Lab Call FY19: Solid Phase Processing for Reduced Cost and Improved Efficiency of Bipolar Plates

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Subcontractor:
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Project End Date: March 31, 2021

Overall Objectives

- Identify the fabrication concepts with the greatest potential to meet or surpass 2020 technical targets for bipolar plates.
- Develop coupons at the sub-scale level for down-selected concepts.
- Complete inspection and testing on sub-scale components toward prescribed 2020 technical targets.
- Down-select concept for full-scale coupon.
- Develop and optimize the down-selected fabrication concept at full-scale coupon level.
- Complete inspection and testing toward prescribed 2020 technical targets.
- Report test data and analysis showing all 2020 technical targets, except cost, are met.

Fiscal Year (FY) 2019 Objectives

- Identify and rank the fabrication concepts with the greatest potential to meet or surpass 2020 technical targets for bipolar plates.
- Select fabrication concepts for continued investigation.
- Begin coupon-level development of fabrication concepts.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration Plan[1]:

- Improve Performance of Bipolar Plates
- Decrease Cost of Bipolar Plates
- Improve Durability of Bipolar Plates.

Technical Targets

This project will generate test data and analysis compared to the 2020 technical targets [1]. As not all targets have defined standards or specifications and some specifications are for non-metallic bipolar plates, test methods will be agreed upon with DOE prior to initiating. Testing criteria for technical targets are defined in the Fuel Cells section of the FCTO Multi-Year Research, Development, and Demonstration Plan [1]. Technical targets include: plate weight ≤0.4 kg/kW_{net}; plate H_2 permeation coefficient <1.3 x 10^{-14}, f @ 80°C, 3 atm, 100% relative humidity; corrosion, anode <1 $\mu A/cm^2$ and no active peak; corrosion, cathode <1 $\mu A/cm^2$; electrical conductivity >100 S/cm; areal specific resistance <0.01 ohm cm^2; flexural strength >25 MPa; forming elongation ≥40%.

FY 2019 Accomplishments

- Identified and ranked the fabrication concepts with the greatest potential to meet or surpass 2020 technical targets for bipolar plates.
- Selected fabrication concepts for continued investigation.
- Began coupon-level development of fabrication concepts.

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

INTRODUCTION

DOE cost estimates recently determined that bipolar plate costs are almost triple their targets of $3/kW even when production volumes for transportation applications are extrapolated to 100,000 to 500,000 polymer electrolyte membrane fuel cell systems per year. A major contributor to this problem is that the material cost for 316 stainless steel and titanium, two preferred sheet materials, prior to processing is already above DOE target costs. Stainless steels also have the disadvantage of being heavy, making it more difficult to achieve weight targets. Titanium is lightweight and, like stainless steel, offers some degree of corrosion resistance, but it also shares the problem of being expensive using traditional sheet materials. Another popular candidate plate material is the graphite/resin composite, which offers decreased material cost, weight, corrosion rate, and improved formability. Unfortunately, graphite/resin composite also offers decreases in strength and electrical conductivity, which is not advantageous for its bipolar plate candidacy. In addition, the resin's curing times are longer than acceptable for volume manufacturing. Aluminum solves most of the issues associated with the candidate sheet materials mentioned above in that it is sufficiently lightweight, formable, strong, conductive, and inexpensive. The shortcoming of aluminum is its low corrosion and oxidation resistance, which requires it to have a coating to prevent these unwanted processes. Stainless steels also require coatings, but they provide sufficient inherent corrosion resistance that defects in the coatings are tolerable. However, in the case of aluminum, the coatings should be pinhole-free because of the propensity of aluminum to corrode and to form an electrically resistive oxide film.

APPROACH

This project will develop and demonstrate new solid phase processing methods to fabricate aluminum-coated bipolar plates such that all 2020 technical targets for bipolar plates are satisfied with particular focus on increasing the durability and conductivity while reducing cost. Thorough lab testing and techno-economic analysis of full-scale parts will be completed with the objective of demonstrating compliance with 2020 technical targets. Methods and results will be documented and provided to fuel cell stakeholders.

Solid phase processes enable economic and material performance advantages in many applications. Solid phase processes are known for their ability to create materials with enhanced performance. These properties enable advanced design techniques and process intensification methods. A fabrication concept is a combination of design techniques, manufacturing processes, and materials. Application of solid phase processing to overcome technical barriers associated with fabrication of bipolar plates is described in Table 1.

