Low-Cost Corrosion-Resistant Coated Aluminum Bipolar Plates by Elevated Temperature Formation and Diffusion Bonding

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Project ID: FC344

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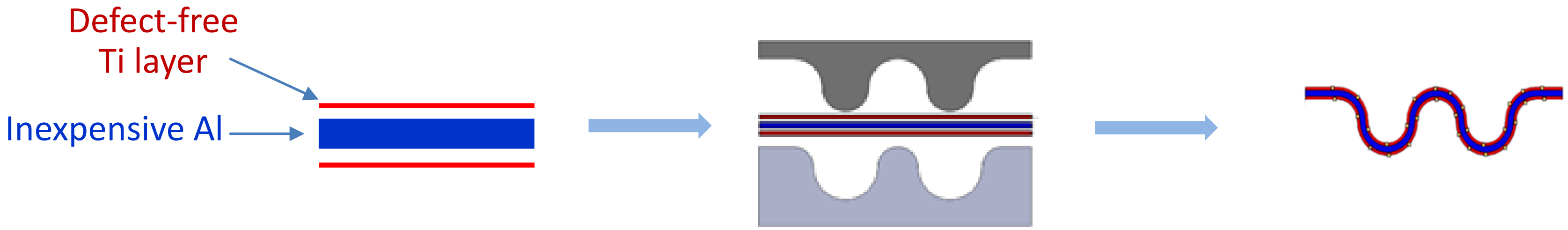
PNNL-SA-183949

TreadStone Technologies, Inc.

Project Goal

- Develop and test a defect-free coating process to fabricate low-cost corrosion-resistant coated aluminum for use as bipolar plates for PEM fuel cells.
- Fabricate full-size bipolar plates and demonstrate progress towards meeting HFTO 2030 technical targets for bipolar plates



Elevated temperature forming (ETF) and diffusion bonding (DB) process

Lower cost Al based bipolar plate

Overview

Timeline and Budget

- Project Start Date: 12/01/2021
- Project End Date: 11/30/2024
- Total Project Budget: $1,565K
  - DOE Share: $1,252K
  - Cost Share: $313K (20%)
  - DOE Funds Spent*: $ 360 K
  - Cost Share Funds Spent*: $ 32 K

  * As of ~ 03/30/2023

Barriers & Challenges

- Targeted bipolar cost of 5 $/ kW
- Die design and forming process development for extremely small tolerances and complex geometries
- Performance of the bipolar plate

Partners

- Pacific Northwest National Laboratory
- TreadStone Technologies, Inc.
- Project lead: Raytheon Technologies Research Center

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Relevance

- Bipolar plates are one of the crucial components of the PEM fuel cell stack, and significant contributor to the stack weight, volume and costs.
- Low-cost metal bipolar plates and fabrication technique(s) address barriers towards meeting HFTO 2030 cost target ($5/kW) and performance targets for heavy-duty applications.

Barriers	DOE Targets	Project Impact
Cost	5 $/ kW	• Develop Al based metal bipolar plates instead of SS or Titanium alone, and fabrication technique(s) to enable cost targets to be met
Durability	25,000 hrs	• Develop defect-free corrosion-resistant Ti coating and optimize DOTS technology (TreadStone) using carbon particles or gold to meet performance and durability targets
Performance	• Corrosion, Anode (μA/cm^2): < 1, no active peak • Corrosion, Anode (μA/cm^2): <1 • Electrical Conductivity (S/cm): > 100 • Contact Resistance (mΩ.cm^2 at 200 psi): 10	

Project objectives and impacts are directly in-line with HFTO 2030 Targets

Approach -- Light Weight Aluminum with Thin Ti Coating

- Aluminum is lightweight, formable, strong, conductive, and inexpensive but prone to corrosion.
- Ti coating on Al through elevated temperature forming (ETF) & diffusion bonding (DB) with high corrosion resistance (Figures 1& 2): proof of concept demonstrated by PNNL

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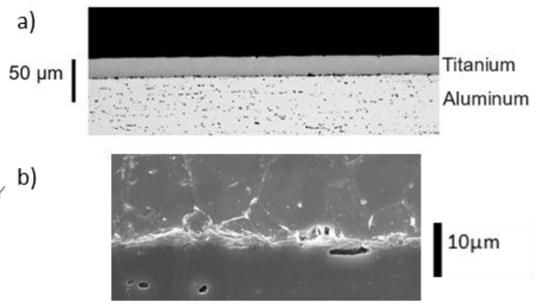

Figure 1. Diffusion bonded Ti to Al

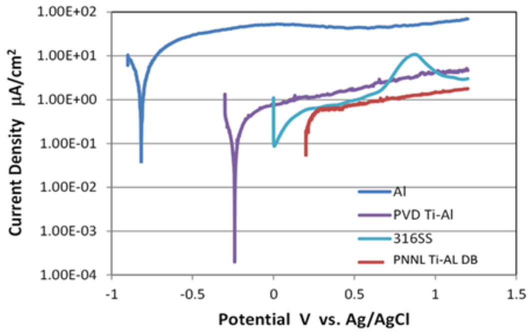

Figure 2. Anodic scan in pH 3 H_2SO_4 and 0.1 ppm HF solution at 80°C

- DOTS technology to deposit gold particles for improved electrical conductivity
  - Has been used for PEMFC and PEM electrolyzers applications for 10 years

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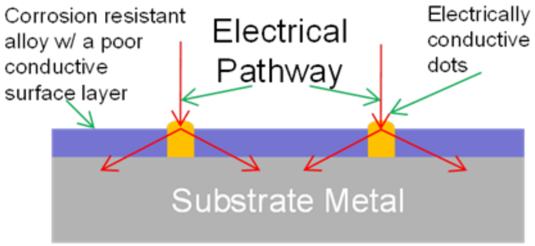


