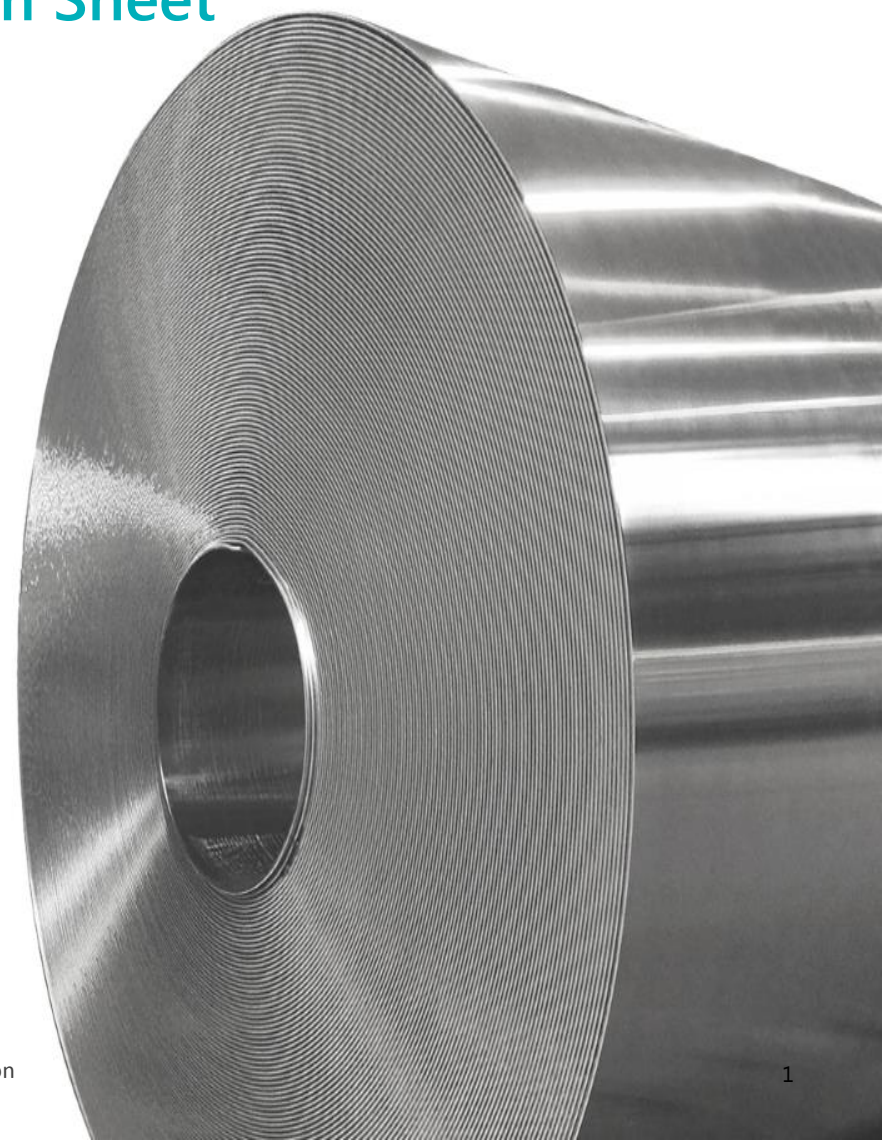
# Development of Low Cost, High Strength Automotive Aluminum Sheet

**Russell Long – Principal Investigator**

**Project ID: LM108**

**2018 Annual Merit Review**

**June, 2018**



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COSMA INTERNATIONAL

OAK RIDGE
National Laboratory

HONDA

# Overview

Timeline

- Start Date: Oct. 1, 2014
- End Date: January 31, 2019
- 80% complete

Budget

- Total project funding (50/50): $4,783,541
  - Govt share: $2,391,771
    DOE: $1,891,771
    ONRL : $500,000
  - Partner share: $2,391,771
- FY 2015 DOE Spend $506,395
- FY 2016 DOE Spend $318,229
- FY 2017 DOE Spend $519,628
- FY 2018 Est DOE Spend $447,519
- FY 2019 Est DOE Spend $100,000

Barriers

- Demonstrate a warm formed part made using a new alloy with an ultimate strength of 600 MPa, 8% minimum elongation with acceptable corrosion.
- Cost premium of less than $2/lb saved over baseline UHSS component

Partners

- Arconic – Lead
- Honda
- Cosma
- ORNL

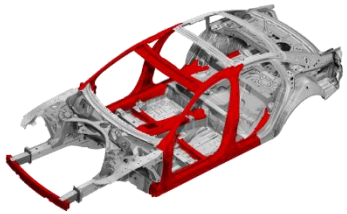
# Project Objectives/Relevance

Project Objectives:

