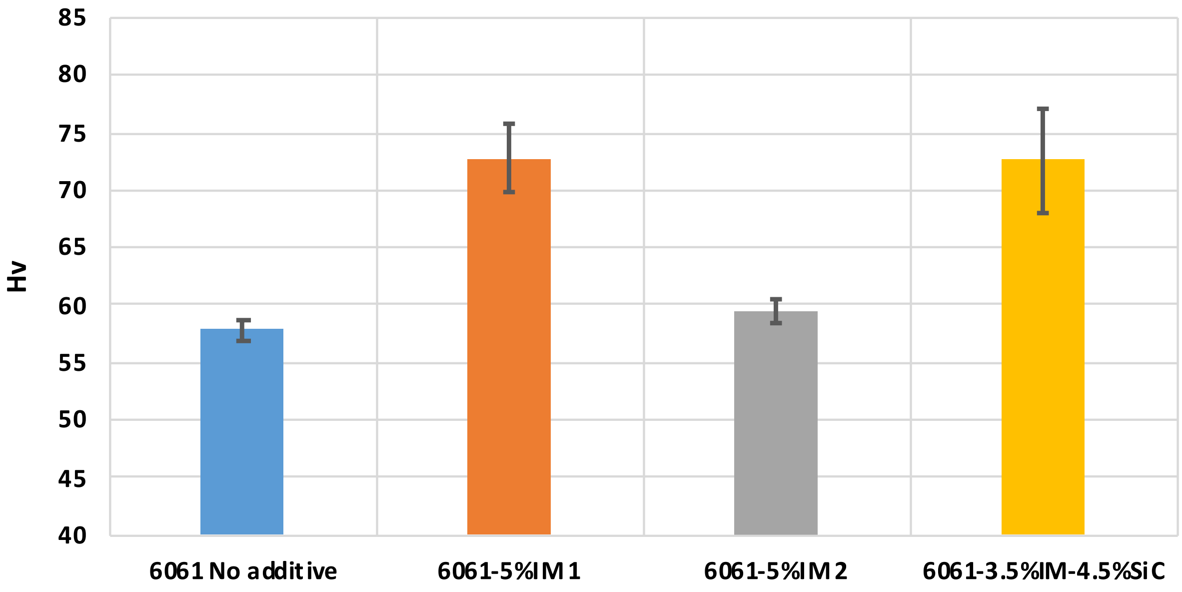


Cross-sectional views of processed region

Technical Accomplishments & Progress

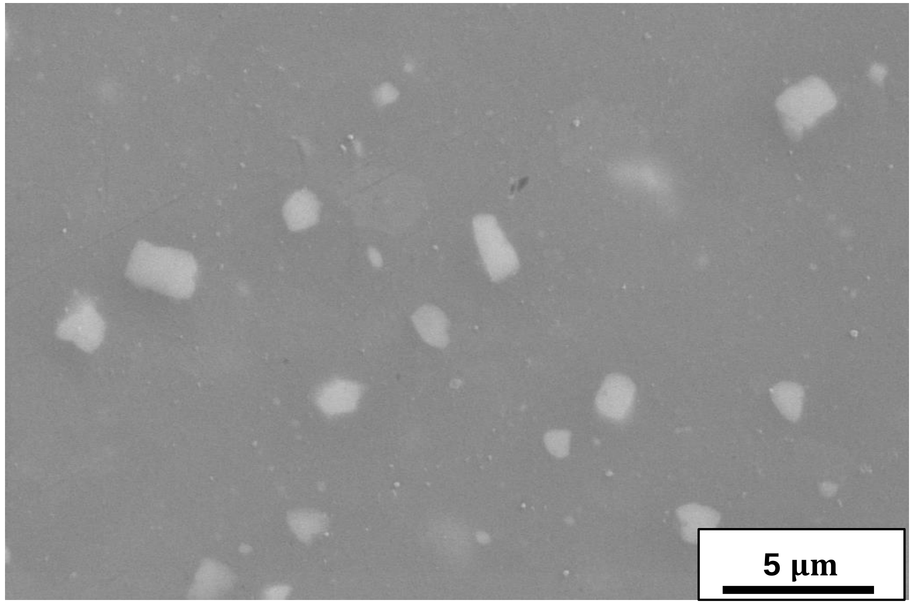
- 6061 matrix with 2 different additives:

Up to 25% increase in microhardness by adding intermetallic particles (IM) and SiC particles to AA6061 matrix:



