IV.D Bipolar Plates

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

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Subcontractor:
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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 and desired properties.
- Evaluate the performance of the bipolar plate materials through fuel cell stack testing.
- Develop, test and evaluate 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 of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- O. Stack Material and Manufacturing Cost

Approach

<u>Phase I</u>

- Design, construct and install material forming, pressing and thermal treatment equipment.
- Systematically investigate material forming techniques and composition ingredients.
- Systematically investigate material processing variables and test material properties.
- Perform fuel cell testing to evaluate plate performance at UTC Fuel Cells.
- Investigate forming techniques aimed at rapid, low-cost production.

<u>Phase II</u>

- Develop net-shape moldable materials for both porous and sealed applications.
- Develop low-cost sealing method for sealed plates.
- Develop bonding methods for both porous and sealed plates.
- Investigate low-cost methods for plate wetting angle control.
- Test performance of near-net and net-shape molded parts in fuel cell.

- Manufacture 10-kW stack in cooperation with commercial partner and test for baseline performance.
- Analyze process costs to assemble detailed product cost analysis.

Accomplishments

- Designed and developed higher-speed forming system to lower component forming costs. Demonstrated rate of forming at approximately one plate per minute with this developmental system.
- Developed moldable materials and process to achieve target tolerance requirements.
- Began investigation into low-cost material wetting angle control.
- Began fabrication of deliverable demonstration stack materials.
- Investigated and optimized coating process to achieve uniform and reliable carbon seal coating.

Future Directions

- Continue process optimization to further reduce processing costs and improve tolerance capability.
- Continue material development to further improve product properties for both porous and sealed product applications.
- Complete demonstration fuel cell stack manufacture and stack testing through commercial partner.
- Continue product wetting angle investigations to provide low-cost, reliable method for wetting angle control.
- Investigate material manufacturing costs with proposed manufacturing process. Estimate costs in large volumes with an envisioned high-speed manufacturing system.

Introduction

Bipolar plates are a key component in the construction of proton exchange membrane (PEM) fuel cells. In 2001, Porvair Fuel Cell Technology, Inc. (PFCT) licensed a promising carbon/carbon composite bipolar plate formation technology from Oak Ridge National Laboratory. The carbon/carbon material has specific advantages in PEM fuel cells in that the material is highly conductive, has high strength and is chemically stable. The goal of PFCT is 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. This DOE-sponsored project is directed at moving the technology from the national lab to develop 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

Porvair Fuel Cell Technology is a specialty materials manufacturer whose goal is to manufacture materials for the emerging fuel cell industry. The activities associated with this project are therefore directed toward the reliable and low-cost manufacture of carbon/carbon bipolar plates.

The approach taken in materials development utilizes information fed back to PFCT by our customers following product property and fuel cell testing. Specific needs and concerns of our customers are evaluated relative to the current state of the product or process development to guide improvements leading toward a better bipolar plate. Internally, materials development efforts are guided through the performance of statistically designed experiments. Key product or process variables are evaluated in orthogonal arrays of experiments. Results are measured and analyzed to determine the degree of influence each variable has on the measured property. A statistical model is then built to aid in moving subsequent experiments into a near-optimum range of investigation.

Cost analysis and projections to large-volume manufacture are made by accounting for estimated material, labor, energy consumption and overhead costs. The cost analysis process includes potential scale-up requirements of raw material suppliers and projected material cost issues that are associated with increasing energy costs.

Results

The past year has focused upon the finalization of Phase I activities and the beginning of Phase II activities. Phase I was completed successfully and led to a separate effort in equipment and process expansion in response to customer product demand. The material and process developed in Phase I proved the material concept and the benefit of the material to fuel cell performance. (Table 1 shows typical material properties of the PFCT material.) However, the material and process demonstrated in Phase I could only produce flat plate materials that required expensive machining processes to demonstrate their use as bipolar plates. Phase II is focused upon the development of low-cost, net-shape molded bipolar plates, and at optimizing processing conditions for the production of fully sealed bipolar plates.

Table 1. Carbon/Carbon Material Properties of PFCT Sealed and Porous Materials

Property	Porous Plate	Sealed Plate
Electrical Conductivity (S/cm) (ASTM C611)	300 - 500	600 - 800
Density (g/cc)	1.15 - 1.25	1.20 - 1.30
Flexural Strength (psi)	4500 - 5500	6000 - 7000
Hydrogen Permeability ($cc/cm^2/sec$) (ASTM D1434)	$<2x10^{-6}$	$<2x10^{-6}$

In Phase II, the material forming method of Phase I was evaluated critically and redesigned to eliminate material waste and to increase the processing rate. A new system design was created that significantly improved the forming process and the quality of the material produced. Figure 1 shows some of the redesigned processing equipment. One of the key aspects of the new forming method is that it eliminates the material waste that was associated with preform machining in the Oak Ridge forming process (the Oak Ridge process is described in Reference 1). Material waste with the early process was as high as 70% of the raw materials used, as material created in a preform "cake" had to be machined into plates. In the new process, plates are created quickly with minimal material waste generated.