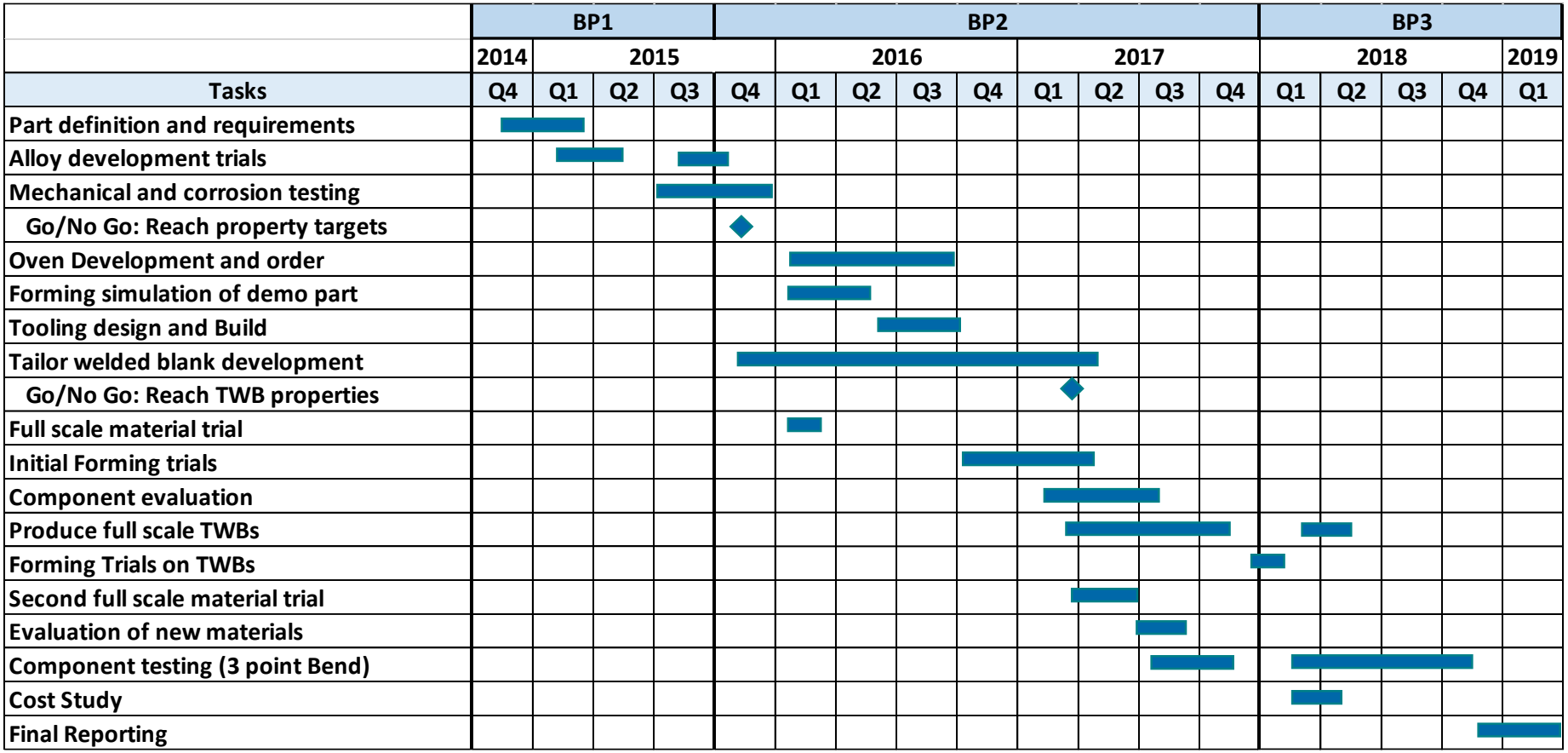
- Develop a high strength aluminum automotive alloy and processing to provide Ultimate tensile strength in the finished stamped component greater than 600 MPa and 8% total elongation
- Produce a representative part at forming temperatures less than 225 deg C with cost of finished, stamped component at less than $2/lb saved compared to a baseline part.

Relevance:

- Reducing weight is a key enabler to reduce fuel consumption thereby reducing green house gas emissions and the dependence on foreign oil.
- 5xxx and 6xxx alloys currently used in automotive BIW are not competitive with Ultra High Strength Steels (UHSS) used for the safety cage components.
- High Strength 7xxx alloys can provide weight savings over hot stamped UHSS components. Baseline part is 1.4 mm thick with a weight of 12.5 kg and the proposed high strength aluminum part is 2.5 mm thick and 7.5 kg or 38% weight savings.



