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Investigation of a Manufacturing Process for Intermediate to Mass Production of Polymer Graphite Based Bipolar Plates for Proton Exchange Membrane Fuel Cells

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Dr. Gurau is a full-time tenure track Assistant Professor of Engineering Technology at Kent State University at Tuscarawas. Previously he worked for seven years as a Senior Research Associate in the Chemical Engineering Department at Case Western Reserve University where he served as Principal Investigator on several research programs funded by the State of Ohio's Third Frontier Fuel Cells Program, by the U.S. Department of Energy or in collaboration with General Motors. In this quality he performed research on different fuel cell technologies, including numerical modeling and simulations (Computational Fluid Dynamics and systems optimization), experimental research design, fuel cell component characterization, fuel cell stack design etc. Dr. Gurau has more than two years experience in fuel cell industry with Energy Partners, l.c. (now Teledyne Energy Systems, Inc.) as a research specialist, where he modeled fuel cell phenomena in order to predict and optimize cell performance, including developing of analytical and numerical models (heat and mass transfer in multi-phase, multi-component flows with electro-chemical reactions, flows in porous media, etc). He is the author of several patents related to PEM fuel cells and the author of more than twenty publications in peer review journals or conference presentations in the fuel cells area. Dr. Gurau obtained his Ph.D. degree in 1998 from the Mechanical Engineering Department, University of Miami.

Investigation of a Manufacturing Process for Intermediate to Mass Production of Polymer/Graphite-Based Bipolar Plates for Proton Exchange Membrane Fuel Cells

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1. Introduction

The proton exchange membrane fuel cell (PEMFC) is an alternative, clean power source for portable, automotive and stationary applications having the potential to reduce our energy use and the nation's dependence on imported oil. It delivers high-power density and offers the advantages of high gravimetric and volumetric power density, rapid start-up and better durability compared with other fuel cells. As identified by the U.S. Department of Energy, one of the obstacles that remain to be resolved on the road to hydrogen economy is the cost of manufacturing fuel cells. A key component of the PEMFC stack represents the bipolar plates which account for 45% of the stack cost [1]. Their functions in the fuel cell are to connect the cells electrically, to house the flow fields and uniformly distribute the reactant and oxidant gasses over the active area of the cells, to separate and prevent the reactant and oxidant gasses in adjacent cells from mixing with each other, to conduct and distribute the heat produced during the electrochemical reaction and to provide structural support to the cells. Bipolar plates must have good electrical and thermal conductivity, good mechanical characteristics, low gas permeability, good chemical stability (corrosion resistant), must be lightweight, easily formable and inexpensive. Table 1 presents the targeted physical properties for bipolar plates as specified by U.S. Department of Energy [2]:

Table 1
Targeted property values for bipolar plates per U.S. Department of Energy [2]

Property	**Requirement**
Bulk electrical resistivity	$< 0.1\ m\Omega\ m$
Corrosion rate	$< 16\ \mu A/cm^2$
Hydrogen permeability	$< 2x10^6\ cm^3/cm^2\ s$
Compressive strength	> 2 MPa
Thermal conductivity	> 20 W/mK
Fabrication tolerance	< 0.05 mm
Cost	< 10 $/kW
Weight	< 1 kg/kW

To meet these requirements, bipolar plates are usually made of graphite, coated or non-coated metals or from polymer composites including graphite powder.

This paper presents the investigation of a manufacturing process of bipolar plates for PEMFCs using compression molding of GP55-B (GrafTech Inc.) synthetic graphite used as electrically conductive matrix and PLENCO 12114 phenol formaldehyde thermoset resin (Plenco Plastics Engineering Company) used as binder. We identify the optimum process characteristics including material composition, compression level, curing temperature, the mold design and performed property measurements on the obtained samples, including the measurement of bulk electrical conductivity using a four-point probe. The samples obtained demonstrate characteristics that exceed the requirements of the U.S. Department of Energy. This investigation was performed by students in the Engineering Technology Department at Kent State University at Tuscarawas during a capstone design project class – *Engineering Technology Project* offered in the spring semester of 2013. The paper presents as well the development of this course.