Figure 3. Schematic of DOTS deposition

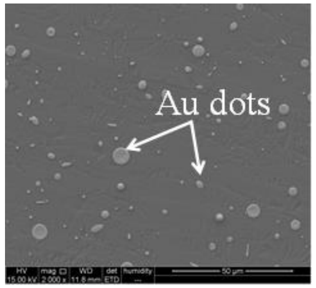
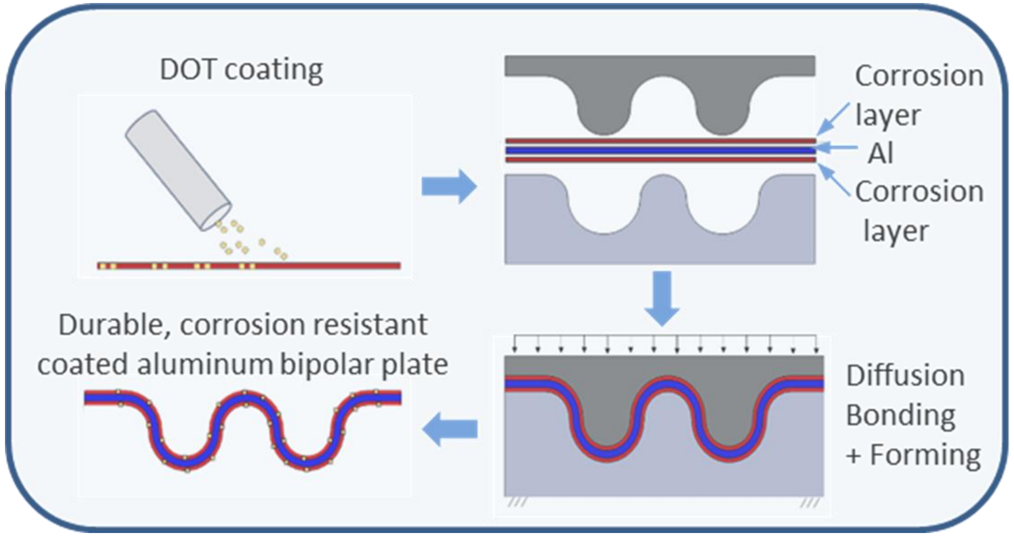


Figure 4. SEM of Au dots on stainless steel plate

Approach – Fabrication Process



(A) ETF Optimization (Y1)

- Optimize PNNL ETF process to minimize forming time, die wear, and geometry reproducibility

(B) ETF+DB Optimization (Y1)

- Incorporate diffusion bonding process into ETF. Optimize for adhesion strength of DB.

(C) Conductivity Optimization (Y2)

- Minimize contact resistance evolution with incorporation of tracers (PNNL) or DOTs/DuraC (TreadStone)

(D) Bipolar Plate Fabrication and Testing(Y3)

- Manufacture full size plates and perform in-cell testing

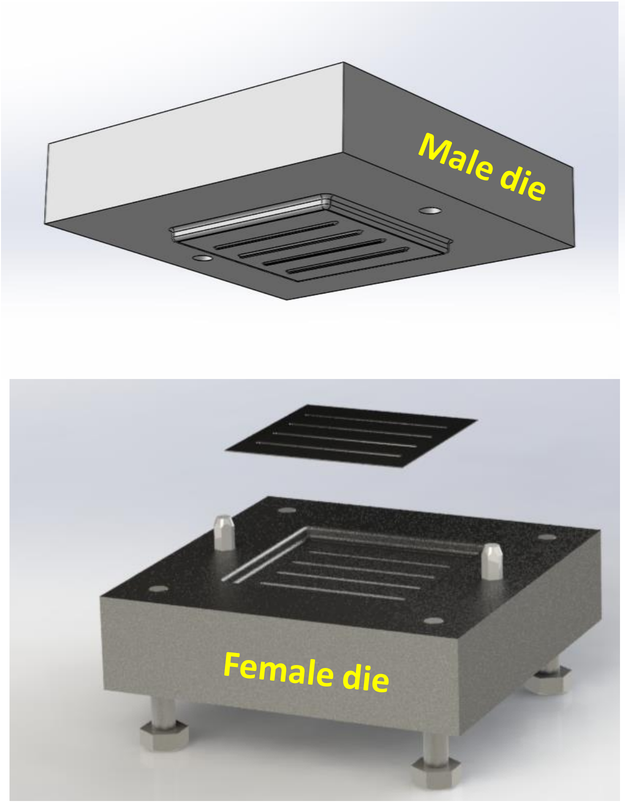
<u>Go/No Go Decision Point #1</u> (May 30th 2023)

- Techno-economic analysis and initial test data establishes that coated or DB coupons fabricated using ETF are projected to meet mechanical technical targets for heavy-duty bipolar plates. Techno-economic analysis will be performed using the same inputs and assumptions as that performed for automotive fuel cell bipolar plates by Strategic Analysis.
- The DB coupons will meet the following targets: flexural strength > 40 MPa evaluated per ASTM D790-10; and forming elongation of > 40% per ASTM E2448-18.

