V.D.1 Scale-Up of Carbon/Carbon Composite Bipolar Plates*

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Contract Number: DE-FC04-02AL67627

Subcontractor:
UTC Fuel Cells, Inc., South Windsor, CT

Start Date: May 2002
End Date: November 2006

*Congressionally directed project

Objectives

- Develop near-net and net-shape molded carbon/carbon bipolar plate materials that meet or exceed customer and DOE requirements.
- Develop process for manufacturing materials with high consistency.
- Evaluate the performance of the bipolar plate materials through fuel cell stack testing.
- Develop deliverable 10 kW fuel cell stack.
- Develop comprehensive cost evaluation of material and process.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section (3.4.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability
(B) Cost
(C) Electrode Performance

Technical Targets

The DOE technical targets and Porvair's current status is shown in Table 1. The cost per kW shown as current status reflects current manufacturing capability (approximately 20,000 bipolar plate pairs per year). Product pricing is greatly influenced by the manufacturing rate. Bipolar plate cost projections over volume are provided in more detail in this report.

TABLE 1. DOE Property and Cost Targets and Current Status

Porvair Progress Toward Meeting DOE Bipolar Plate Property and Cost Targets			
	Units	**2010/2015 Targets**	**Current Status**
Cost	$/kW	6/4	<150
Weight	kg/kW	<1	<0.5
H_2 Permeation Rate	cc/cm^2/sec (80°C, 3atm)	2x10^{-6}	2x10^{-5}
Corrosion Resistance	mA/cm^2	<1	
Electrical Conductivity	S/cm	>100	>500
Resistivity	Ohm/cm^2	<0.01	
Flexural Strength	MPa	>4 (crush)	>34 (flexural)
Flexibility	% deflection at mid-span	3-5	>10

Accomplishments

- Manufacturing process improvements realized this year with new system compared to original (Phase I system).
  - Improved material utilization by more than 80%
  - Doubled productivity (as measured by plates produced per worker per unit time)
  - Reduced internal product cost by more than 75%
  - Reduced customer costs considerably by providing parts in net shape (eliminated customer machining costs)
- Characterized material shrinkage characteristics over a wide variety of fuel cell channel designs to enable the design of mold tooling for new bipolar plate designs.
- Characterized methods for wetting angle control and durability.

- Manufactured, tested and delivered plates for stack testing.
- Optimized sealing method to reduce process time and labor, and to improve sealing effectiveness.

Introduction

Bipolar plates are a key component in the construction of proton exchange membrane (PEM) fuel cells. In 2001, Porvair Advanced Materials, Inc. (PAM) licensed a promising carbon/carbon composite bipolar plate formation technology from Oak Ridge National Laboratory. The carbon/carbon material has specific advantages for PEM fuel cells in that the material is highly conductive, has high strength and is chemically stable. The goal of PAM through the assistance of this DOE co-funded project has been to transfer this novel technology from the laboratory to full-scale, low-cost mass production to meet the emerging need of the rapidly developing fuel cell industry. The DOE-sponsored project is directed at moving the technology to a manufacture-capable material that can meet the performance, durability and cost demands of the fuel cell industry. The project is further designed to demonstrate product performance in fuel cell testing, and to project the cost of the product when in high volume manufacture.

Approach

Bipolar plate costs are driven by process efficiency, materials utilization and production labor. The approach in this project to demonstrate the feasibility of the manufacturing process to meet the 2010 and 2015 DOE cost targets for bipolar plates has been to focus upon process consistency improvements (to improve product yields and process control), labor reduction, and process rate improvements. To achieve these goals, specific activities have been performed in this project that range from process development, materials development and product demonstration.

The taken approach in materials development utilized information fed back to Porvair by our customers following product property and fuel cell testing. Specific needs from our customers were evaluated relative to the current state of the product or process development to guide improvements leading toward the manufacture of a better bipolar plate. Internally, materials development efforts were guided through the performance of statistically designed experiments, set up in orthogonal arrays of experiments.