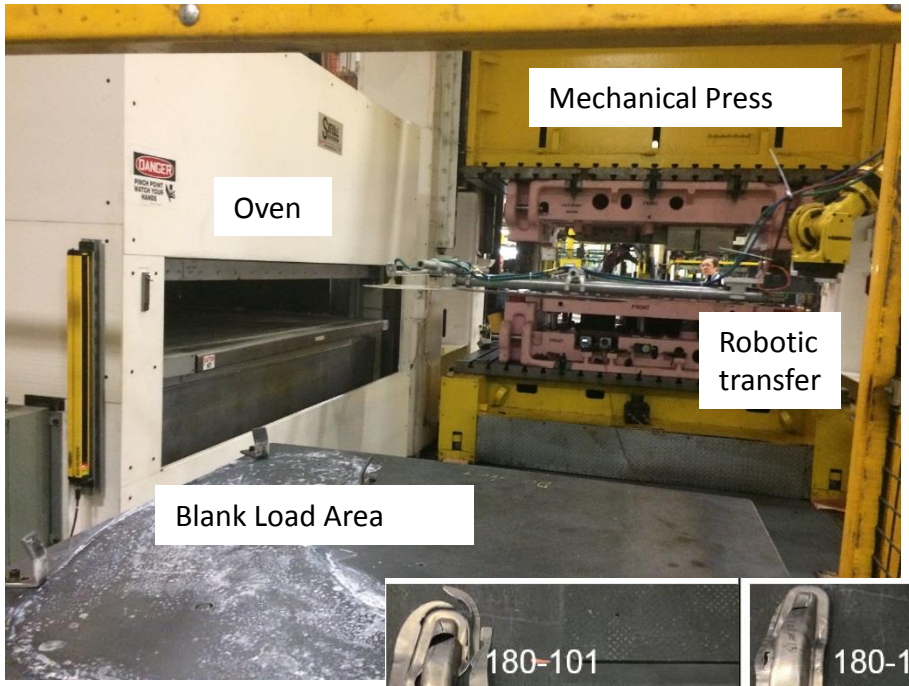
# Milestones

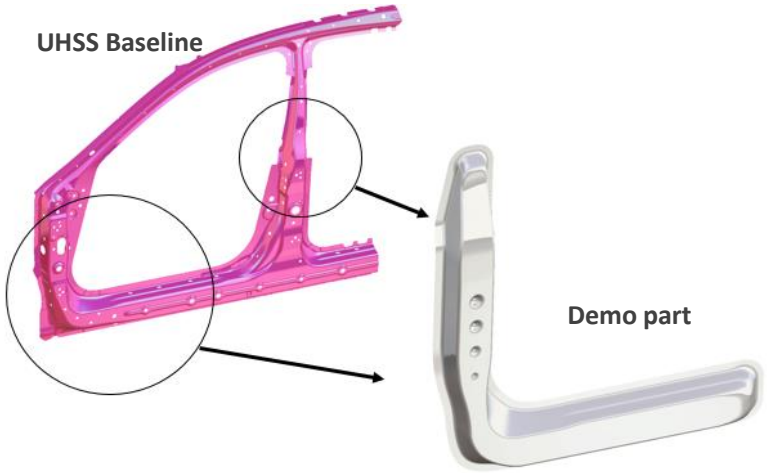

BP1
BP2
BP3
2014
2015
2016
2017
2018
2019
Tasks
Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1
Part definition and requirements
Alloy development trials
Mechanical and corrosion testing
Go/No Go: Reach property targets
Oven Development and order
Forming simulation of demo part
Tooling design and Build
Tailor welded blank development
Go/No Go: Reach TWB properties
Full scale material trial
Initial Forming trials
Component evaluation
Produce full scale TWBs
Forming Trials on TWBs
Second full scale material trial
Evaluation of new materials
Component testing (3 point Bend)
Cost Study
Final Reporting

# Approach/Strategy

- Conduct alloy development trials.  The strength and elongation targets are based on DOE requirements.  The formability and corrosion targets are based upon the Honda part design.
- Purchase warm forming oven and install in existing press line along with robotic blank transfer to the tooling
- Design and build tooling for warm forming of material.
- Produce full coils of experimental alloys for use in forming trials
- Conduct warm forming trials on development alloys (without tailor welding)
- Develop Friction stir welding process for tailor welded blanks to improve material utilization.
- Conduct warm forming trials on development alloys with tailor welding
- Characterize properties and performance including strength, deformation (energy absorption) and corrosion performance of final warm formed parts after paint bake cycle.
- Characterize the performance of the tailor welded blanks.
- Update Forming Limit diagrams and stress strain curves for new materials and corrulate the forming simulation with the observed behavior in the forming trials.
- Complete cost study.

# Technical Accomplishments:
# Forming Cell and Tooling is used for all forming trials





| | |
|---|---|
| | Pillar end |
| | Inside elbow |
| | Outside elbow |
| | Sill End |


