V.B.3 Carbon-Carbon Bipolar Plates*

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Contract Number: DE-FC04-02AL67627

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

Project Start Date: May 1, 2002
Project End Date: November 30, 2007

*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 comprehensive cost evaluation of materials and processes.

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:

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

Technical Targets

The DOE technical targets and Porvair's current status are 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. The Porvair bipolar plate product meets or exceeds the DOE 2010/2015 technical targets in weight, electrical conductivity, flexural strength and flexibility.

TABLE 1. Progress Towards Meeting Technical Targets for Bipolar Plates

Characteristic	Units	2010/2015 Targets	Porvair Status
Cost	$/kW	5/3	150
Weight	kg/kW	<0.4	0.3
H2 permeation flux	$cm^3\ sec^{-1}\ cm^{-2}$ @ 80°C, 3 atm (equivalent to <0.1 ma / cm^2)	$<2x10^{-6}$	$<2x10^{-5}$
Corrosion	$\mu A/cm^2$	<1	
Electrical conductivity	S/cm	>100	>600
Resistivity	Ohm-cm	0.01	0.015
Flexural Strength	MPa	>25	35
Flexibility	% deflection at mid-span	3 to 5	3

Accomplishments

- Manufacturing process optimization:
  - Improved process capability for several key product characteristics.
  - Increased productivity by more than 25% over previous year.
  - Reduced product cost by 20% over previous year.
  - Improved product quality and yield over previous year.
- Finalized material shrinkage characterization of product over range of rib height to rib width of <0.65.
- Investigated rapid molding methods for <10 second molding times.

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Introduction

Bipolar plates are a key component in the construction of proton exchange membrane (PEM) fuel cells. The bipolar plates provide for effective gas distribution of air and fuel to the PEM membrane, transport electricity through the fuel cell stack, and allow for the effective removal of heat from the stack caused by reaction inefficiencies. The Porvair carbon/carbon bipolar plate is well suited for use in PEM fuel cell systems, as the material is highly conductive, very lightweight, high in flexural strength, has low system contact resistance and is chemically stable.

The project has not been aggressively worked on since September 2006. Results presented in this report are from the timeframe June 2006 to September 2006 only, as work on the project was halted temporarily as Porvair addressed near-term business opportunities in the bipolar plate program. Activity on this project is expected to resume in June 2007. The activities in the June to September 2006 timeframe were centered around final optimization of the developed process, investigation into next-generation bipolar plate molding methods, and characterization of product shrinkage for the purpose of effectively meeting end-user tolerance requirements.

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 approach taken 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

The results are from the time period June 2006 to September 2006. Activities in this timeframe centered on manufacturing optimization, molding optimization and rapid molding development.

Manufacturing Optimization

A large production trial run was made to demonstrate the capability of the process to manufacture bipolar plates with consistent dimensions and characteristics. An analysis of the run was performed, and several improvement activities were undertaken to address yield and product inconsistency.

Yield issues encountered in the large production run were associated with local plate curvature, and plate defects caused by forming solution inconsistencies and surface defects. The first issue was addressed through the use of improved fixtures in our process to remove the curvature during carbonization. These fixtures provide support to areas that are otherwise unsupported in our heat treatment cycle and reduce warp that occurs during heat treatment and material shrinkage. Figure 1 shows the measurements of this curvature before the implementation of the improved fixtures. Figure 2 shows the measurements after implementation of the improved fixtures.

Molding Optimization

High quality molding of challenging flow field features is a goal for this project. We have found that specific trends in molding and subsequent shrinkage of flow field features occur with our material and process. The thorough understanding of these shrinkage trends will enable mold dies to be built that will yield flow field features that conform to the design of the customer. For

