V.D.5 Economical High Performance Thermoplastic Composite Bipolar Plates (Small Business Technology Transfer Project)

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Phase I End Date: March 26, 2006
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Phase I Objectives (2005-2006)

- Fabricate bipolar plates using novel wet-lay materials
- Demonstrate superior performance metrics (mechanical properties, conductivity, chemical resistance, low permeability)
- Preliminary process modeling for processing time/cost estimates

Phase II Objectives (2006-2008)

- Downselect best material compositions
- Semi-continuous bipolar plate fabrication
- Full-scale bipolar plate production cost analysis
- Fuel cell device integration, including hybrid system development

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

Technical Targets

NanoSonic/Virginia Tech Progress Toward Meeting DOE Composite Bipolar Plate Targets

Performance Metric	Units	2007 Target	NanoSonic/VT bipolar plates
Electrical Conductivity	S/cm	>100	Up to 271
Tensile, Flexural Strength	MPa	41, 59	57, 96
Bipolar Plate Cost	$/kW	10	TBD

Accomplishments

Novel wet-lay composites and associated bipolar plate processing have shown superior performance compared to other technologies:

- High flexural strength (96 MPa)
- High tensile strength (57 MPa)
- Low gas permeability, estimated ~10^{-8} $cm^3/cm^2{*}s$ (DOE target <$2x10^{-6}$)
- High conductivity, up to 271 S/cm
- Rapidly moldable, no machining required
- Short processing times, projected <2 minutes/plate (TBD Phase II)
- Low materials cost (cost/plate area TBD Phase II)

Introduction

Polymer electrolyte/proton exchange membrane (PEM) fuel cell systems are an environmentally friendly power source for a wide range of applications that have received considerable and growing interest for both transportation and stationary power. Bipolar plates are by weight, volume, and cost one of the most significant parts of a PEM fuel cell stack. Bipolar plates have four main functions: 1) distribution of gases homogeneously over the whole area of the individual cells; 2) separation of the fuel and oxidant gases; 3) prevention of gas leakage; and 4) current collection. Structural integrity, high electrical conductivity, and low cost are crucial for a successful bipolar plate technology. Current technologies have not met both the performance metrics and the cost target of $10/kW set forth by DOE.

To address the performance and cost goals for bipolar plate technologies, NanoSonic and Virginia Tech have developed a bipolar plate technology based on novel materials and innovative processing techniques that result in economical, high performance bipolar plates. During Phase I, the technology was proven to have significantly higher mechanical strength, higher in-plane conductivity and considerably reduced weight as compared to other current state-of-the-art polymer and/or graphite-based composite bipolar plate technologies. Importantly, processing time and energy requirements were found to be significantly lower directly translating to reduced fabrication costs that are anticipated to meet the DOE cost target when continuously manufactured.

Approach

NanoSonic and Virginia Tech have made wet-lay sheet materials (mats consisting of graphite particles, thermoplastic fibers and carbon or glass fibers) using a slurry-making process, which are subsequently compression molded to form bipolar plates with high definition gas flow channels. Compared to the traditionally compression-molded (with dry-blended thermoplastic resins and graphite powders) bipolar plates, the wet-lay composite plates have excellent in-plane conductivity, mechanical properties, chemical resistance and thermal stability.

During Phase I of this STTR project, NanoSonic and Virginia Tech have worked together to fabricate bipolar plates using a polyphenylenesulfide (PPS) thermoplastic matrix, a crystalline polymer with a melting point of 280°C and an inert aromatic backbone that lends tremendous chemical resistance. The superior chemical resistance of PPS, coupled with excellent mechanical properties, dimensional stability, and high temperature resistance, makes it an ideal matrix for bipolar plates. Development of the PPS plates, along with preliminary investigation of a novel skin-core bipolar plate using a combination of PPS and polyvinylidene fluoride (PVDF), have proven to be suitable materials to rapidly mold bipolar plates with high conductivity, excellent mechanical properties, superior chemical resistance, low mass density, excellent moldability/formability, and low cost based on preliminary processing time and energy estimates.

