Pacific Northwest NATIONAL LABORATORY

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# Room-temperature Stamping of High-Strength Aluminum Alloys


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Project ID # mat126

# Overview



## Timeline

- Start: 10/2016 (FY17)
- Finish: 09/2019 (FY19)
- % Complete (scope): ~60%

## Barriers

- Strength: Develop process for stamping high-strength aluminum (Al) for structural applications without degrading its high strength
- Formability: Develop ways to enable sufficient formability of Al to stamp it at room-temperature

## Budget

- Total project funding
  - DOE: $ 1M
  - Industry cost share: 30%
- Funding since inception: $ 1M
- Future funds anticipated: 0

## Partners

- Magna-Stronach Centre for Innovation (Tier-1)
- General Motors (original equipment manufacturer (OEM))

# Relevance/Objective



- DOE-VTO
  - Long-term objective → 50% mass reduction of a vehicle
  - 2025 Target → 25% glider mass reduction, relative to comparable 2012 vehicles, at an added cost of no more than $5/lb weight saved
- USDRIVE
  - Aluminum components offer potential overall weight reduction of 40-60% when replacing cast iron/steel
  - Methods to improve the formability of high-strength Al alloys (>600 MPa), to values equivalent to steel, are a high priority research need
- Project objective
  - Develop thermo-mechanical approaches to enable room-temperature stamping of high-strength (7xxx) Al alloys
- Challenges
  - High-strength Al alloys do not have sufficient formability to be stamped at room-temperature
  - Warm/hot stamping is costly and may require post-forming heat-treatments to regain the high-strength

# Approach

| Task Name | FY 2017 | | | | FY 2018 | | | | FY 2019 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| Task 1 Component identification | G | | | | | | | | | | | |
| Task 2 Strengthening potential of W-temper 7xxx Al | | | M | | | | | | | | | |
| Task 3 Constitutive relations | | | | | | G | | | | | | |
| Task 4 Stamping simulations | | | | | | | | | | | | |
| Task 5 Integrate microstructure and mechanical properties models | | | | | | | | | | | | |
| Task 6 Fabricate prototype | | | | | | | | | | | M | |
| Task 7 Characterize prototype | | | | | | | | | | | | |

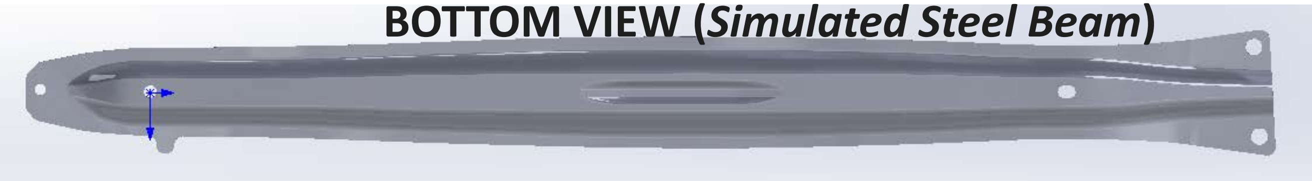
Phase II (Stamping Simulations)

Phase III In-progress (Microstructural Modeling & Prototype Fabrication)

- Gate 1 (FY17-Q1): Potential component identification
- Milestone (FY17-Q3): Forming limit diagram (FLD) determination
- Gate 2 (FY18-Q2): Stamping simulations predict that the component can be stamped at room-temperature
- Milestone (FY19-Q3): Determine hardness distribution over the as-stamped component

# Technical Accomplishments and Progress






- An in-production hot-stamped steel side-impact beam was scanned to create a 3-dimensional computer-aided design (CAD) model and provide an initial design for the target Al side-impact beam
- Emulation of in-production design provides a suitable and realistic initial target design for prototype fabrication