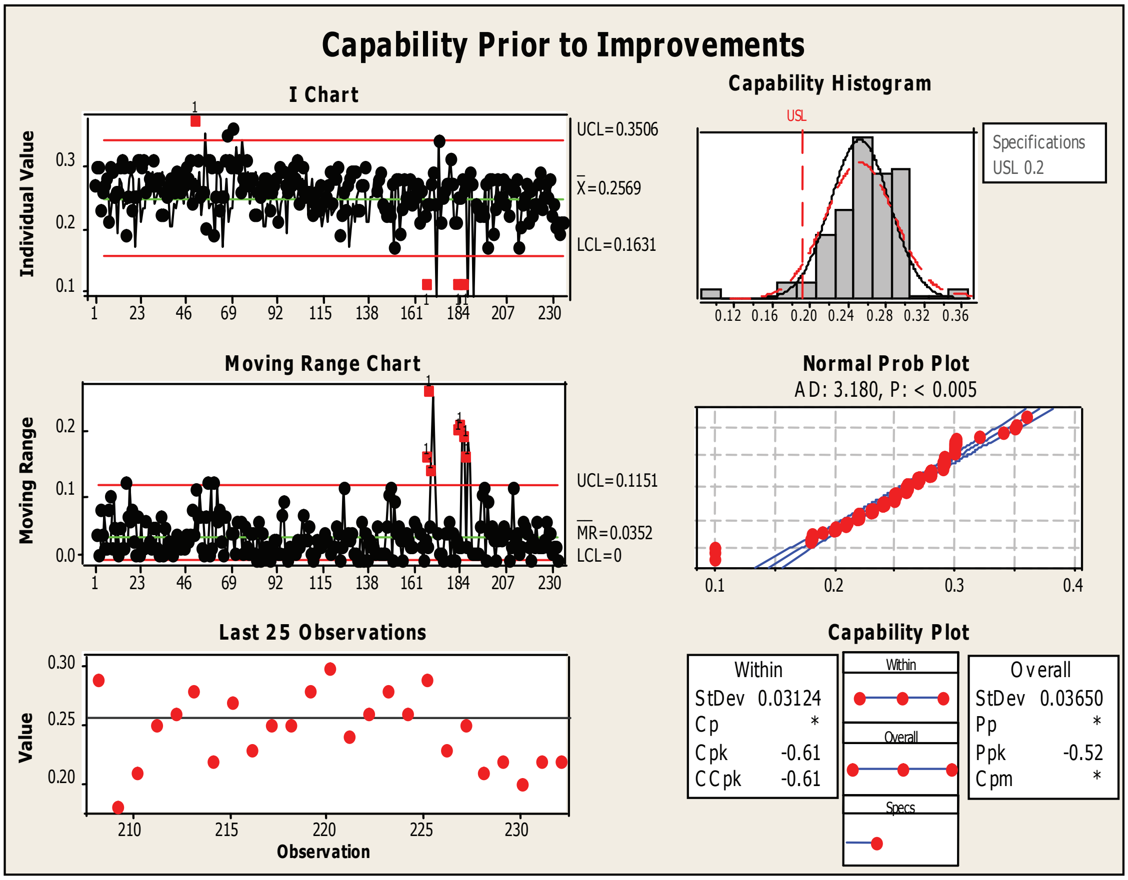

FIGURE 1. Capability of small-scale warp before fixture design and use. Nearly all of the product showed out-of-spec conditions before improvements.