Table 1. FCTO-Defined Technical Barriers [1] and Tasks, and Corresponding Project Strategy

FCTO-Defined Barriers and Tasks	Project Strategy
Improve Performance of Bipolar Plates • Decrease weight and volume • Develop coatings to eliminate plate corrosion and maintain conductivity	Multi-material design enables improved performance Elevated temperature forming (ETF) of titanium-coated aluminum sheet Potential use of internal and/or external high conductivity tracers for improvements in conductivity
Decrease Cost of Bipolar Plates • Evaluate the use of different low-cost materials and coatings to improve corrosion resistance	Simultaneous ETF and diffusion bonding enables foils to potentially be bonded to plate during forming Advanced cold spray for corrosion barriers Cold spray enables selective property modification Cold spray can be used for high speed joining/sealing within little to no distortion. Use of internal and/or external high conductivity tracers with the cold spray powder can be used for improvements in power density
Improve Durability of Bipolar Plates • Identify degradation mechanisms • Develop strategies/technologies for mitigating degradation	Use of multi-material design Industrial collaborator, TreadStone, is a leader in developing corrosion barriers for bipolar plates

The first phase of this project is to identify the fabrication concepts with the greatest potential to meet or surpass 2020 technical targets for bipolar plates. This will be done by creating a cost analysis and concept scoring tool. This tool is created to rank conventional as well as new solid phase processing fabrication concepts. An important feature of this tool is that it captures nonobvious but highly impactful interactions using math models, for example, values associated with design enabling increased power density. Industry collaborators will provide feedback on the tool and ranking to ensure assumptions and analysis comply with realities of high-volume automotive production.

The second phase is to develop and optimize the down-selected fabrication concept(s). Fundamental development of these fabrication concepts will occur at the coupon level. Coupons will be tested and analyzed to establish a technical basis for their success in meeting 2020 technical targets. The final phase is development and testing of one-half of a full-scale bipolar plate. The project intends to develop one side of the plate, which would eventually be attached to the other side in future phases of the project to form a fully functional bipolar plate.

RESULTS

The primary objective of Task 1 was to rank concepts and down-select the most promising concepts. A simplified cost model was provided by Strategic Analysis, Inc. This simplified model was combined with published data to create a cost model. The TreadStone Technologies, Inc. “dots” concept was the baseline cost point. The baseline costing and simplified cost model was used to generate a fabrication cost score for bipolar plate fabrication concepts.

Inputs to the concept scoring matrix included fabrication cost, plate weight, H_2 permeation coefficient, electrical conductivity, corrosion resistance, through-plate electrical conductivity, areal specific resistance, flexural strength, and forming elongation. Concept scoring employs simplified models and best estimates to identify the concepts most likely to meet design criteria and cost targets out of dozens of concepts generated.

Top-ranked fabrication concepts included ETF, ultra-high-velocity cold spray, diffusion bonding, or a combination of these technologies. ETF refers to processes where forming occurs at elevated temperatures to achieved improved elongation. Examples include but are not limited to warm forming, hot forming, and super plastic forming and their variants. ETF provides the ability to form large-surface-area parts due to the low flow stresses that can allow for multi-part forming operations in one cycle that not only reduces manufacturing costs but also increases throughput.

High-pressure cold spray systems can deposit titanium powders with less than 1% porosity and no interconnected porosity. A process diagram for high-pressure cold spray is shown in Figure 1. A single cold spray nozzle can deposit titanium at deposition rates exceeding 12.5 g/s (99.2 lb/h). Multiple nozzles can be used simultaneously to increase deposition rate linearly with number of nozzles. Cold spray can also be used for additive manufacturing. Cold spray is already used for corrosion barriers for various automotive and aerospace applications. Significant cost savings should be achieved by spraying titanium coating directly onto bipolar plate material instead onto sputtering targets. Furthermore, sputtering requires 10s of minutes to put down a sub-micron layer and build rates are measured in Å/s. Cold spray coating of titanium-based coating onto aluminum before or after ETF are high ranked fabrication concepts.