During the next phase of the STTR project, NanoSonic and Virginia Tech will collaborate to fabricate bipolar plates on a semi-continuous basis and evaluate the performance of these plates in a functional fuel cell. Comparisons to currently available bipolar plate technologies will be performed through development of hybrid fuel cell systems powering functional platforms with varying power requirements. Processing techniques will be investigated for continuous plate manufacturing to identify the most appropriate heating mechanism and processing scheme to continuously manufacture these bipolar plates at low costs, specifically aiming at the DOE target of $10/kW.

Results

Multiple compositions of wet-lay fabric were generated for the Phase I project. Composite monopolar (one side flow channels) and bipolar plates (flow channels on both sides) were fabricated by compression molding of wet-lay sheets. A heated platen press was used to press wet-lay composites in the plate mold at 1,000 psi (temperature was chosen based on thermal analysis data). The formability and shapeability of PPS based wet-lay composites are sufficient to form gas flow channels with excellent resolution. Additionally, holes can be machined around the plate perimeter for integration into an existing fuel cell test station or appropriate fuel cell geometry, or can be similarly integrated with the mold geometry.

The outstanding mechanical properties of the PPS-based composite plates are believed to be associated with the unique structure of the wet-lay sheet materials. Traditionally, thermoplastics in powder form have been used to facilitate uniform blending with the conductive fillers, followed by compression molding to fabricate the polymer composite bipolar plates. Although the polymer particles bind the composite together following compression-molding, it is likely that numerous weld lines exist within the composite, compromising bulk mechanical properties. The use of high filler loading levels and relatively low molding temperature to raise the electrical conductivity of the material exacerbates this problem. As a result, polymer composite bipolar plates (including those reinforced with carbon fibers or other fibers) typically have inadequate mechanical properties. The structure of the wet-lay composite materials is significantly different. The starting materials for compression molding are preformed sheets consisting of fine thermoplastic fibers and reinforcing fibers. Compared to the blend of graphite and polymer powders, these sheets form composites with significantly higher strength. In addition, relatively long (on the order of 1") reinforcing fibers (carbon or glass fibers) can be integrated into the wet-lay process without any difficulties, lending to even greater composite strength.

Flexural properties of the PPS wet-lay composites were determined using an Instron 4204 tester (three-point bending) in accordance with the ASTM D790 standard at room temperature. Flexural strength of the PPS-based bipolar plates was found to be approximately 96 MPa, far exceeding the 59 MPa target. The tensile strength of the PPS-based wet-lay composite plates was measured using ASTM D638 with an Instron 4204. Tensile strengths of 57.5 MPa were measured, which well exceed the target value of 41 MPa. The Izod impact test (unnotched) was also performed for the PPS wet-lay composite plate on a Tinius Olsen 92T Impact Tester based on ASTM D256. An average impact strength of 1.56 ft-lb/in with a standard deviation of 0.16 ft-lb/in was measured, significantly higher than the 0.75 ft-lb/in target.

Half-cell resistances of various compositions of both polyethylene teraphthalate (PET)- and PPS-based wet-lay composite monopolar plates have been measured and found to have whole resistance and baseline resistance values of 0.03~0.05 Ω-cm^2 and 0.01 Ω-cm^2, respectively, indicating that the total resistance is strongly dependent on the magnitude of the baseline resistance. All of the resistances measured are less than the FreedomCAR goal of 0.2 Ω-cm^2. Half-cell resistances were also measured at 80°C and found to be lower (translating to higher conductivity) than that at room temperature for all plates measured, with an approximately 10% decrease in the half-cell resistance at elevated temperatures.

In-plane bulk electrical conductivity measurements were taken according to ASTM Standard F76-86 using the Van der Pauw method. The in-plane conductivities of the both the PET materials developed previously and the current PPS materials are 230 and 271 S/cm, respectively. The in-plane conductivites of these materials far exceed the DOE target of 100 S/cm.

Hydrogen permeability through the bipolar plates is crucial to prevent catalyst fouling and resultant membrane electrode assembly (MEA) shutdown. Permeability of simple gases, such as hydrogen and oxygen, can be estimated via an Arrhenius-type analysis and through multiple sets of empirically determined equations. Permeability for PET and PPS at 3 atm pressure was calculated to be 2.49 and 1.29x10^{-8} cm^3/cm^2*s for PET and PPS, which is approximately two orders of magnitude below the required DOE permeability of 2x10^{-6} cm^3/cm^2*s for hydrogen at 3 atm and 80°C.