Process improvement activities were accomplished through two approaches. The first utilized process design to economically design and build process improvements to improve product consistency and reduce process production times. The second approach utilizes process lean activities (lean events, value stream events, and other manufacturing improvement activities) performed periodically to critically evaluate the current state of the process and to eliminate unneeded steps to reduce overall product production times.

Exploratory process development activities were approached in this project from two perspectives. The first involves materials development efforts that are designed to enable the utilization of one or more significant process improvements (these are significant process improvements to dramatically reduce process times). The second is through the design of the equipment required to demonstrate the advanced concepts. The steps investigated include the molding step to reduce process times from approximately 3 minutes per plate to less than 10 seconds per plate, and the plate heat treatment step to significantly reduce process times and costs.

Results

Manufacturing System Optimization

In 2004/2005, PAM significantly redesigned the manufacturing process to reduce material waste, to improve product consistency and to reduce labor requirements. In 2005/2006, the focus in manufacturing development shifted to refining the manufacturing process through system optimization. This focused upon evaluating and improving product consistency and quality.

The effort cumulated in a demonstration production trial of net shape anode and cathode plates in our customer's design. The data collected and evaluated from this trial is shown in statistical process charts for key measurable parameters throughout the process. Figure 1 shows the initial sheet weight capability for one plate style. The consistency of the initial sheet weight is highly important in the manufacturing process because this parameter drives the overall bipolar plate properties and characteristics as it progresses through the remainder of the process steps. The process capability for this parameter is $C_{pk} = 2.33$, indicating a highly controlled and capable process.

Figure 2 shows a process chart for finished plate thickness. The data shows that while this process shows excellent capability and control, the plate thickness is off-center somewhat. Process adjustments have been made to re-center the part thickness.

Material Shrinkage Characterization

In our process it is important to fully characterize the material shrinkage throughout the process so