# Technical Accomplishments and Progress

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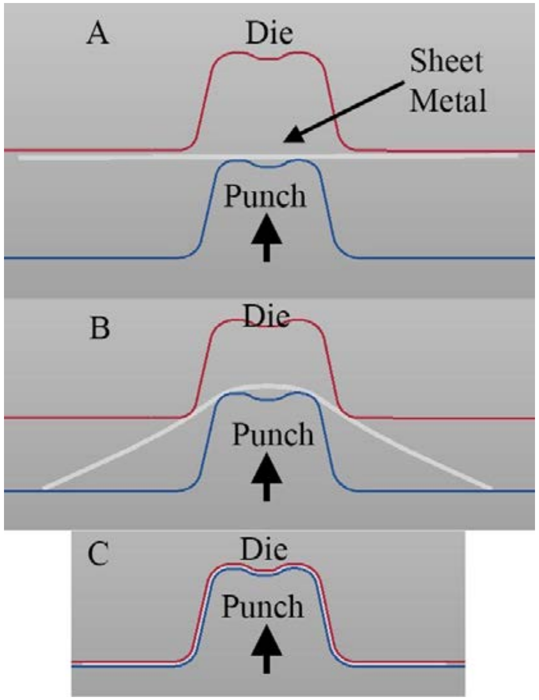
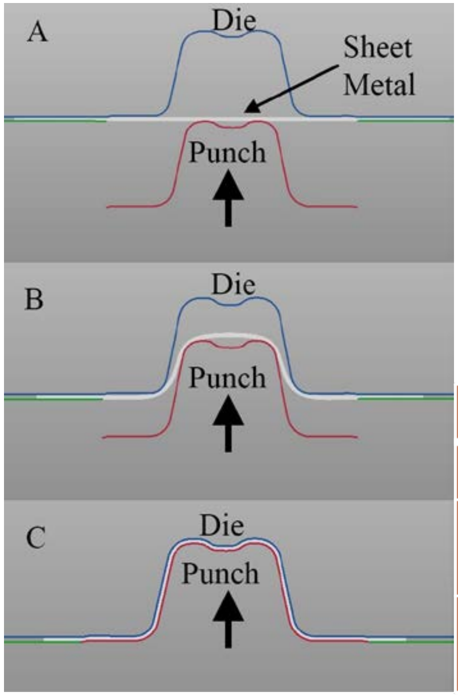
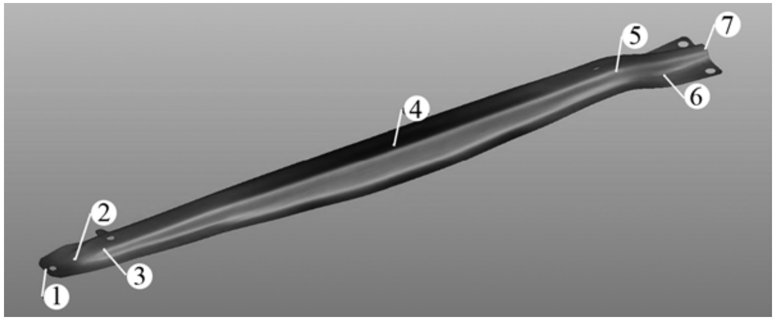
Crash-forming




Draw-forming




Simulated Stamped Al Beam




| | % Thinning (At Indicated Locations) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | Max |
| Crash Form | +1.2 | +3.6 | -3.6 | -0.13 | -4.4 | -4.5 | -6.2 | -11 |
| Draw Form | +0.4 | +2.6 | -3.8 | -0.08 | -5.2 | -4.4 | -5.9 | -10.1 |

Note: “-” = Thinning, “+” = Thickening

- Mechanical testing was completed and material cards developed that were used by the tier-1 partner to perform stamping simulations of Al 7075

## Precipitates/Precipitation Strengthening in AA7075

- Saturated solid solution → GP-zones (coherent) → η′ ($MgZn_2$) → η (incoherent)
- Precipitate (ppt.) strengthening (radius, r < 3.3. nm) (coherency, atomic-order, chemical effects)
  - Precipitate shearing (sh.)
- Softening (r > 3.3 nm)
  - Precipitate by-passing (bp.)

$$\Delta\sigma^{\mathrm{sh}} = \frac{M\pi\mu k^{3/2}}{16}\sqrt{\frac{3 f_v r}{\beta b}}$$

$$\Delta\sigma^{\mathrm{bp}} = \frac{M\beta\mu b}{r}\sqrt{\frac{6 f_v}{\pi}}$$

**Δσ = Strength increment**
**M = Taylor factor**
**μ = Shear modulus**
**k = Proportionality const. (line tension in shear)**
**fv = Volume fraction of ppt.**
**r = Radius of precipitates**
**β = Proportionality const. (line tension during by-passing)**
**b = Burger's vector**

- Proposal at Advanced Photon Source (APS)
  - Small-angle X-ray scattering (SAXS) → precipitate radius (*r*) ; volume fraction ($f_v$) = f(time)
  - Resolution ~2-3 Å
  - In-situ control (temperature, deformation)
  - Penetration power (sheet thickness = 2.5 mm), better bulk statistics than electron microscopy
- Model: SAXS data as input → Predict strengthening/ softening regimes → Predict component strength as a function of prior thermo-mechanical history