At the recommendation of the ABET accreditation committee, a new capstone design project class - *Engineering Technology Project* was introduced in the Engineering Technology Department at Kent State University at Tuscarawas in the spring semester of 2011. Students work in groups under direct faculty supervision on creative, challenging, open-ending projects proposed by the professor in the area of renewable energy. Practical, hands-on experience is emphasized and analytical and design skills acquired in companion courses are integrated. These projects align with *Ohio's Third Frontier Fuel Cell Program* commitment to accelerate the growth of fuel cell industry in the state, to investigate manufacturing processes and technologies, to adapt or modify existing components and systems that can reduce the cost of fuel cell systems, to address technical and commercialization barriers and to demonstrate market readiness [3]. Projects on which our students worked during the capstone design project class included the design and fabrication of a nine-cell, 50 cm^2 active area proton exchange membrane fuel cell (PEMFC) stack, a first ever successful demonstration of an automated assembly process of a PEMFC stack using robotic technology, design and fabrication of instrumentation for measuring physical properties for fuel cell components and the investigation of manufacturing processes for polymer/graphite-based bipolar plates for PEMFCs.

2. Course Development

The capstone design project class – *Engineering Technology Project* was first offered in the Engineering Technology Department at Kent State University at Tuscarawas in the spring semester of 2011–2012 academic year as a 3 credit hours course. The course was implemented at the recommendation of the ABET accreditation committee and was converted from a previously offered class, *Robotics and Flexible Automation*. The new course introduces the students to automated manufacturing systems, computer numerical control (CNC) programming and industrial robotics through creative, challenging, open-ending engineering design projects in the area of renewable energy. Practical, hands-on experience is emphasized and analytical and design skills acquired in companion courses are integrated. Students work in groups under direct faculty supervision on projects proposed by the professor. Engineering communication such as reports, oral presentations and poster presentations are covered. The course is offered to associate's and bachelor's degree students in Engineering Technology Department with a major in mechanical or electrical engineering technology.

The objectives of the Engineering Technology Project class are:

i. To introduce the students to CNC programming including programing G-code for milling and turning operations;
ii. To introduce the students to industrial robotics and robot programming;
iii. To understand the fundamentals of fuel cells, fuel cell components, materials and manufacturing processes used in the fuel cell industry;
iv. To be knowledgeable with the computer aided design and computer aided manufacturing (CAD/CAM) process;
v. To acquire experience in project planning, team work, design and creative thinking;
vi. To learn how to communicate effectively through reports, engineering drawing, oral presentations supported by PowerPoint and through poster presentations.

The course is divided into a lecture session and a laboratory session. In the spring semester of 2013 the lecture session covered an introduction to fuel cells, CNC programming, an introduction to polymers and compression molding of polymers, robotics technology, robot programming and an introduction to bulk electrical resistivity measurements. The class notes which are supported by PowerPoint slides were made available to students on Blackboard Learn. During the laboratory session, students familiarized with PEMFC manufacturing processes, designed and developed G-codes for machining a compression mold and fabricated the compression mold using CNC milling. They investigated various graphite-polymer mixtures, performed compression molding experiments using these mixtures and identified optimum process characteristics that led to successful fabrication of bipolar plates. Students performed bulk electrical resistivity measurements on the obtained samples using a four-point probe and identified the material compositions that meet and exceed the U.S. Department of Energy targeted properties. They fabricated a fixture for flow field visualization tests using CNC milling and performed visualization tests. They learned to program a Fanuc robot and programmed the robot using leadthrough programming to mix the graphite-polymer powder mixture. Students practiced to communicate effectively engineering ideas through CAD drawings, progress reports, an oral presentation and a final poster presentation covering their achievements during the class.

For the engineering technology project class students were graded based on their mold design, progress report, oral presentation, final poster presentation and class participation. The mold design was graded based on concept and on students' knowledge to express technical idea using CAD software such as AutoCAD or Inventor and the ASME Y14.5M-1994 standard rules. The progress report was graded based on the G-code developed and neatness of presentation. The oral presentation and final poster presentation were graded based on student's knowledge to communicate their achievements.