Bipolar plate performance in a single fuel cell was evaluated using an FCT (Fuel Cell Technologies) fuel cell test station. Polarization curves of the fabricated bipolar (or monopolar) plates were obtained for comparison to other composite technologies. POCO Graphite (POCO) plates were evaluated first because their form factor facilitates direct integration with the FCT test station geometry. The monopolar plates fabricated by NanoSonic and Virginia Tech using PET and PPS were machined to fit into the FCT test geometry. The polarization curves for these materials are shown in Figure 1 for the PPS, PET, and POCO graphite plates following break in. The PET plates performed significantly worse than the PPS or POCO graphite plates, which performed similarly except at the lowest voltage measured. The slight difference in polarization

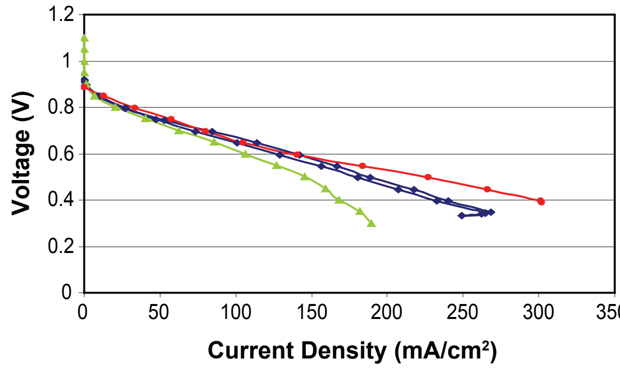

FIGURE 1. Polarization Curves for PET (green), PPS (blue) and POCO Graphite (red) Bipolar Plates

curves at the lowest voltage is due to less through plane conductivity in the PPS plates than with the POCO plates.

In order to quantitatively illustrate the cost savings associated with this bipolar plate technology, a process model is being developed that focuses on evaluation of the heating and cooling times, which is the limiting factor that will directly translate to energy requirements, stamping times, and production (man-hour, maintenance) time required for wet-lay composite sheet formation and bipolar plate consolidation. For this model, two forms of heating are being considered, namely radiation and induction heating. The total fabrication cost on a per-plate basis will be largely dependent on expected total production volume, so preliminary cost modeling has focused on minimization of processing time and comparison to other current state-of-the-art processing time requirements. Based on measured material properties, an estimated time of 47 seconds has been found to heat the centerline temperature of a 3 mm thick PPS plate sufficiently for bipolar plate stamping using radiation heating. Using induction heating, and assuming an 80% efficiency, a 3 kW heater in a wrap around coil configuration is sufficient to heat the wet-lay materials sufficiently for molding in 10 seconds. Both heating mechanisms suggest that plate molding times can be significantly reduced compared to current technologies, directly translating to significant bipolar plate cost reductions.

Conclusions and Future Directions

During Phase I of this STTR project, NanoSonic and Virginia Tech successfully fabricated bipolar plates that met (and in many cases exceeded) the DOE requirements for bipolar plates. The technology developed during Phase I shows significant promise for mass integration of thermoplastic composite bipolar plates into current fuel cell technologies. The bipolar plates met the DOE/FreedomCAR performance targets for mechanical strength, in-plane conductivity, operating temperature capability, and (estimated) gas permeability. Process modeling and preliminary estimates predict plate formation times of less than 2 minutes per plate using multiple heating and cooling mechanisms, which is significantly less than the cure time required to fabricate current state-of-the-art vinyl ester bipolar plates.

The materials and methods developed during Phase I suggest that the bipolar plate technology presented here has significant potential to replace currently available technologies with a more economical, robust bipolar plate at a significantly reduced cost. Total energy consumption reductions will be realized through lighter payloads and reduced processing times, resulting in net lower fuel cell fabrication and operation costs. Phase II will prove the commercial viability of the materials and processing schemes developed during Phase I through semi-continuous processing and further cost modeling, as well as compare the performance of these bipolar plates to those used in commercially available fuel cell platforms.