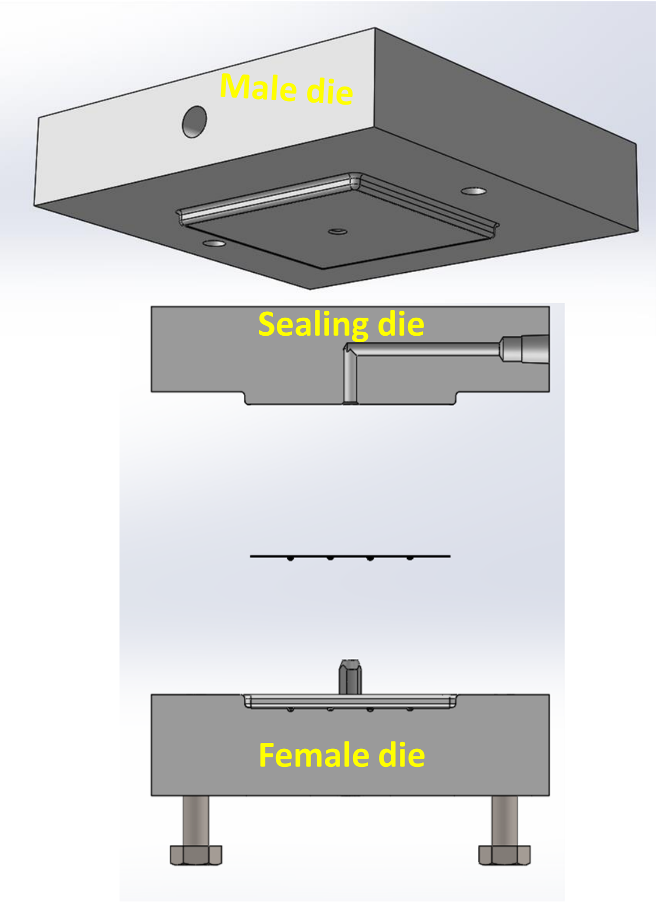
Accomplishments: Completed Validation Die Design and Fabrication

Generate forming trial data to aid subscale and full-scale die design

Male / Female forming

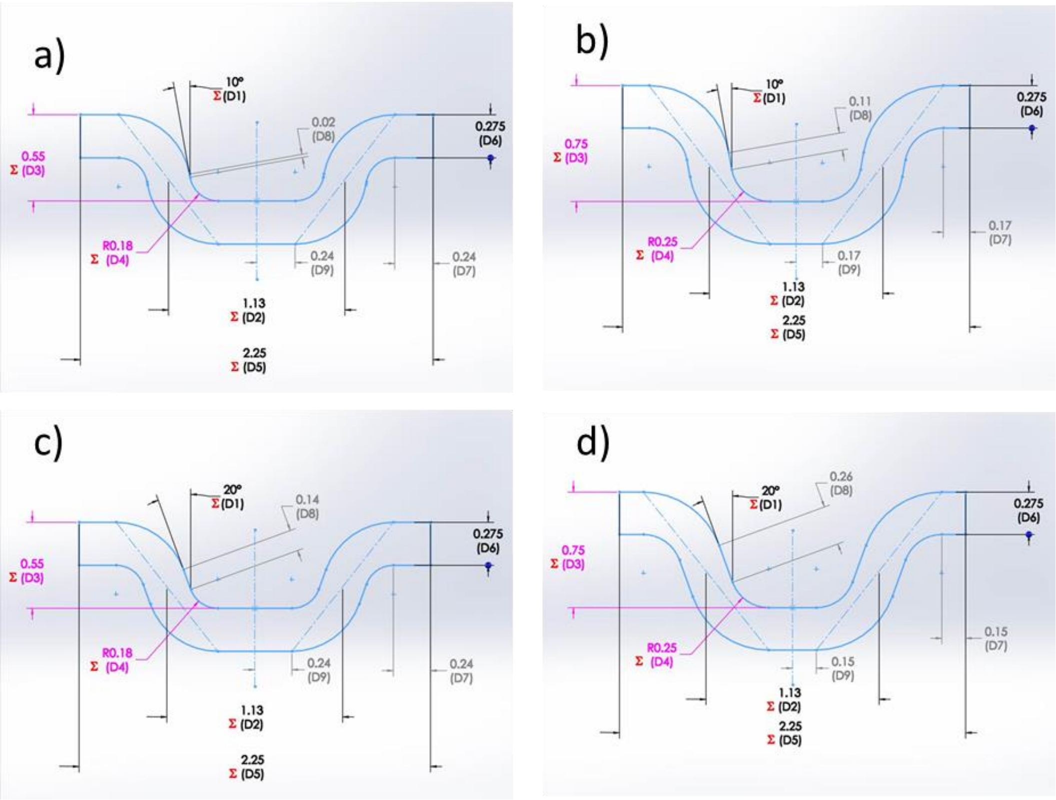


Gas forming



4 variants in channel depth and edge angle

- 25 µm Grade 2 Ti to 0.25 mm 1100-O Al
- Significant spacing to avoid forming interactions between channels



Accomplishments: Demonstrated Flexural Strength & Forming Elongation

Elongation needed is <30% ➔ potential to significantly increase forming speed

Tensile test results for 0.25 mm 1100-O aluminum diffusion bonded to 25-micron grade 2 titanium mini-E-8 specimens at 400°C, **Target >40%**

Run	Strain Rate (s^{-1})	Elongation (%)
1	0.005	50
2	0.0125	43
3	0.02	33
4	0.1	32
5	0.0125	44
6	0.0125	47

Flexural strength of > 40 MPa: demonstrate by PNNL in a separate DOE funded project, (figure from final report)