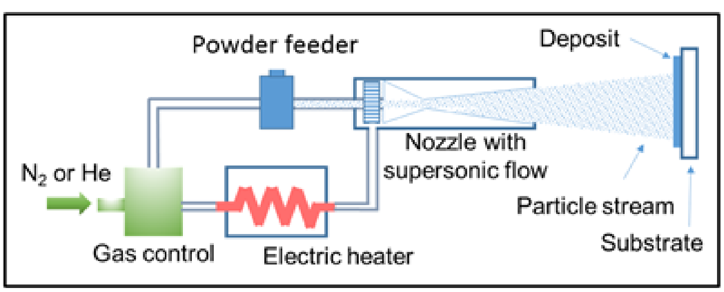

Figure 1. High-pressure cold spray process diagram

Diffusion bonding is a solid phase joining process whereby metallurgical bonding occurs due to elevated temperature and pressure at the interface. Top-ranked bipolar plate fabrication concepts include diffusion bonding of titanium foils to aluminum plate after ETF and potential diffusion bonding of aluminum to titanium during ETF.

A technical review of top-ranked concepts was executed to establish viability, identify technical risks, and select materials for coupon development work. Materials have been down-selected and procured for initial coupon development and testing. Forming simulation efforts have begun to identify optimal starting parameters for ETF. Die design for coupon-level forming test is near completion.

CONCLUSIONS AND UPCOMING ACTIVITIES

Work done in FY 2019 has established the following as bipolar plate fabrication concepts that are most likely to meet targets established by FCTO:

- Simultaneous ETF and diffusion bonding of titanium-based coating layers to aluminum base material
- Iterative ETF and diffusion bonding of titanium-based coating layers to aluminum base material
- Cold spray coating of titanium-based coating layers onto aluminum-based material after ETF
- TreadStone’s existing coating processes applied to aluminum-based materials before and after ETF
- Potential addition of tracer material in titanium-based coatings to create improved electrical conductivity across and through coatings.

In FY 2020 this project will execute coupon-level process development and characterization, subscale forming and characterization, and start full-scale forming work. While multiple fabrication concepts may be investigated at the coupon level, only one fabrication concept will be developed and characterized at full scale.

The objective of the coupon-level development and characterization is to demonstrate that fabrication concept(s) have the potential to meet or exceed 2020 cost and performance targets for bipolar plates. PNNL equipment for developing fabrication concepts is shown in Figure 2. The secondary objective is to understand the process parameter relationships versus the geometric control and repeatability of flow channel test geometries, plate stiffness, arc specific resistance, conductivity, corrosion of the anode and cathode, electrical conductivity, and hydrogen permeation coefficient.

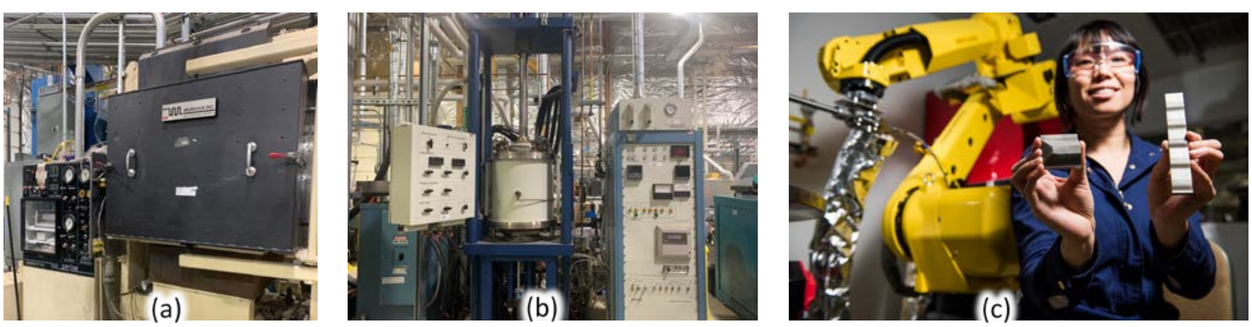

Figure 2. PNNL equipment for coupon fabrication in FY 2020: (a) super plastic forming machine; (b) vacuum hot press; and (c) high-pressure cold spray robotic system

Sub-scale forming and characterization work develops an understanding between the process parameter and the plate flatness, geometric control and repeatability of flow channels, plate stiffness, arc specific resistance, conductivity, corrosion of the anode and cathode, electrical conductivity, and hydrogen permeation coefficient. This data will be used to down-select one of the fabrication concepts for the full-scale component.

REFERENCES

1. Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan, 2016 Fuel Cells Section, https://www.energy.gov/sites/prod/files/2017/05/f34/fcto_myrdd_fuel_cells.pdf.