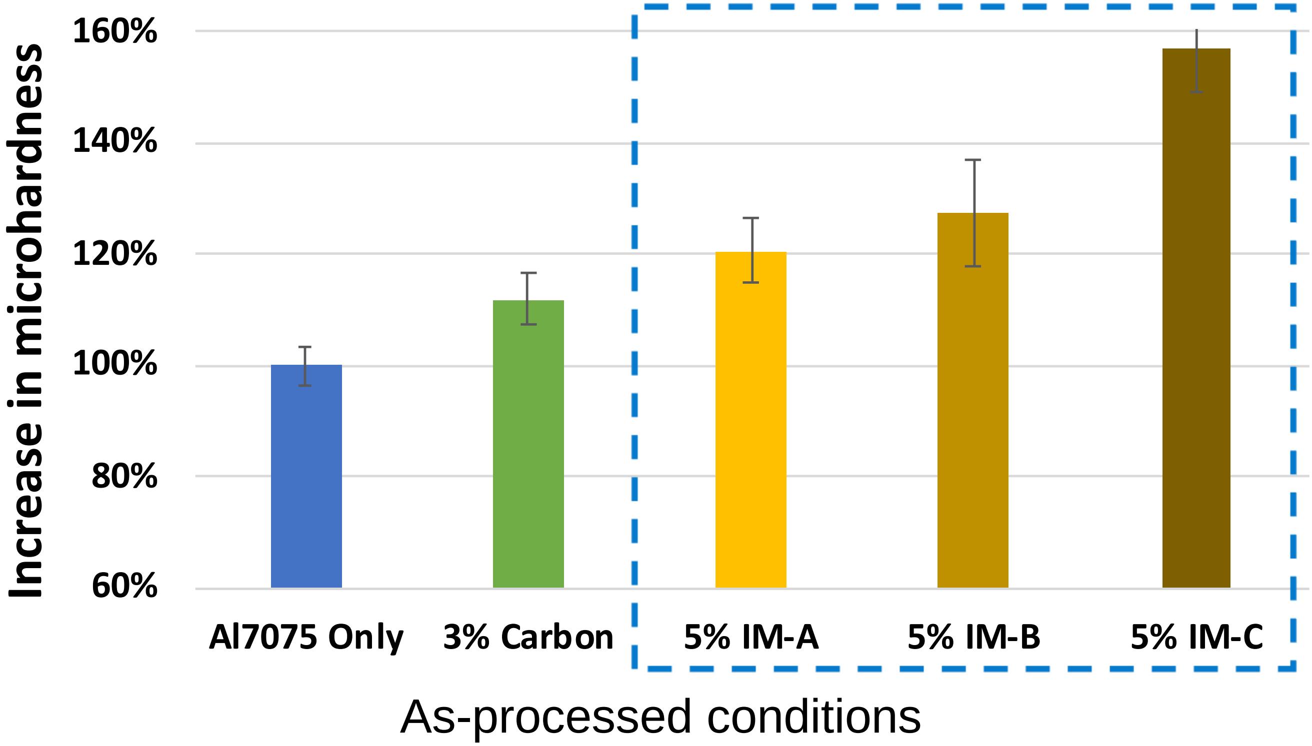
As-processed conditions

Uniform distribution of intermetallic particles (IM) in AA6061 matrix



Technical Accomplishments & Progress

- 7075 matrix with carbon and intermetallic additives
  - Up to 50% microhardness increase with 5%wt intermetallic additive
  - 15% increase with 3%wt carbon addition



Collaboration and Coordination

- A Parallel Research between ORNL and PNNL
  - ORNL focused on FSP/FSE high throughput route
  - PNNL focused on ShAPE route
  - Frequent conference calls and web meetings
  - Coordinated on materials and additives
    - Provided ORNL's ACMZ alloy to PNNL
- Interest from industry
  - GM Powertrain, Magna/Cosma, Ford

Proposed Future Research

- Complete study on post process heat treatment to T6/T651 condition
- Complete microstructure, mechanical property, and functional properties characterizations

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

Summary

- A 12-month exploratory research project successfully demonstrated the feasibility of solid-state material processing with mechanical alloying to synthesize stronger and lighter aluminum metal composite materials for engine and body structures
  - Up to 50% hardness increase achieved for AA7075 based metal composite materials with 5%wt intermetallic additives
  - Up to 25% hardness increase achieved for AA6061 based metal composite materials with 5%wt SiC or intermetallic additives
  - Baseline process condition established for high throughput FSP synthesis of Al metal composite materials

Technical Backup Slides

Technical Back Up: Challenges in making Metal Matrix Composite

- For same volume fraction, nano-sized particles are much more effective – the Orowan hardening effects

$$\sigma \sim \rho \sim {}^{1}/_{\lambda};\ \lambda = a\left(f_v^{-1/3} - 1\right)$$

σ: strength
ρ: dislocation density
λ: particle spacing
a: particle size
f_v: particle volume fraction

- However,
  - Uniform dispersion of nano-sized particles in molten metal and subsequent solidification in metal casting process has been very difficult [*Yan 2004*]
  - Functional additives such as carbon/graphene could also degrade or decompose due to strong chemical affinity in molten metal [*Saboori 2018*]
- Solid-state based process could potentially overcome above issues with metal casting process

- *Yang, Y. Lan, J. and Li, X., (2004). Study on bulk aluminum matrix nano-composite fabricated by ultrasonic dispersion of nano-sized SiC particles in molten aluminum alloy, Materials Science and Engineering A, 380(1-2), 378-383*
- *Saboori, A, Moheimani, KS, Dadkhah, M, Pavese, M, Badini, C, Fino, P. (2018) An Overview of Key Challenges in the Fabrication of Metal Matrix Nanocomposites Reinforced by Graphene Nanoplatelets. Metals-Basel, 8(3) doi:10.3390/met8030172.*