3. Project Details

To achieve the goals, students designed and machined a prototype mold (see Figure 1) for circular samples of 2 inch diameter using a Tormach CNC milling machine. It consists of a force and a cavity mold containing channels for venting the water vapor produced during the curing process of the polymeric resin. The mold initially contained stainless steel porous circular plates aimed to facilitate the water vapor transport from the samples to the venting channels. These plates turned out to be insufficiently rigid, bent during the sample ejection process, indented into the venting channels and transferred the channel shape into the samples. The porous plates were subsequently replaced with more rigid steel plates. The samples quality improved while the interstice between the force mold and the cavity mold proved sufficient for vapor removal. To further improve the sample quality, two 0.030 inch thick, #8 mirror gloss stainless steel plates sprayed with mold release were added in the mold at the interface with the powder charge.

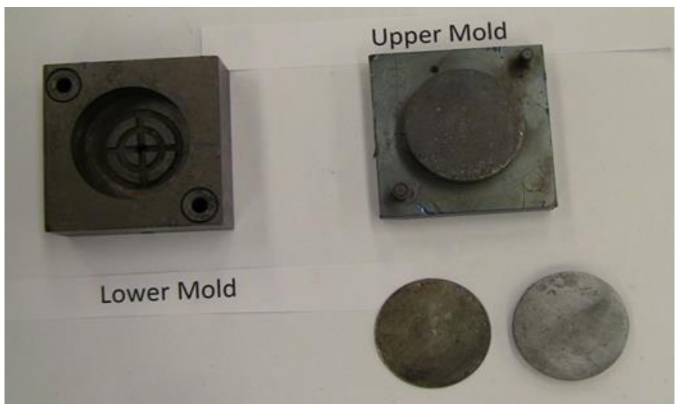

Figure 1
Mold prototype fabricated by students using CNC milling and used to study the compression molding of bipolar plates for fuel cells

The press used for compression molding the bipolar plates was a DAKE hydraulic press with 12in X 12in heating platens. The bulk resistivity of the 2 inch diameter samples was measured using a four-point probe (see Figure 2) designed and manufactured by students during the previous year capstone design project class.

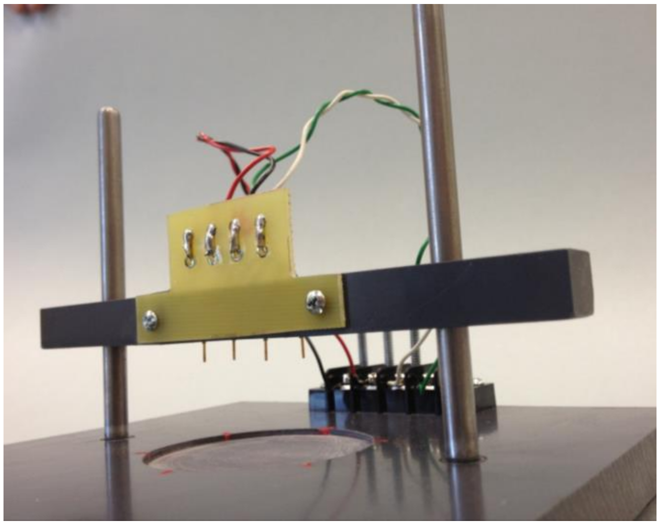

Figure 2
Four-point probe fabricated by students to measure bulk electrical conductivity

Visualization tests were carried out on acrylic plates with 5 channels serpentine flow fields machined in house using a Sherline CNC milling machine (see Figure 3). Fluorescent die was injected into the flow fields using a submersible pump (Little Giant Pump Comp.) controlled by a Matheson Scientific variable transformer.

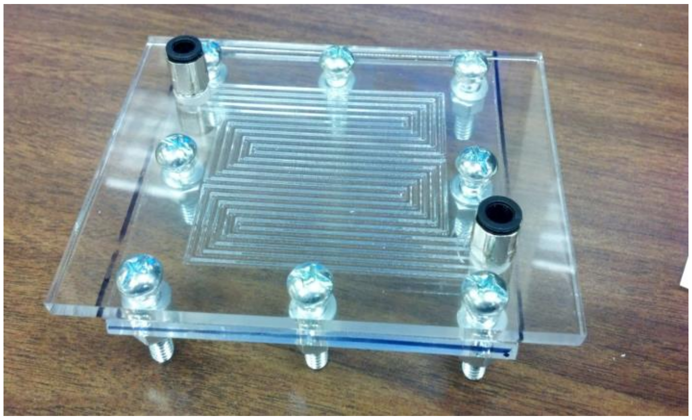

Figure 3
Fixture for visualization tests machined by students using CNC milling

The charge powder for compression molding bipolar plates consisted of various weight percent (%wt) of GP55-B synthetic graphite powder from GrafTech Inc. used as electrically conductive matrix and Plenco 12114 phenol formaldehyde powder from Plenco Plastics Engineering Company used as binder. Dry 20 g samples of powder blend were charged into the preheated mold without preforming.