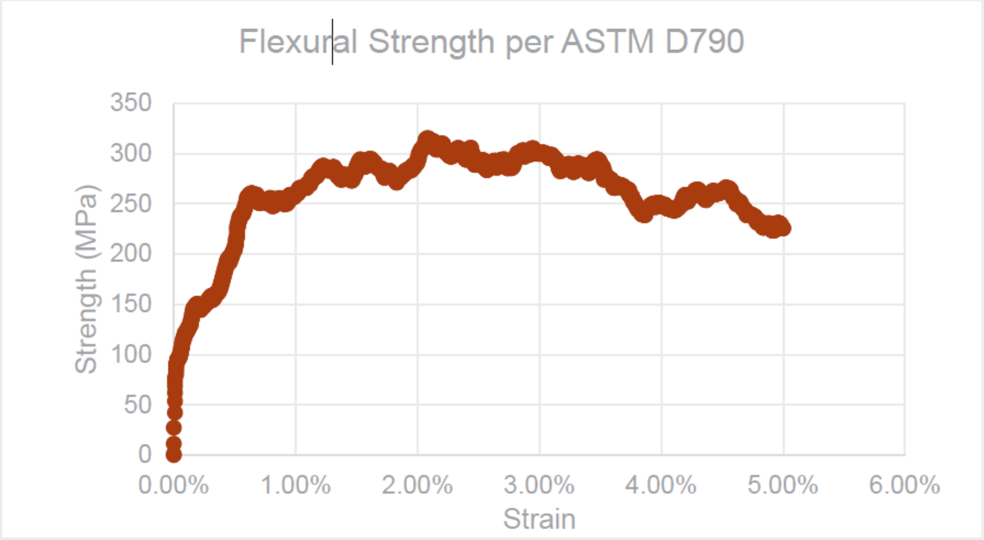
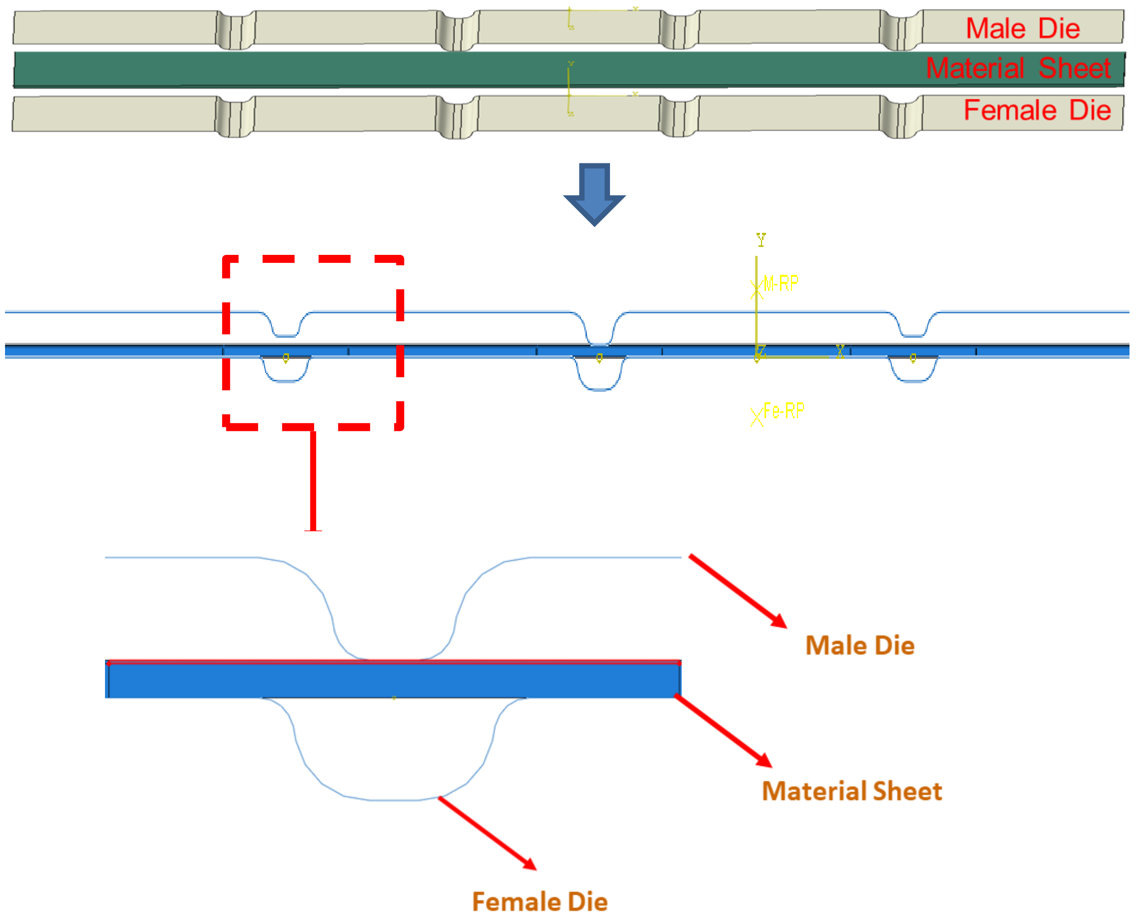