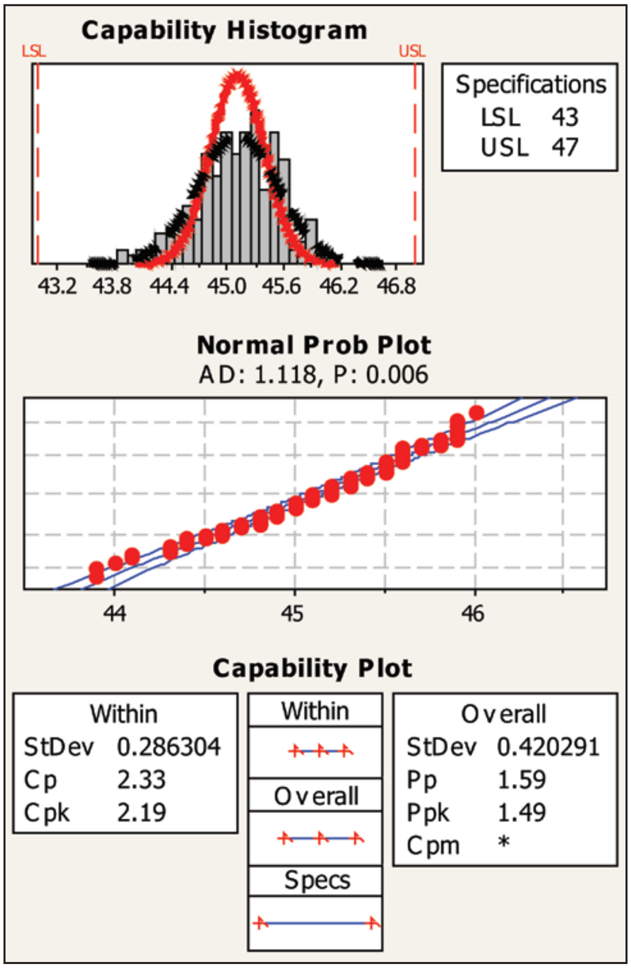

FIGURE 1. Formed Sheet Weight Stability and Process Capability

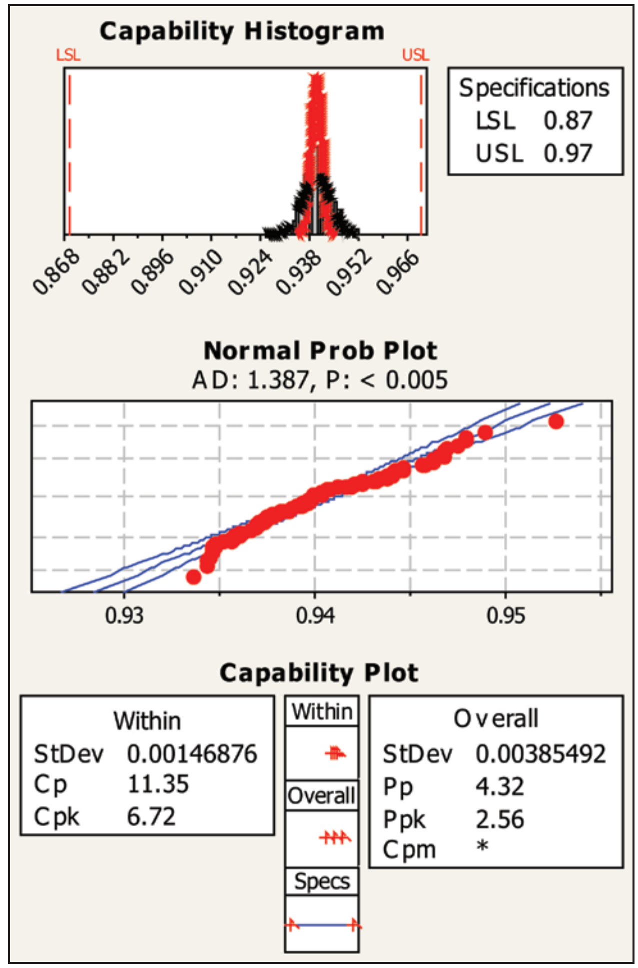

FIGURE 2. Final Product Thickness Stability and Process Capability

that new designs can be accurately manufactured. Because the PAM process is considerably different from other bipolar plate manufacturing processes, this characterization must be done from a fundamental level. The PAM material shrinks differently than other bipolar plate manufacturing technologies. To characterize the shrinkage rates accurately, we have measured several different flow filed designs over a wide range of channel width and depth. It has been found that the PAM material shrinks uniquely in the channel depth and channel width directions. Shrinkage rates depend upon specific ratios of channel height and channel width. Figure 3 shows results for channel shrinkage over a wide range of channel designs. As shown in this figure, rib width shrinkage rates decrease as the ratio of rib width to rib height increases. This is a result of our forming method and the materials utilized in formulation. A good degree of effort in this project was placed on the accurate measurement of channel features internally. An imaging analysis method was utilized to magnify the measurement region. A calibrated correlation between the image and a standard reference was utilized to obtain accurate measurements from the system.

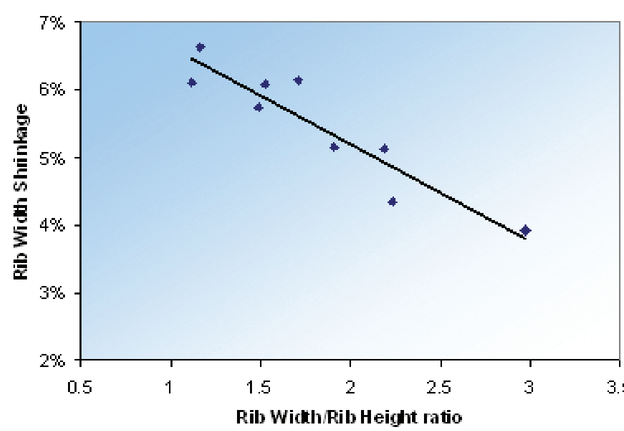

FIGURE 3. Channel Shrinkage Characteristics for a Wide Range of Flow Field Designs

A full gage repeatability and reproducibility study was performed with this system, indicating 14% gauge error relative to the tolerance specifications (a robust measurement system has 20% or less total gauge error).