| | |
|---|---|
| | Pillar end |
| | Inside elbow |
| | Outside elbow |
| | Sill End |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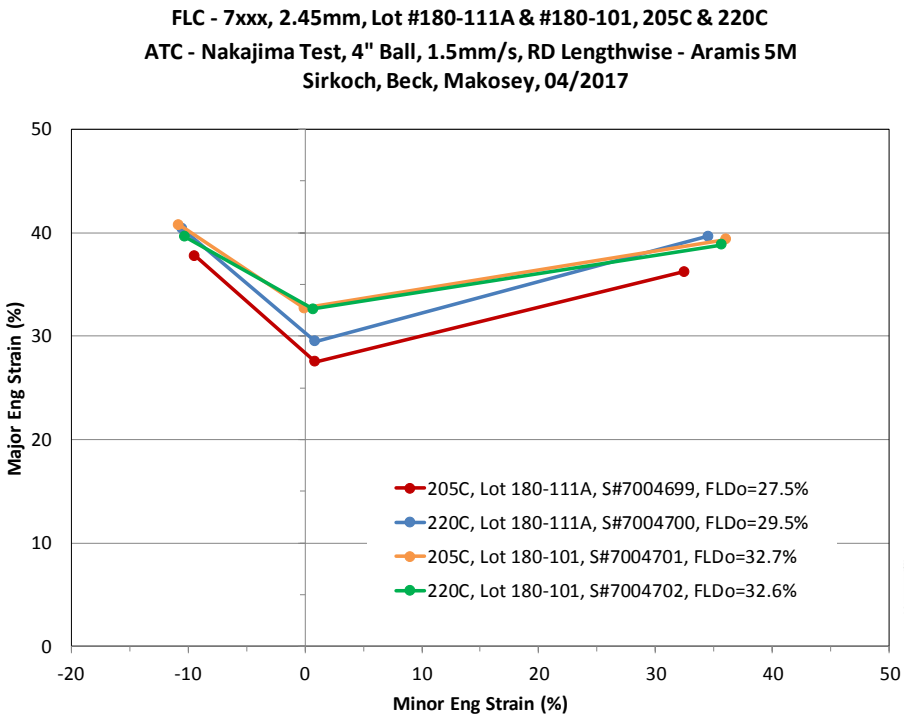
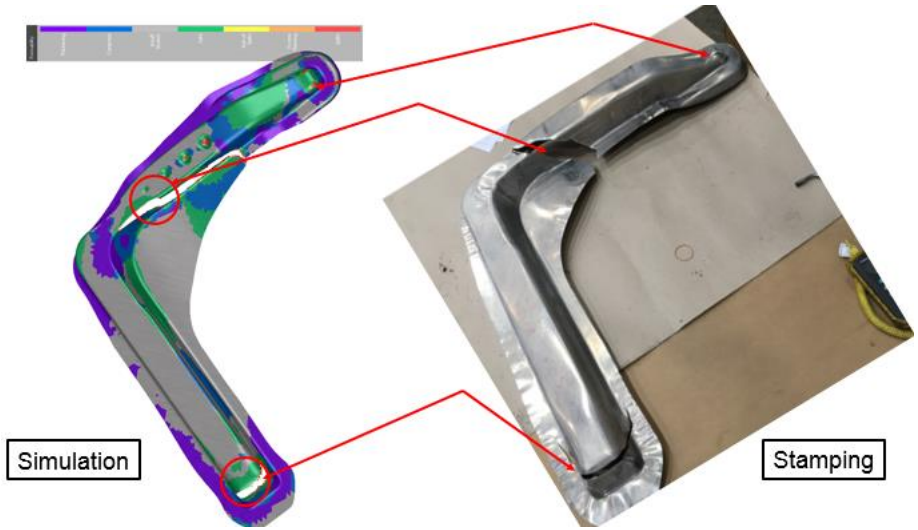
| | Pillar end |
| | Inside elbow |
| | Outside elbow |
| | Sill End |


| | |
|---|---|
| | Pillar end |
| | Inside elbow |
| | Outside elbow |
| | Sill End |

# Technical Accomplishments: Forming Simulation Correlation with Part trial

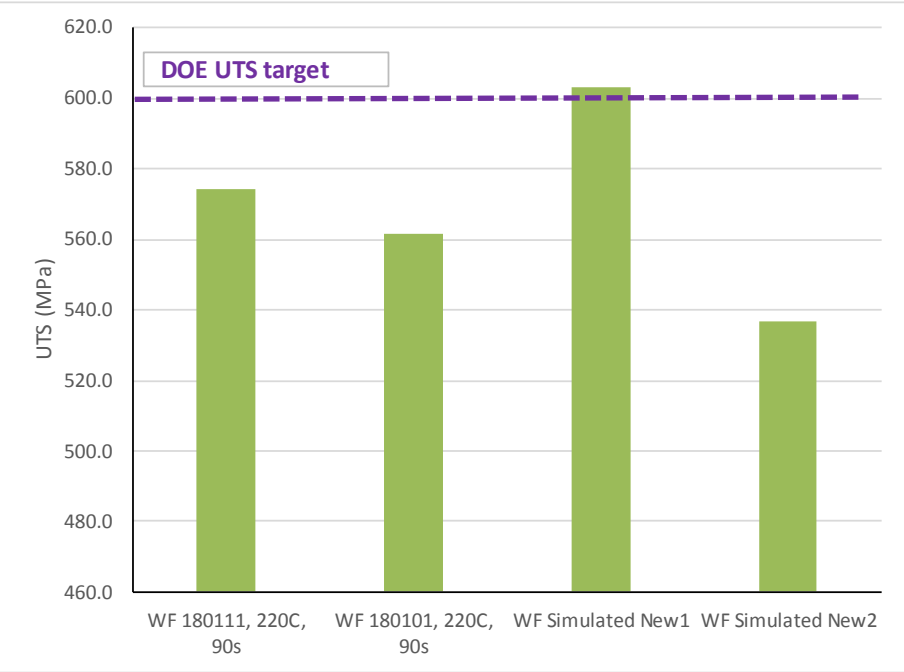
- Material properties were developed (FLD and Stress strain curves at forming temperature at multiple strain rates for alloys 101 and 111
- This data was used to update the forming simulation of the demo part.
- Reasonable correlations were achieved in some components. Many parts were formed successfully without cracking. The two ends of the part often had small cracks which were predicted in the simulation.