The best samples were obtained after the porous stainless steel plates were replaced with two #8 mirror gloss stainless steel sheets sprayed with mold release. Optimum mechanical characteristics including compression level, curing temperature and compression time were identified. No post bake process was used. Samples consisting of 50%wt, 60%wt, 70%wt, 80%wt, 90%wt and 95%wt graphite were fabricated for evaluation. All samples showed sufficient mechanical rigidity, but only the samples containing higher %wt graphite resulted with even, smooth surfaces. The electrical resistivity measurement results were corrected for the finite thickness and shape of the 2 inch diameter samples. The samples containing 90%wt graphite (.09 mΩ.m) and 95%wt graphite (.07 mΩ.m) meet the minimum resistivity requirement of U.S. Department of Energy. The optimum process characteristics identified during this research will be used to manufacture 50 cm^2 bipolar plates having anode and cathode flow fields indented into the plates during the compression molding process. Flow visualization tests were therefore performed to insure that all flow field channels are capable of transporting fluids uniformly. Visualization tests were performed using acrylic plates with a 5-channel serpentine flow field machined on one of the plates. The tests were performed with fluorescent die dissolved in water and under UV light (see Figure 3).

4. Course Assessment

The Engineering Technology Project class described here was for most students the first opportunity to integrate skills acquired in companion courses and to apply them in a class in which hands-on experience was emphasized. In this class individual supervision and consultations took place in contrast to other more traditional lecture/laboratory courses. While initially some students appeared uncertain in meeting class expectations in terms of time organization and planning, through the course of the semester most of the students appreciated the value of this course and added it to their portfolios.
Some of the student comments in their unedited form are presented below:

- Should require a prerequisite for project management.
- I highly enjoyed the content of this class.
- No tests, project class.

In the spring semester of 2013 when the project described here was finalized, students worked in groups and all groups performed all the necessary tasks for the successful completion of the project. We learned that while this approach ensures that all students acquire the necessary experience for the completion of a complex manufacturing process, some students could rely on their colleagues' efforts. When the project class will be offered next time, students will be assigned specific tasks within a group and will collaborate for the integration of the final design.

Since the capstone design project class - *Engineering Technology Project* was first offered in 2011, a number of projects in the area of renewable energy were successfully completed by students which supports the conclusion that the course met the expectations in terms of quality, team work and project management. For the next time this course will be offered, students will work on similar creative, challenging projects which will include the fabrication of a methanol reformer for fueling fuel cells with hydrogen and a fuel cell operated underwater remotely operated vehicle (ROV).

5. Conclusions

This paper describes the development of a capstone design project class – Engineering Technology Project offered to associate's and bachelor's degree students in the Engineering Technology Department at Kent State University at Tuscarawas. We present the course objectives and details on students achievements during the project class offered in the spring semester of 2013. During this class, students investigated the manufacturing process of bipolar plates for fuel cells using compression molding. They identified the optimum process characteristics that led to bipolar plate materials that meet the U.S. Department of Energy targeted properties. Students designed, wrote the G-code and fabricated the mold for compression molding using CNC milling. They measured the bulk electrical resistivity of the obtained samples and performed visualization tests for flow fields. Students learned to program a Fanuc robot to mix the powder used in compression molding. These projects align with Ohio's Third Frontier Fuel Cell Program commitment to accelerate the growth of fuel cell industry in the state, to investigate manufacturing processes and technologies, to adapt or modify existing components and systems that can reduce the cost of fuel cell systems, to address technical and commercialization barriers and to demonstrate market readiness.

6. Acknowledgements

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References

[1] Tsuchiya H, Kobayashi O.: Mass production cost of PEM fuel cell by learning curve. Int. J. Hydrogen Energy, vol. 29, pp. 985-990, (2004)

[2] US Department of Energy: Transportation Fuel Cell Power Systems. Annual Progress Report, Washington DC, (2000)

[3] www.ohiothirdfrontier.com/FuelCellProgram.htm