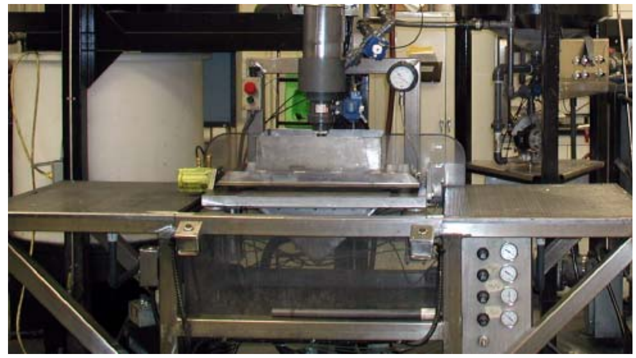

Figure 1. Redesigned Manufacturing Apparatus for High-Speed Product Forming

One of the key activities associated with Phase II is the development of net-shape molded bipolar plate materials. In the fabrication process, PFCT materials are formed, pressed with the flow field pattern of the particular plate, and carbonized to yield a carbon/carbon material in net-shape form. In the carbonization process, a degree of product shrinkage occurs that adds variability to the final part dimensions. This variability must be controlled to tight finished part dimensions. Variability control is key to demonstrating the capability of producing quality parts with good product yield. Figure 2 shows an example of the improvement made in achieving dimensional tolerances in Phase II.

Proprietary development efforts have been undertaken in Phase II to improve material properties and characteristics. Investigations have taken place for both porous and sealed bipolar plate materials. Porous products, used by UTC Fuel Cells, have specifically designed porosity characteristics that are key to plate performance in UTC Fuel Cells systems. Sealed products have more latitude in material design and can therefore be made with improved material properties (strength and conductivity) and can potentially use lower-cost raw materials in their manufacture.

Because all of the materials that are made at PFCT are porous in the beginning, the manufacturing

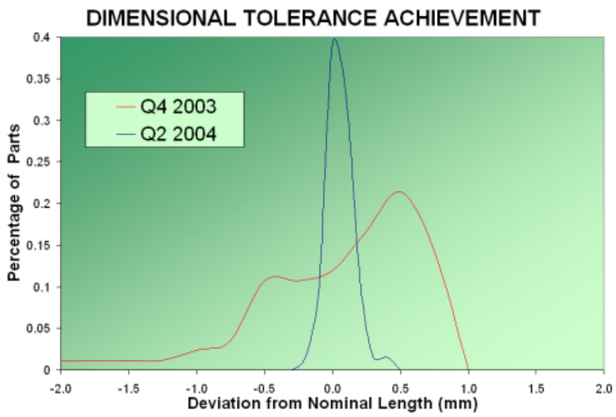

Figure 2. Comparison of Early Phase II Geometric Tolerance Capability and the Improvement Resulting from Process and Materials Development Efforts

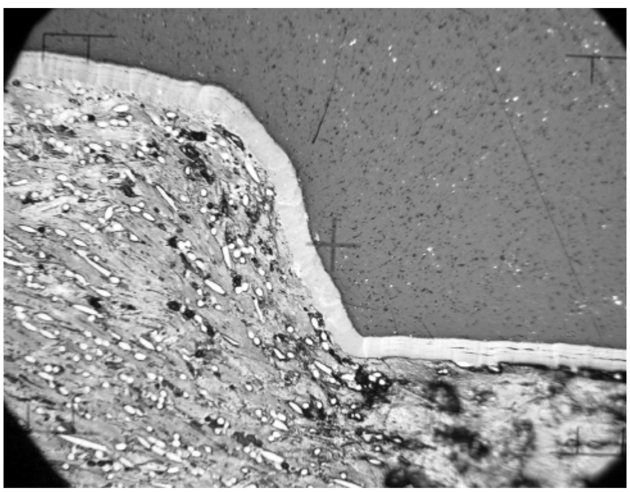

Figure 3. Optical Micrograph of a Molded Section of Bipolar Plate Material (The micrograph shows the structure and thickness of the CVD-deposited carbon coating on the plate surface.)

process for sealed plates includes the application of a seal layer onto the surface of the plates. This seal layer is applied through a chemical vapor deposition process (CVD), where the plates are surface-coated with a controlled-thickness carbon layer. Figure 3 is an optical micrograph that shows the carbon seal layer. The CVD coating is inert in fuel cell operation and allows the plates to retain their low overall density. PFCT's sealed plate densities, as shown in Table 1, are approximately 1.25 g/cc – about 30% lighter than typical resin-bonded graphite composite bipolar plates. The low density of PFCT plates allows for the construction of lighter fuel cell stacks and lower raw material costs when compared to other types of bipolar plates.

Numerous fuel cell tests continue to be performed at UTC Fuel Cells. Additional testing of sealed plate products is scheduled for the summer of 2004 at a second customer's site, using a proprietary plate design, and more fuel cell tests are being scheduled with other customers not related to this DOE project. Initial near-net shape molded plate tests have been conducted at UTC Fuel Cells. The goals of the fuel cell testing have been focused at both investigating the product for basic performance and for evaluating aspects of the product for acceptable fuel cell performance and durability. Specific feedback to PFCT has been used to guide product design and process changes to yield a better performing and more consistently manufactured product.

Conclusions

- Porvair Fuel Cell Technology continues to develop materials and manufacturing processes to supply high-quality bipolar plates to the fuel cell industry. Activities over the past year have centered on material and manufacturing technology improvements focused at reducing the cost of complicated shape bipolar plate manufacture.

References

1. Bessmann, T.M., et. al., "Carbon/Carbon Composite Bipolar Plate for Proton Exchange Membrane Fuel Cells," J. Electrochem. Soc., 147, 11, 4083-4086 (2000).