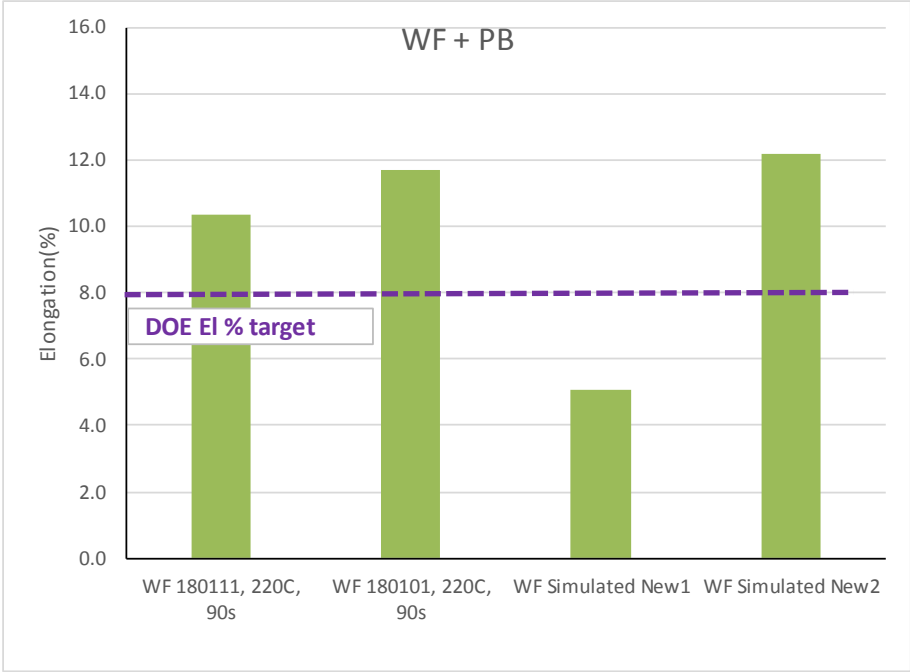


## Technical Accomplishments
## Two new alloys have been produced, properties have been measured and compared to Warm Formed parts from Cosma Eagle Bend trials

7055 and 180101 properties are from Cosma Warm Formed parts. Data for the two new alloys are aged to simulate the Warm Form and Paint Bake process approaching peak strength; the alloys show a range of UTS/Elongation properties



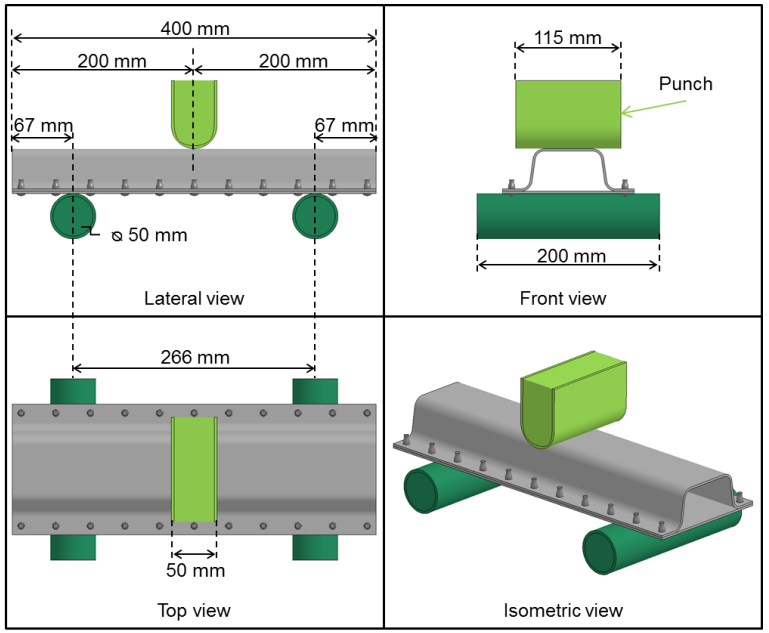




1. Alloy 101 has shown the best formability so far – about 40 MPa below DOE Strength Target
2. New Alloy 1 reaches the target 600 MPa strength but falls short of the elongation target
3. New Alloy 2 has lower UTS but has good elongation at ~12%

# Technical Accomplishments
# 3 Point Bend Hat Section Crush Test – used to simulate side impact

Full scale stamping die contains a portion which will be used for Side Pole performance assessment.

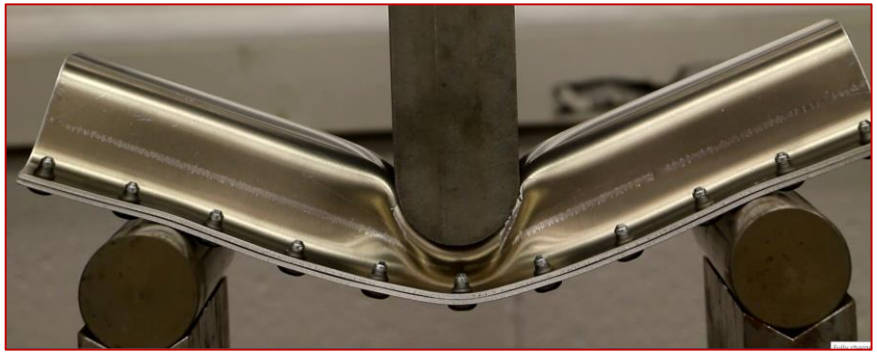
Lab scale geometry can be expedited to provide directional assessment on basic performance.




Schematic views of the Al7055T6 hat section setup under 3-point bending load.

**Preliminary Assessment:**

- **High strength aluminum function study used a press formed hat and plate attached using high strength blind rivets.**
- **Force response curve can be judged for stiffness, strength, and energy absorption comparative performance.**



**7055 Specimen: Deformation at 69mm of ram stroke**

# Technical Accomplishments
# Gauge justification – 3Pt Bend Hat Section Crush Study


**Basic comparison of crush functionality in 3Pt Bend:**
**7055 600MPa 2.5mm**
**UHSS 1500MPa 1.5mm**

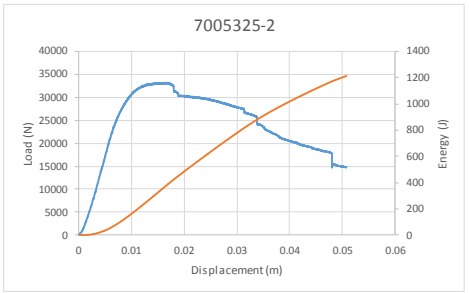
Mass merit: [1 - (7055 / UHSS)] = 41%

1. Initial stiffness is component geometry driven, so no difference is expected.
2. Initial peak reaction force is higher with 7055 → Good for relative improvement.
3. Stroke to first major force drop is higher for 7055 → Good for relative improvement.
4. Reaction force recovery after initial drop is preferred for stable functionality.