# Responses to Previous Years Reviewers' Comments

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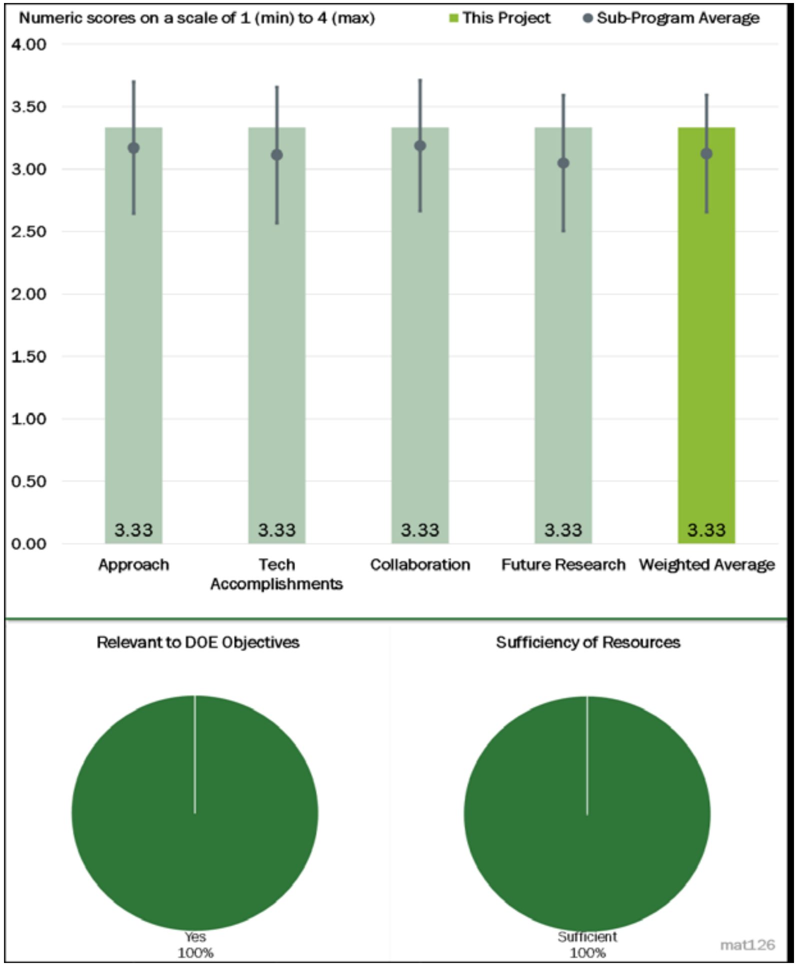
Summary 2018 AMR Results




- Comment (Approach)
  - Sound engineering approach to couple experiments, modeling and stamping simulations before fabrication; good use of actual automotive parts
  - 1st Go-No Go gate and weight reduction analyses: Listed references in back up slides; analyses based on GM and Magna internal research and hence, not described publicly
  - Targets for mechanical strength: Hardness of stamping within 80% of the T6 temper
  - Mechanical testing for qualification; testing of component: 3-point bend test of stamped beam and compare against steel beam; hardness measurement across the stamped beams
  - Heavy reliance on modeling and simulations: Stamping simulations were important to give confidence to proceed to Phase III; microstructural modeling is to develop the scientific understanding for interactions between precipitation, strength, and plasticity

# Responses to Previous Years Reviewers' Comments

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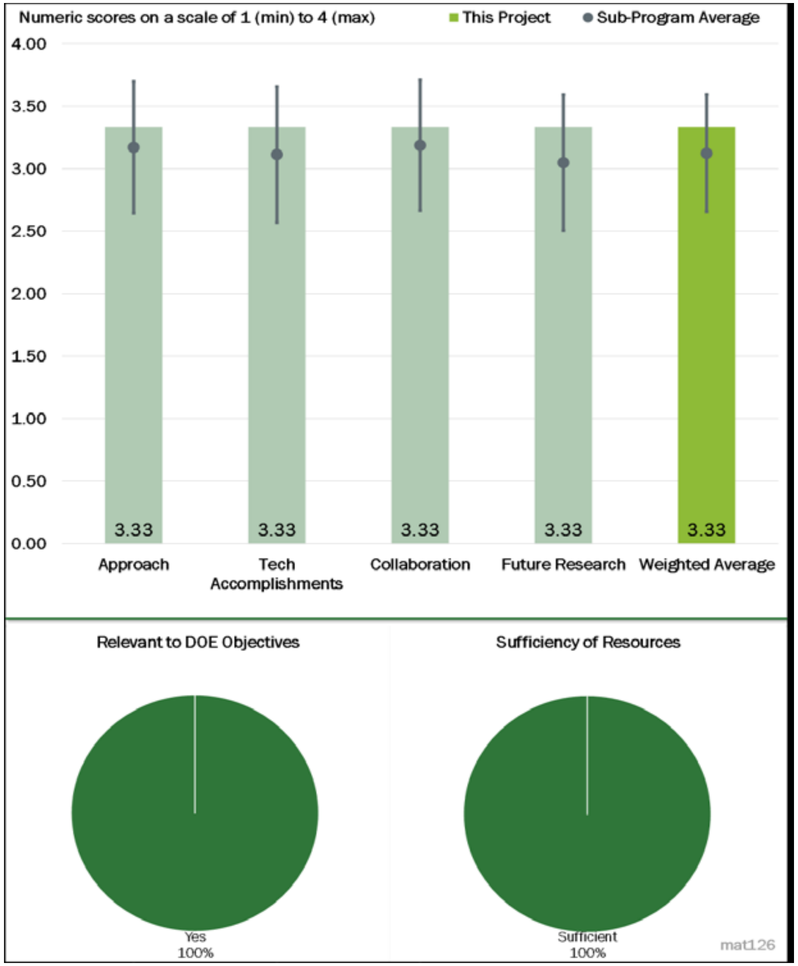
Summary 2018 AMR Results