Figure 33. Average Flexural Strength Testing Data

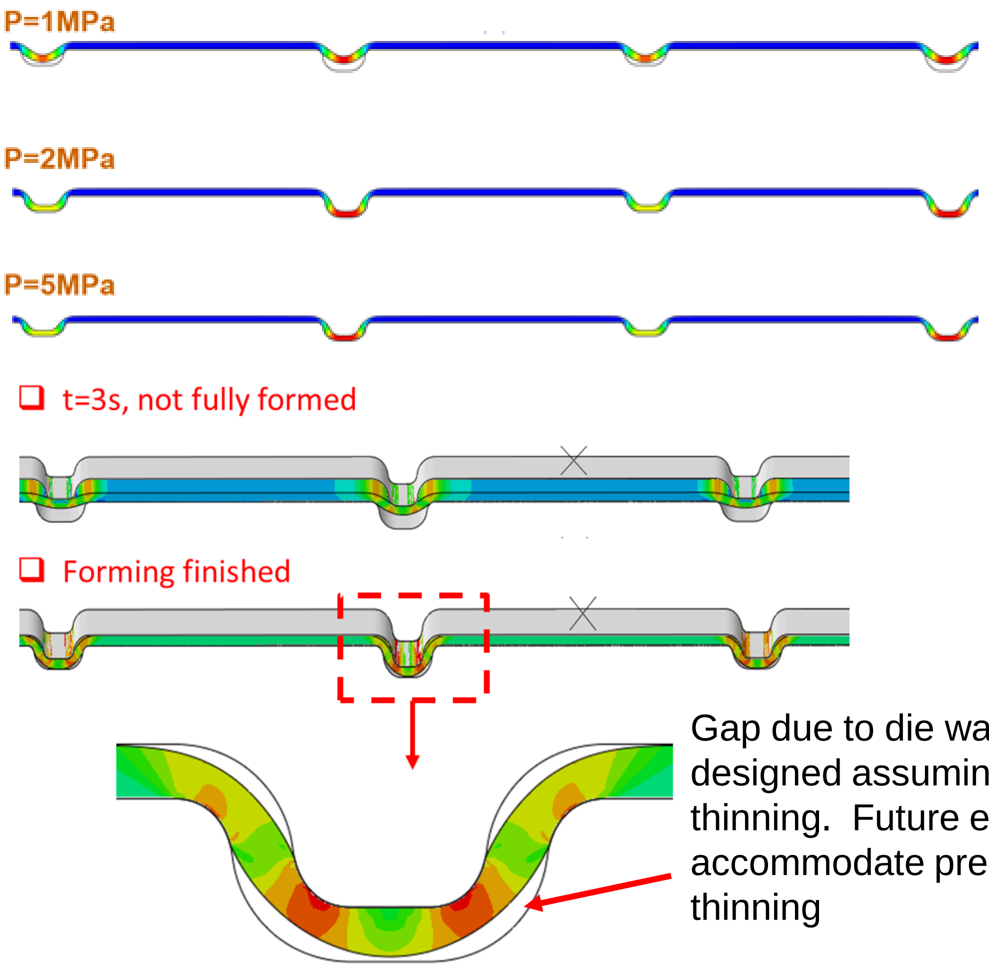
~200 mm x ~200 mm sections of 25 μm grade 2 titanium diffusion bonded to 0.5 mm 1100-O aluminum

Accomplishments: FEA Modeling for Process Optimization in Progress

Model setup for 4 channel Die



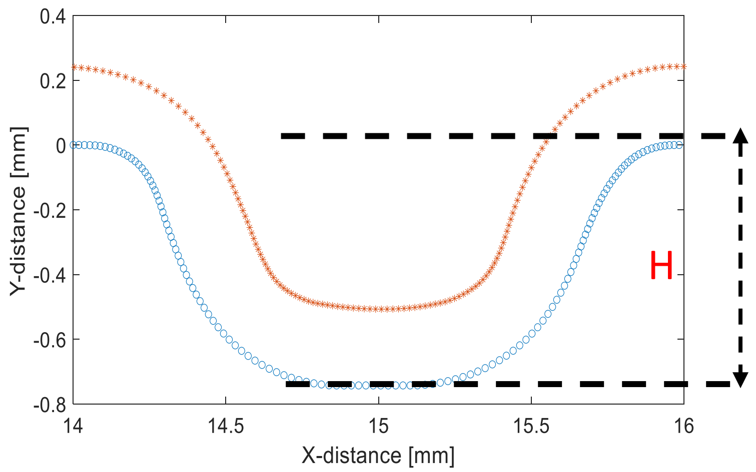
Simulation of Al forming to evaluate forming time and pressure, 400 °C