# Technical Accomplishments
# 3-point bend test results for new materials

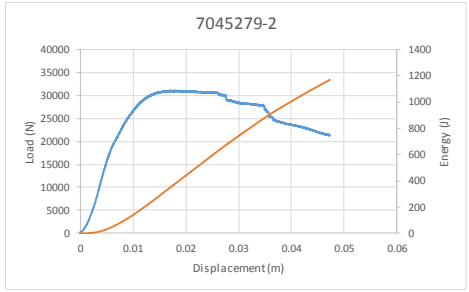
Load-deflection data and sample photos (tested using 290 mm sample span)

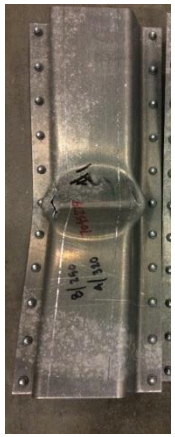
DC 7055



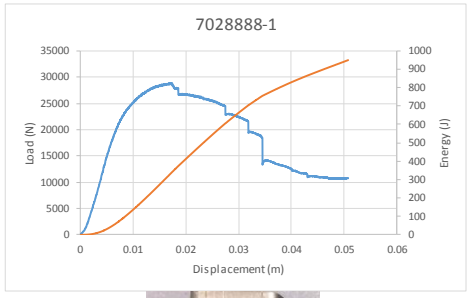


180101

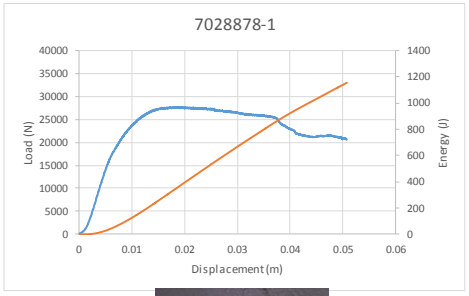


New Alloy 1




New Alloy 2




| Alloy | UTS (MPa) | Tot El (%) |
|---|---|---|
| DC 7055 | 571.4 | 12.7 |
| 180101 | 576.0 | 12.5 |
| New Alloy1 | 602.9 | 5.1 |
| New Alloy2 | 536.6 | 12.2 |

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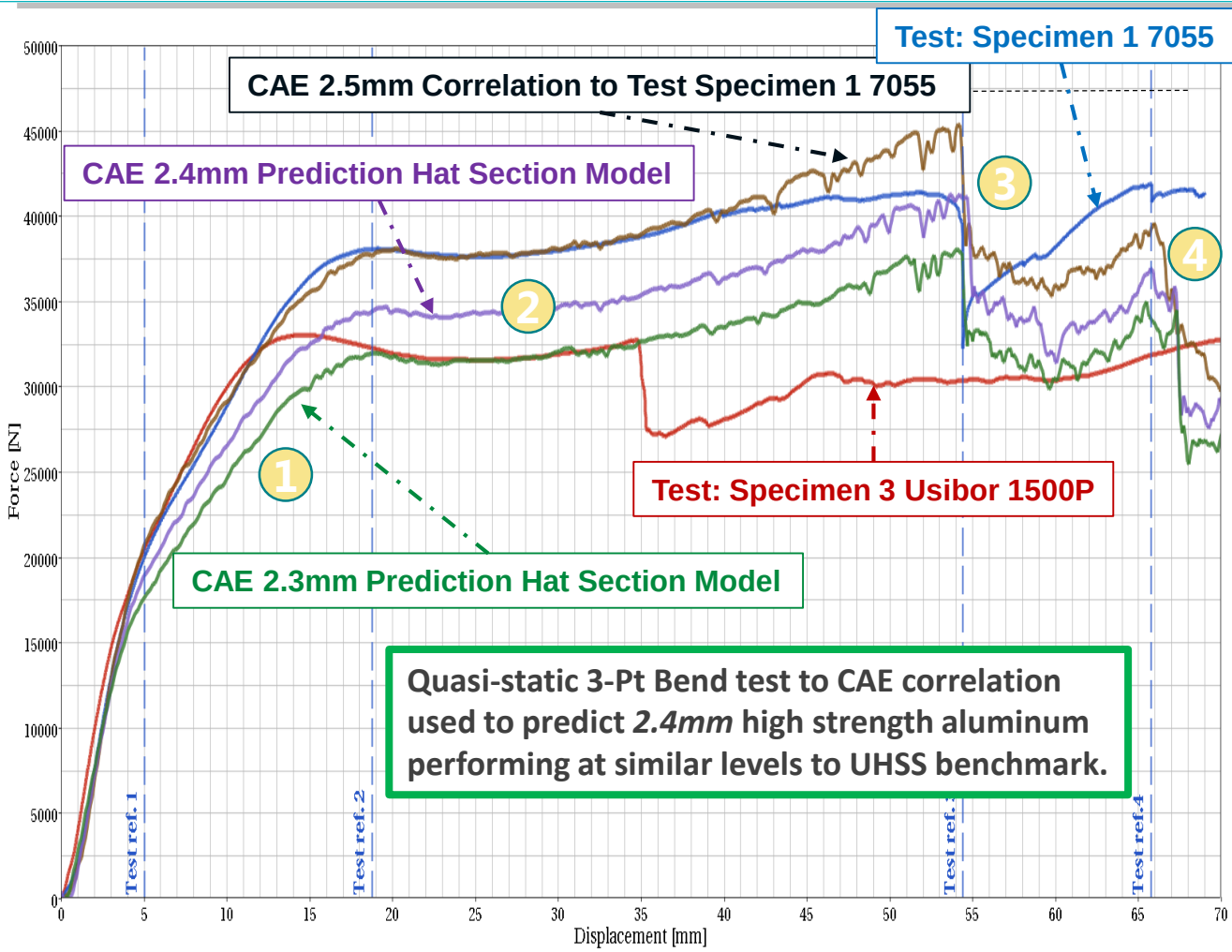
# Technical Accomplishments:
# Gauge justification – 3Pt Bend Hat Section Gauge Study