Rapid Molding Development

The current method of applying the fuel cell flow field pattern to the bipolar plate at PAM is through a compression molding step that takes approximately 3 minutes per cycle. Cost and production analyses have determined that this rate is far too slow to be feasible in the long-term. Instead, production rates will have to increase significantly over the next few years to meet the DOE cost targets and customers' projected level of bipolar plate demand. PAM is investigating the potential of imparting the flow field pattern on the bipolar plate materials rapidly and accurately through a proprietary method. The total cycle time for this example is less than 8 seconds. Sample plates have been prepared using this method, but much work remains to be done. Provided that this rate of pattern replication can be maintained in a prototype production system, the system productivity will increase by a factor of 3-5, even without additional development activities to reduce other process bottlenecks. Work will continue in this area through the completion of the project.

Sealing Development

In 2005, PAM began investigating an alternative sealing method that promises to significantly reduce product costs and increase fuel cell performance, compared to the carbon vapor deposition method originally proposed for this project. The sealing method is proprietary. Measurements of sealing effectiveness show room temperature hydrogen permeability of $2x10^{-5}$ $cc/cm^2/sec$, with hydrogen back pressure of 30 psig. Soaking in 80°C 0.1M sulfuric acid for 500 hours does not degrade sealing effectiveness. Additional testing and development is required in this area to improve the hydrogen permeability further and to implement effective manufacturing techniques. Testing in a fuel cell system is underway at a customer site.

Fuel Cell Testing and Product Demonstration

Fuel cell testing on PAM's net-shape porous bipolar plates in UTC Power's proprietary designs has taken place in single and multiple cell formats. A multi-cell stack was assembled and tested to 2,000 hours under simulated driving cycles and other various loading and environmental conditions with good performance. A polarization curve of the stacks performance is shown in Figure 4. Fuel cell performance is similar to results obtained with the use of machined graphite plates.

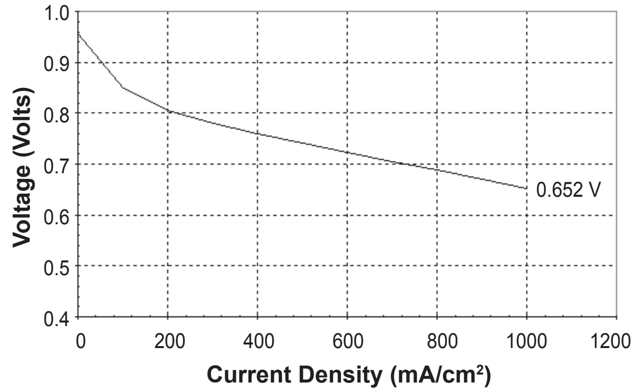

FIGURE 4. Polarization Curve Obtained from Multi-Cell Stack using PAM's Porous, Net-Shape Molded Bipolar Plates

Conclusions and Future Directions

- Process optimization and continuous improvement activities resulted in a robust, consistent manufacturing process capable of repeatable manufacturing high quality bipolar plates.
- Channel shrinkage measurements generated design information for the prediction of processing shrinkage rates for any channel configuration.
- Sealing development demonstrated effective plate sealing after 500 hours of simulated corrosion testing. Development activities are required to create a robust manufacturing method from this concept and to secure additional field-testing.
- Progress was made in rapidly molding a test flow field pattern. Additional investigation in this area is needed to evaluate materials properties, and the repeatability of the concept.
- Fuel cell testing indicates excellent fuel cell performance (comparable to machined graphite plates).

FY2006 Publications/Presentations

1. Scale-up of Carbon/Carbon Bipolar Plates, presented at the 2006 DOE Hydrogen Fuel Cells & Infrastructure Technologies Program Review, Crystal City, VA, May 2006.