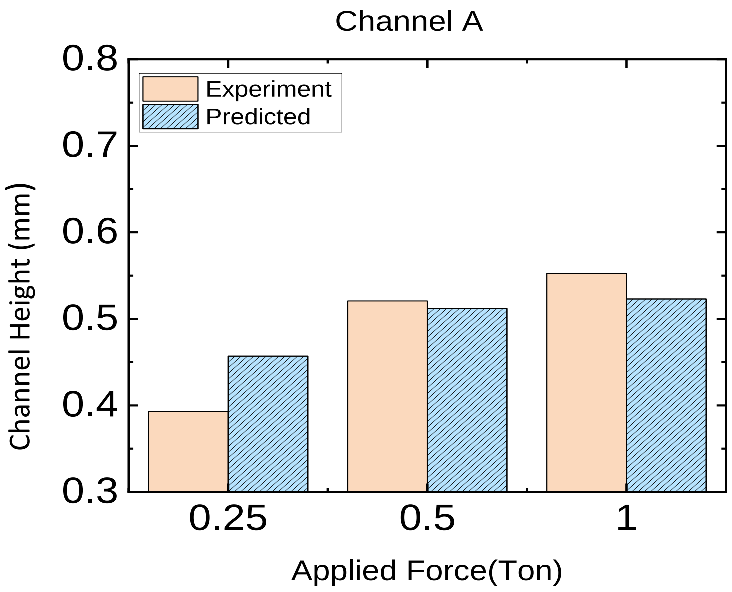


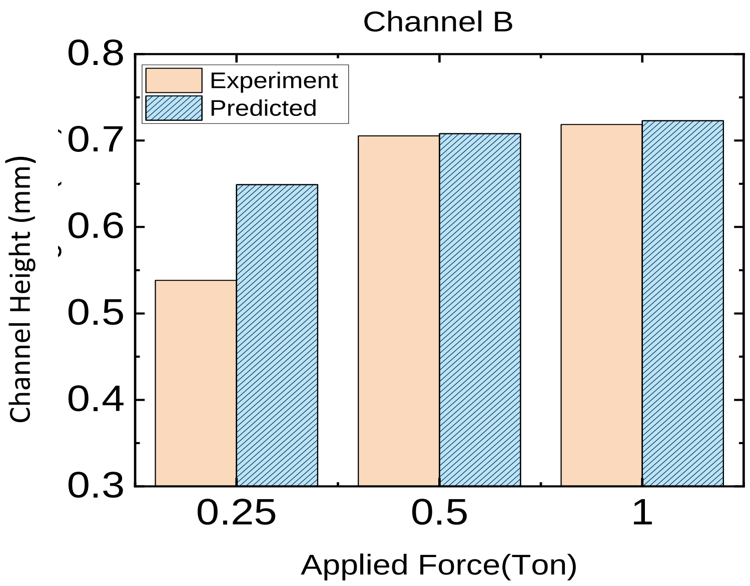
Gap due to die was designed assuming no thinning. Future efforts to accommodate predicted thinning

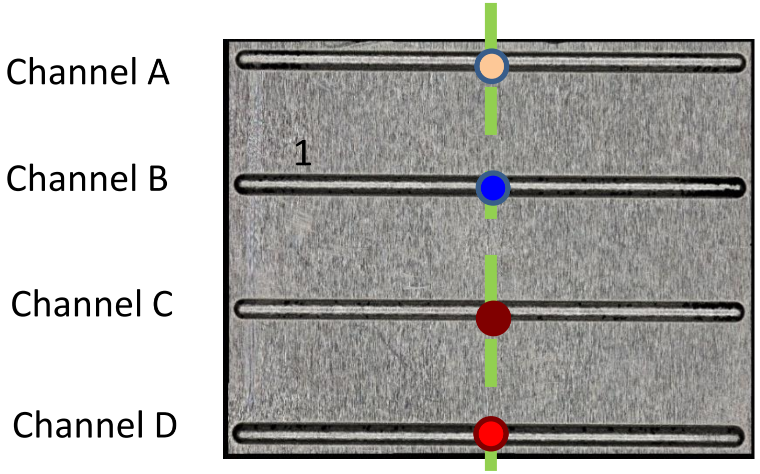
Accomplishments: FEA Modeling for Process Optimization in Progress

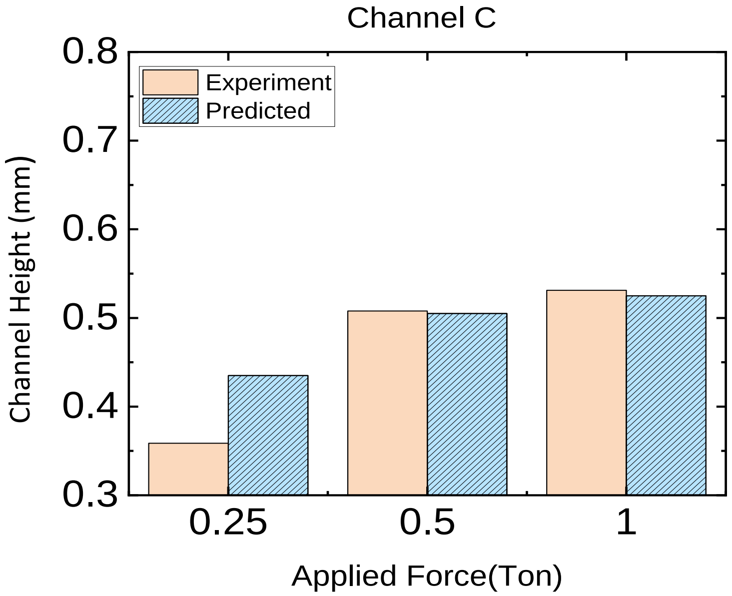
Prediction of channel height mostly consistent with experiments