**Preliminary correlation of 7055 test and CAE model:**

- **Basic property alignment**
- **Plastic strain failure limit**
- **Mesh type & size**

Pending refinement: friction coefficients, failure method

1. Initial stiffness is directly affected by gauge reduction, as expected.
2. Initial peak reaction force is reduced with gauge reduction.
3. Stroke to first major force drop is consistent across all possible gauges since base failure criteria was set by the 2.5mm correlation model.
4. Reaction force recovery after initial drop is difficult to accurately recreate in CAE due to unique failure mechanism modeling.

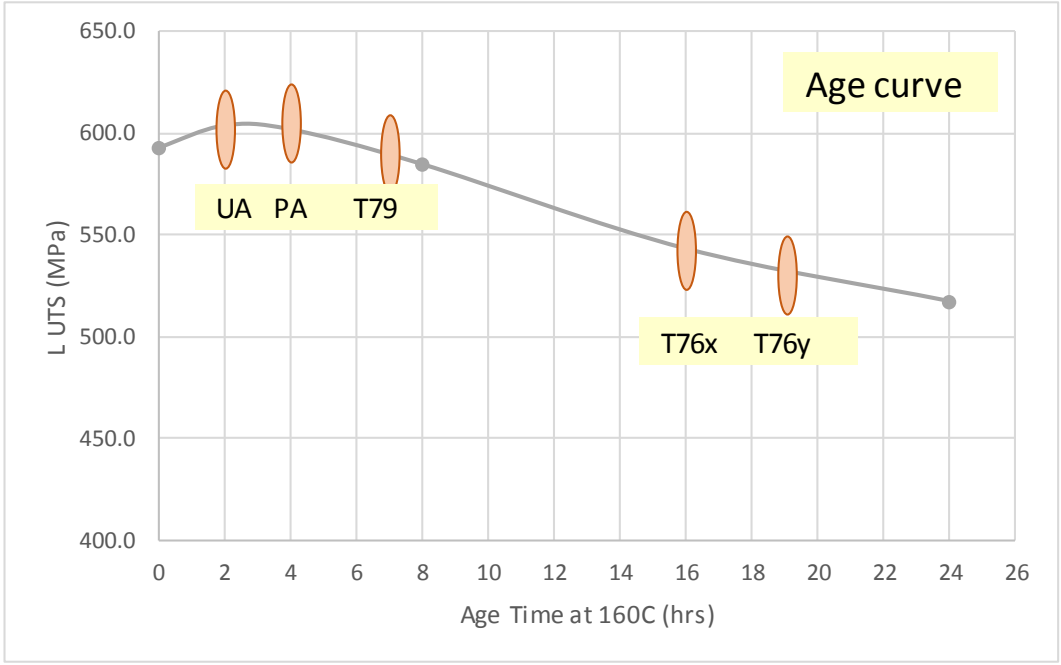
# Technical Accomplishments
# Alloy 101 Corrosion evaluation complete, new alloy corrosion tests underway

Corrosion tests will be conducted over a range of temper conditions for the two new alloys

Standard corrosion tests will be run for peak and overage conditions. Data for 180-101 already available

Environmental corrosion tests will be conducted over a more discrete range of tempers in both of these aging regimes

Age curve and nominal aging (temper) conditions for corrosion testing




## 180-101 IG data (ASTM G110)

| Alloy (Lot) | WF: 1.25 mins @ 204C | WF: 30 secs @ 227C |
|---|---|---|
| 180-101 | 86.4µm | 40.4µm |

## 180-101 SCC data (ASTM G44)

| Alloy (Lot) | Stress Level | WF: 1.25 mins @ 204C | | | WF: 30 secs @ 227C | | |
|---|---|---|---|---|---|---|---|
| 180-101 | 75% | 26 | 26 | 37 | 34 | 37 | 45 |

## 180-101 Exfoliation data (ASTM G85)

| Alloy (Lot) | WF: 1.25 mins @ 204C | | | | WF: 30 secs @ 227C | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 wk | 2 wks | 3 wks | 4 wks | 1 wk | 2 wks | 3 wks | 4 wks |
| 180-101 | P | P | P | P | P | P | P | P |

# Technical Accomplishments: Tailor Welded Blank trials

- Produced 16 TWB of 180-101 and 12 TWB of 180-111
- Conducted forming trials at Cosma heating the blanks for 230 degrees C for 90 seconds
- Initial trials failed in weld. Weld was very close to the transition in the blank. Moved the weld line 50 mm from transition and achieved better performance.
- TWB of 180-101 material performed better than the TWB of 180-111.
- Weld quality impacted on forming of this complex shape. Lack of bonding on the root side (surface contacting the punch) resulted in weld failures.
- Improvements to the weld quality are underway.