- Accomplishment and Progress
  - Good job on LS-Dyna modeling/friction effects
  - Underspent and remaining activities (Gantt Chart): The project had somewhat slow start and has since ramped up and project costs are in line with scope of work completed. A post-doc was hired last year to lead the task on integrating microstructural - mechanical properties modeling and in-situ SAXS experiments on the beam-line. A sub-contract is being pursued with Magna for die-fabrication and stamping of prototype component
- Collaboration and Coordination
  - "Excellent" collaboration between National Lab, tier-1 supplier and automotive OEM

# Collaboration and Coordination



- Magna-SCFI (Tier-1)
  - Component selection
  - Component model
  - Stamping simulations
  - Prototype fabrication
- General Motors (OEM)
  - Internal studies on lightweighting
  - Component and Al alloy selection
  - Component design
  - Die design

# Remaining Challenges and Barriers

- Determine the thermomechanical processing that allows simultaneous formability (at room-temperature) and high strength in the formed component
  - Combined experimental and modeling approach
- High-strength Al can continue to undergo natural aging after forming
  - Post-formed mechanical properties need to be evaluated for long-term thermal stability
- Cost-effectiveness of the proposed approach is unknown

# Proposed Future Work



- Integrate microstructure and mechanical property models (PNNL)
  - In-situ experiments at APS
  - Models from literature
  - Improved understanding of precipitation/dissolution
- Design stamping die and stamp prototype component (Magna)
  - Purchase of blanks
  - Paint-bake treatment of stamped beams
- Characterize the stamped component (PNNL and Magna)
  - 3-point bend test
  - Hardness measurements

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

# Summary



- Goal is to develop a process to stamp high-strength Al at room-temperature without a separate precipitation-hardening heat-treatment
- Side-impact beam was identified as the structural component to form out of AA7075 Al alloy, as an alternative to high-strength steels
- PNNL is working with tier-1 supplier and OEM to stamp a prototype side-impact beam using AA7075 Al
- An integrated experiment and modeling approach is being developed to predict alloy strength under different temper and deformation conditions

# Technical Backup Slides

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# Approach



- Phase I (3 months)
  - Task 1: Identify 3-5 potential stamped sheet components
  - Gate 1: Demonstrate potential for sufficient return on (DOE) investment and the potential for commercialization to replace high-strength steel with high-strength Al
- Phase II (15 months)
  - Task 2: Determine strengthening potential of W temper formed 7xxx Al alloys
  - Task 3: Determine constitutive relations for selected Al alloys
  - Task 4: Perform stamping simulation for the selected prototype structural component
  - Gate 2: Stamping simulations that predict with confidence that the selected component can be stamped in at least one 7xxx Al alloy-temper combination at room-temperature
- Phase III (18 months)
  - Task 5: Integrate microstructure and mechanical property models for the selected Al alloys
  - Task 6: Fabricate prototype component
  - Task 7: Characterization of prototype component

# Example of Prior Literature Reviewed

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6. https://www.amag.at/fileadmin/user_upload/amag/Downloads/AluReport/EN/AR-2014-3-EN-S14-15-.pdf. Accessed 29th Nov. 2016.
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8. Kumar, S.D., Amjith, T.R., Anjaneyulu, C., Forming Limit Diagram Generation of Aluminum Alloy AA2014 Using Nakazima Test Simulation Tool, In Procedia Technology, Volume 24, 2016, Pages 386-393.
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