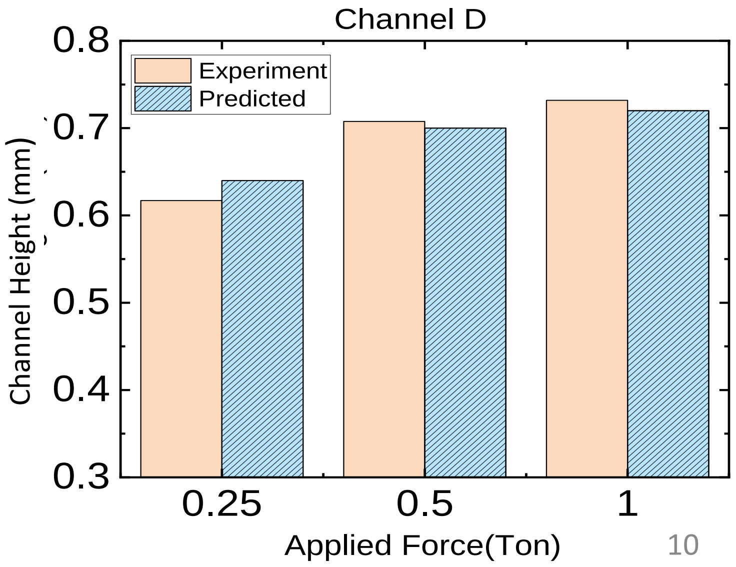








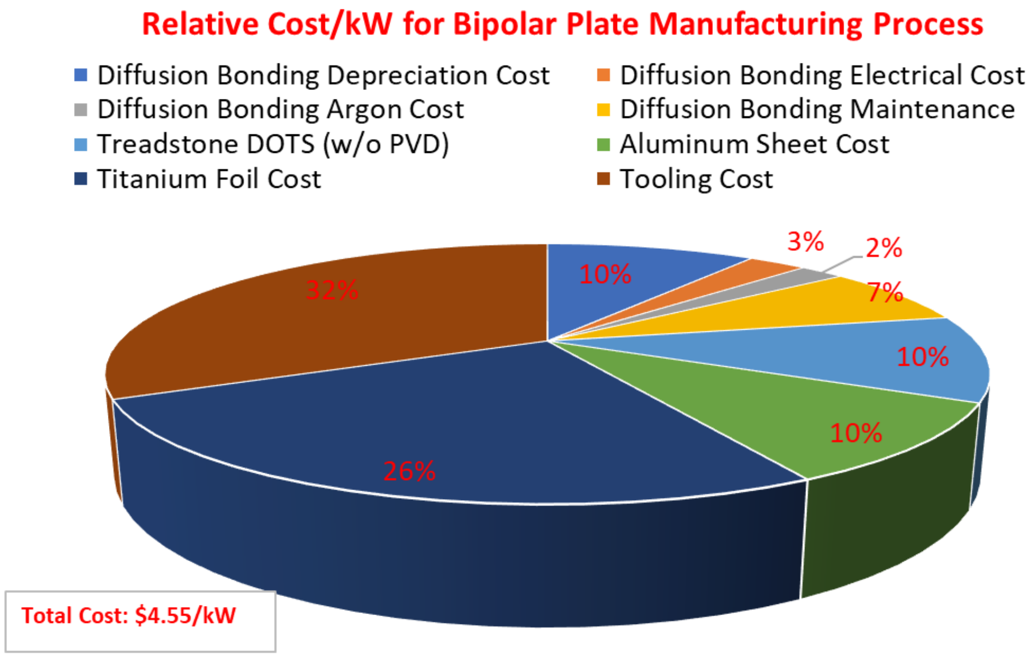




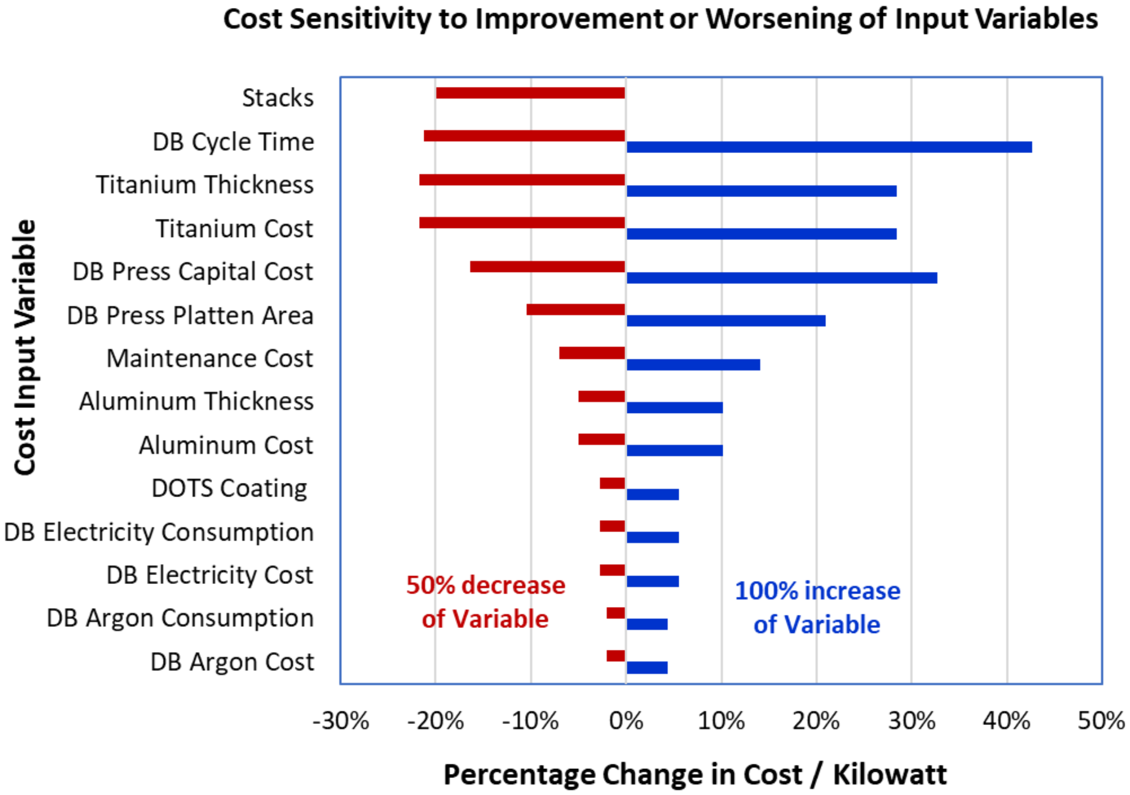
Accomplishments: T2M Analysis Of Current BP Fabrication

Current Estimate $4.55/kW for Ti/Al

- 0.25 mm Al and 0.01 mm Ti
- 340 cm^2 overall area, 217 cm^2 active area
- 377 bipolar plates in fuel cell stack
- DB Cycle Time: 15 minutes
- Stack of 2
- $5.72/kW for Ti/Al/Ti