Sample with root side lack of bonding

# Technical Accomplishments: Cost Study

- A cost study has been completed comparing the current single piece UHSS door ring to the warm formed aluminum door ring:
- The processing steps were included
  - Material production at Arconic including aging to an underaged temper
  - Blanking and tailor welding at TWB Co.
  - Blank heating using the 230 deg C for 90 second cycle
  - Warm forming
  - Part is press trimmed
  - Part is cleaned to remove lube
  - Tooling is amortized over 400,000 vehicles per year
  - Recyling scrap credit is included
- The final thickness of the aluminum part was 2.4 mm resulting in a weight savings of 11.2 lb.
- The cost per lb of weight savings was $2.26/lb saved.

# Responses to Reviewer Comments

1. Friction stir welding is going to be an expensive approach to joining. Did the team consider MIG welding?

   The 7xxx alloys underdevelopment in this project are not weldable because of hot cracking tendency. FSW has been demonstrated to be viable in high volume production in a previous DOE contract and 6xxx series alloy TWB are being produced using FSW for the Ford F150 today. 5xxx series TWB are also in production using FSW.

2. No information was provided to assure that the 2.5 mm thickness in aluminum is suitable for the side impact load case.

   See Slide X showing steel/aluminum comparison

3. No cost comparison was presented.

   We had not yet completed the cost study last year and have presented it this year.

4. No Stress corrosion cracking test results were presented and highly recommended SCC tests be conducted and reported.

   SCC tests have been conducted on the first 4 experimental alloys and presented during the 2016 AMR. Additional corrosion testing is being done on the 2 new alloys.

5. Work should include development of FLDs at the warm forming temperature to enable accurate forming simulations. These simulations should be compared to the actual results from the forming trials.

   The initial forming simulation of the part prior to building the tooling was done using FLDs of 7055 at several temperatures and strain rates. After the experimental materials were available, FLD and strain stain curves were developed at multiple temperatures and strain rates. Cosma has used this information and the strain measurements from formed parts to correlate the models to the results observed in the trials.

# Partnerships/Collaborations

| | |
|---|---|
| ARCONIC | **Arconic will develop compositions, processing and thermal treatments to reach the target DOE/Honda requirements on a lab scale. Alcoa will select the most promising alloys and produce full-scale blanks for forming trials.** |
| HONDA | **Honda will provide specifications for the component and test criteria, as well as functional performance expectations. Honda will provide specifications for related coupon testing that will be conducted by Honda, industry partners, and ORNL. Finally, Honda will assess functional performance of the component.** |
| MAGNA COSMA INTERNATIONAL | **Cosma will develop the tool surface and perform forming simulations of the 7XXX alloy component to successfully develop the forming tool. Cosma will construct the forming die for trials. Operating parameters of the tool/oven will be developed. Finally, Cosma will integrate both the oven and forming tools on an existing press line for demonstration.** |
| OAK RIDGE National Laboratory | **ORNL will develop the friction stir welding (FSW) process and produce initial samples for forming characterization at warm forming temperatures. Once the weld strengths and forming characteristics are understood, ORNL will produce the TWB for the forming trials.** |

# Remaining Challenges and Barriers

- Increasing the temperature of the tool has been tried as part of this project and improved the part formability.  Will this also improve the performance in the TWBs.
- The press that we have been using for this project is being moving into another production line and cannot be used for further trials.  We will move the tool to another Cosma location to complete a forming trial on the new alloy.  A second trial will be run with warmed tooling.
- Tailor welded blank quality still needs to be improved.
- Complete the forming trial of newest alloys and evaluate the formed part properties.
- Additional cost reduction is still needed to reach the goal.

# Proposed Future Work

- Move the tooling to a different location for future trials
- Forming trial using the latest new alloys produced.
- Forming trial with warmed tooling
- Additional forming trial of TWB with improved quality
- Additional cost reduction options to be explored.

- This project is concluding January 31, 2019.  This is the last AMR presentation for this project.

# Summary

- Initial Warm forming trials on a representative demonstration part have been conducted on 7055 and 4 new alloys.
- Alloy 180-101 has shown the best forming and TWB forming performance to date. It's strength is below the DOE targets (about 570 MPa UTS, 11% elongation after WF and PB).
- Alloy 180-101 corrosion testing is complete and acceptable.
- TWB produced using alloy 180-101 were successfully formed. Additional improvement of weld quality is required.
- Two additional alloys have been produced. New Alloy 1 meets the DOE UTS target of 600MPa but does not reach the elongation target
- The higher strength alloys did not provide the desired bending (measured by 3-point bend tests) behavior, we are recommending the lower strength New Alloy 2 for future study.
- The corrosion testing of the two new alloys is underway.
- Final evaluation of new alloys relative to formability, corrosion and toughness (3 point bend) will be completed.
- Cost of 7xxx aluminum warm formed part was $2.26/lb saved relative to the UHSS part.

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