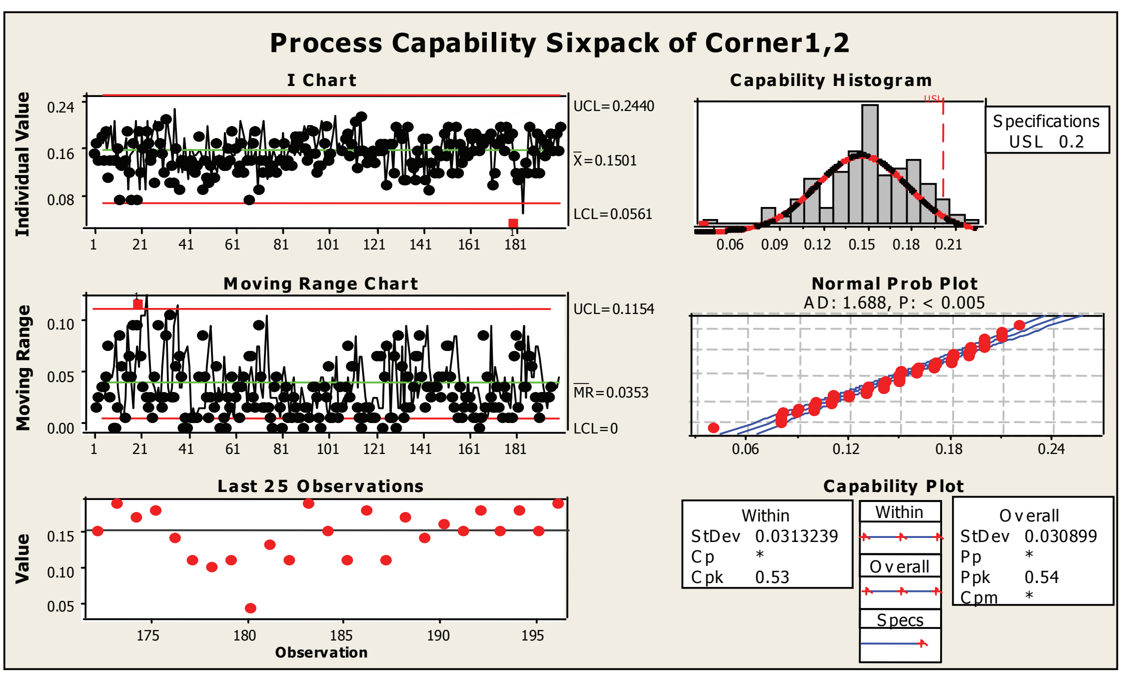

FIGURE 2. Capability of small-scale warp after fixture design and use. Considerable improvement was made.

the Porvair material, it has been discovered that feature shrinkage rates depend upon the ratio of the rib height and the rib width. Figure 3 shows an example of a molded rib. The figure displays alignment of materials into the rib during the molding process. The alignment of this material induces unique shrinkage rates in the planar and through-plane directions in the material. We have characterized this characteristic for a variety of mold geometries, and have developed proprietary correlations for product shrinkage vs. the ratio of rib height to rib width.

Rapid Plate Molding Development

Some work has progressed with our rapid molding development program. The proprietary rapid molding method has been investigated for the quality of the preformed features. It has been found that, while we can effectively impart a flow field to a sample plate, the quality of the flow field is unsatisfactory. Additional work will follow in the coming quarter with materials development to improve the molded material quality.

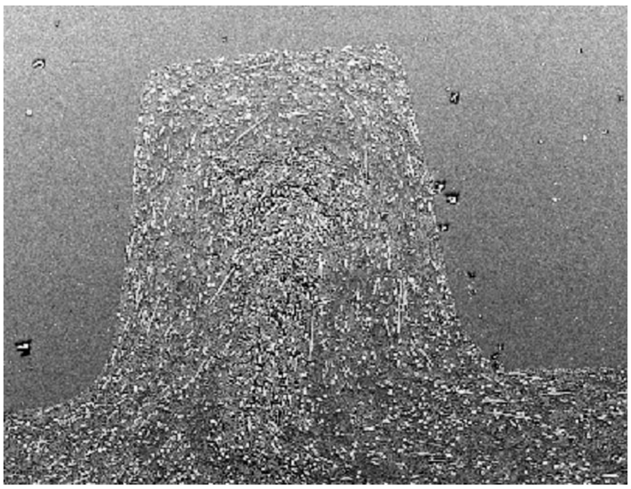

FIGURE 3. Micrograph of a Molded Rib of a Typical Fuel Cell Geometry

Conclusions and Future Directions

Progress with this project over the last 12 months has been slowed by the shifting of resources to address near-term opportunities in the bipolar plate program in areas other than this DOE contract. However, the work accomplished in the short timeframe of June to September 2006 resulted in important findings as follows:

- Production optimization resulted in improving small scale plate warp to levels acceptable for use in advanced fuel cell systems. Capability of the improved parts was found to be good, but improvement was still desired.
- Channel shrinkage measurements generated design information for the prediction of processing shrinkage rates for a range of channel configurations.
- 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.

Special Recognitions & Awards/Patents Issued

1. Fuel Cell South 2007 Crystal Flame Innovation Award in Industry.