Most sensitive factors are DB cycle time/stack, and Ti sheet cost/thickness

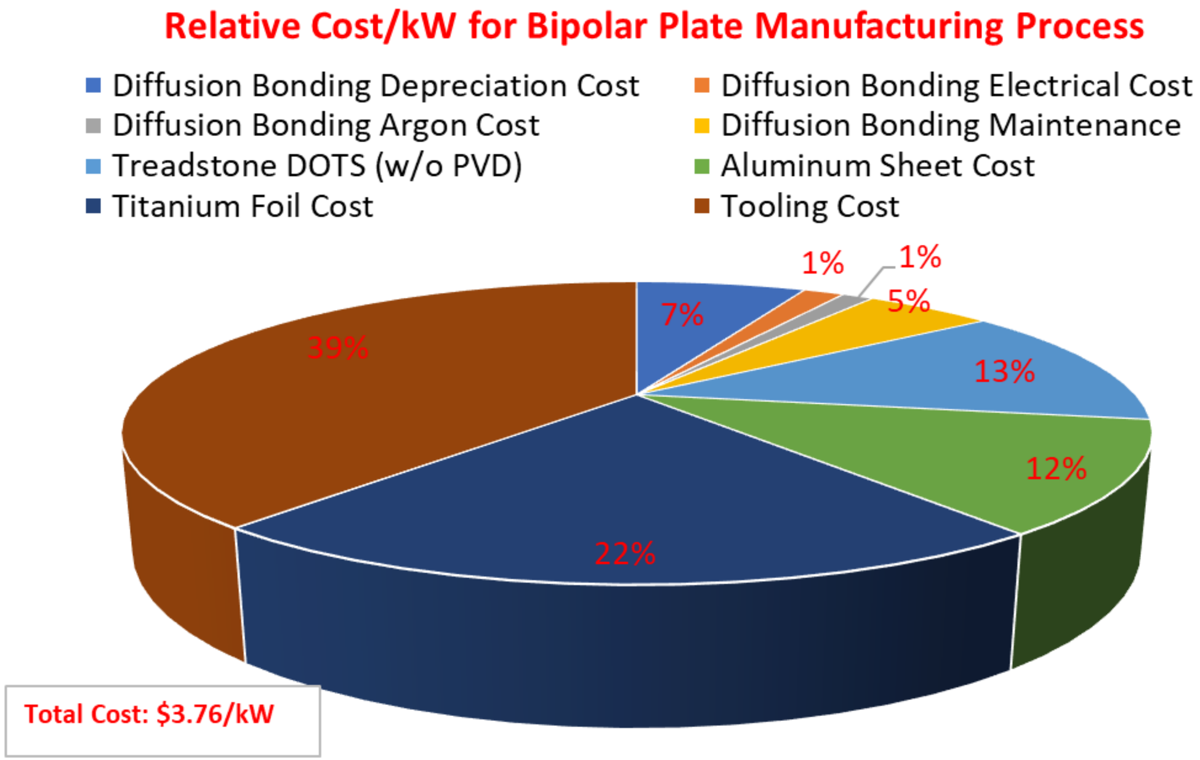


Accomplishments: T2M Analysis Provided Paths to Meet Cost Target

Potential Future State

- Diffusion bonding operation:
  - Cycle Time: 15 minutes
- **Stack of 4**
- Aluminum thickness: 0.25 mm
- **Titanium thickness: 0.007 mm (not currently available, needs to be developed)**

- **$3.76/kW for Ti/Al**
- **$4.58/kW for Ti/Al/Ti**



Collaborations

Company	Role	Logo
Raytheon Technologies Research Center	• Project lead • Corrosion Testing • Electrical Testing • Accelerated Stress Testing • 100-Hr full-cell durability test	Raytheon Technologies
Pacific Northwest National Laboratory	• ETF+DB Process Optimization • Bipolar Plate Fabrication • Mechanical Testing	Pacific Northwest NATIONAL LABORATORY
TreadStone Technologies, Inc.	• DOTs Optimization	TreadStone Technologies, Inc.

Remaining Challenges and Barriers

- **Challenges and approaches:**
  - Engineering challenges associated with die design and forming process development for extremely small tolerances and complex geometries needed for next generation bipolar plates
    - Much of the key technical risks of DB and forming have been addressed through the proof-of-concept work performed so far by PNNL. The remaining risk is mitigated by PNNL's leading expertise in solid-phase processing.
  - The proposed plates have not yet been operated within a fuel cell. Issues may exist that were not exposed by prior testing and analysis.
    - Leverage RTRC's expertise in fuel cell design, testing and failure analysis, as well as TreadStone's experience in the development of corrosion barriers for metal bipolar plates, to address potential unseen issues in using current bipolar design for PEM.

Proposed Future Work

BP1 (End May 31, 2023)

- Complete initial corrosion testing of DB treated subscale validation die coupons fabricated using ETF
- Meet BP1 Go/no G: flexural strength > 40 MPa and forming elongation of > 40% / TEA pathway to < $5/kW

BP2 (June 1, 2023 – May 31, 2023)

- Design of Experiments for ETF+DB process
- Generate 10 multimaterial subscale coupons with repeatable channel features within ±15µm
- Optimize DuraC coating and integrate with ETF process
- Finalize approach to integrate advanced coating into bipolar plate forming process
- Finalize full scale (200-250 cm^2 active area) design

BP2 Go/no Go: **anode corrosion < 1 µA/cm2 with no active peak, cathode corrosion < 1 µA/cm2, ASR < 0.01 Ωcm2, TEA < $5/kW**

Summary

- **Objective**: Develop and test a simultaneous forming and defect-free coating process to fabricate low-cost corrosion-resistant coated aluminum for use as bipolar plates for PEM fuel cells

- **Relevance:** This project addresses fuel cell cost and durability by developing low-cost corrosion-resistant coated aluminum bipolar plates and fabrication techniques. The project is directly in-line with HFTO 2030 Targets.

- **Approach:** develop Al based, corrosion resistant (by Ti coating), bipolar plates through ETF-DB and DOTS technologies that aims to meet the HFTO 2030 technical and cost targets for bipolar plates.

- **Accomplishments:**
  - Establish validation die and process modeling
  - Demonstrated flexural strength & forming elongation per BP1 GO/NO GO target
  - Identified paths to meet DOE bipolar cost target

Acknowledgement

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