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SCALE-UP OF CARBON/CARBON BIPOLAR PLATES DE-FC36-02AL67627

2005 DOE Hydrogen Fuel Cells & Infrastructure Technologies Program Review

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Porvair Fuel Cell Technology
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This presentation does not contain any confidential or proprietary information.

Project ID #**FC33**

PROGRAM OVERVIEW

Scale-up of Carbon/Carbon Bipolar Plates

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Timeline

- **Project Start Date:** **May 2002**
- **Project End Date:** **November 2006**
- **Percent Complete:** **90%**

Partner

UTC Fuel Cells

Budget

50% Porvair Cost Share	FY2005	FY2006	Program Total
Porvair Contribution	$962,409	$548,269	$4,180,809
DOE Contribution	$650,659	$576,192	$3,897,000
Total	$1,613,068	$1,124,461	$8,077,809

DOE TECHNICAL BARRIERS AND TARGETS

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Bipolar Plate Technical Barriers, from HFCIT Program Multi-Year Program Plan

Technical Barrier	Units	Porvair Status 2005	Target 2010	Target 2015
Component Cost	$/kW	Volume Dependent	$6	$4
Component Weight	kg/kW	0.36	< 1	< 1
Hydrogen Permeability	cc/cm^2/sec (x10^-6)	< 5	< 2	< 2
Conductivity	S/cm	> 600	>100	> 100
Resistivity & Contact Res.	ohm/cm^2	< 0.02	< 0.01	< 0.01
Flexural Strength	MPa	> 34	> 4 (crush)	> 4 (crush)

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PROJECT OBJECTIVES 2005

Overall	* Develop carbon/carbon bipolar plate manufacturing process * Evaluate product stability to 1000 hours * Investigate next-generation manufacturing techniques * Demonstrate product performance in fuel cell testing
2005	* Perform detailed manufacturing demonstration study * Investigate manufacturing process improvements * Evaluate product tolerance achievement for complex geometries * Develop plate sealing method * Begin investigation into rapid forming methods
2006	* Demonstrate fuel cell operation with net shape molded plates * Optimize plate sealing method * Complete manufacturing process improvments * Complete rapid forming method investigations * Final product cost analysis

TECHNICAL APPROACH
2005 OBJECTIVES

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- **Develop Net-Shape Molding Technology**
  - Optimize materials
  - Develop measurement methods
  - Evaluate varied molding geometries and characterize material shrinkage
  - Determine net shape molding process capability
  - Improve plate hydrophilic/hydrophobic characteristics
- **Develop and Evaluate Sealing Method**
  - Materials development
  - Test method development and implementation
  - Product stability evaluation

TECHNICAL APPROACH
2005 OBJECTIVES

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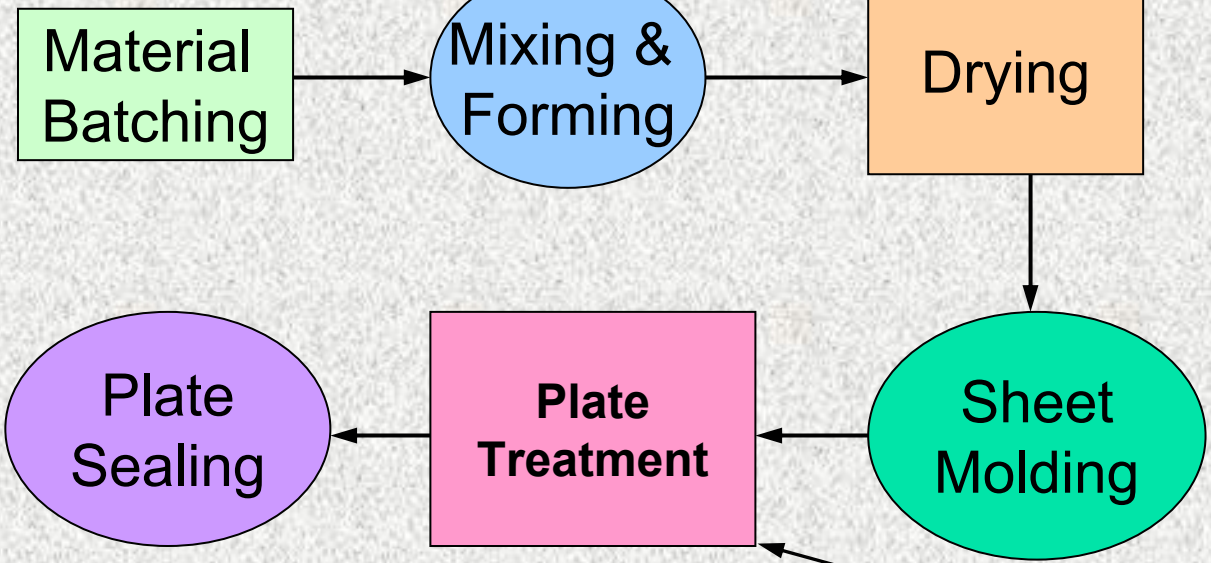
- **Manufacturing Demonstration**
  - **Operate system, collect relevant data**
  - **Examine data statistically**
- **Optimize Manufacturing Process**
  - Materials development
  - Property measurement and development
  - Process control improvements
  - Process improvement activities
    - FMEA
    - Quality plan
    - Lean events

TECHNICAL ACCOMPLISHMENTS

- **Process Overview**



TECHNICAL ACCOMPLISHMENTS

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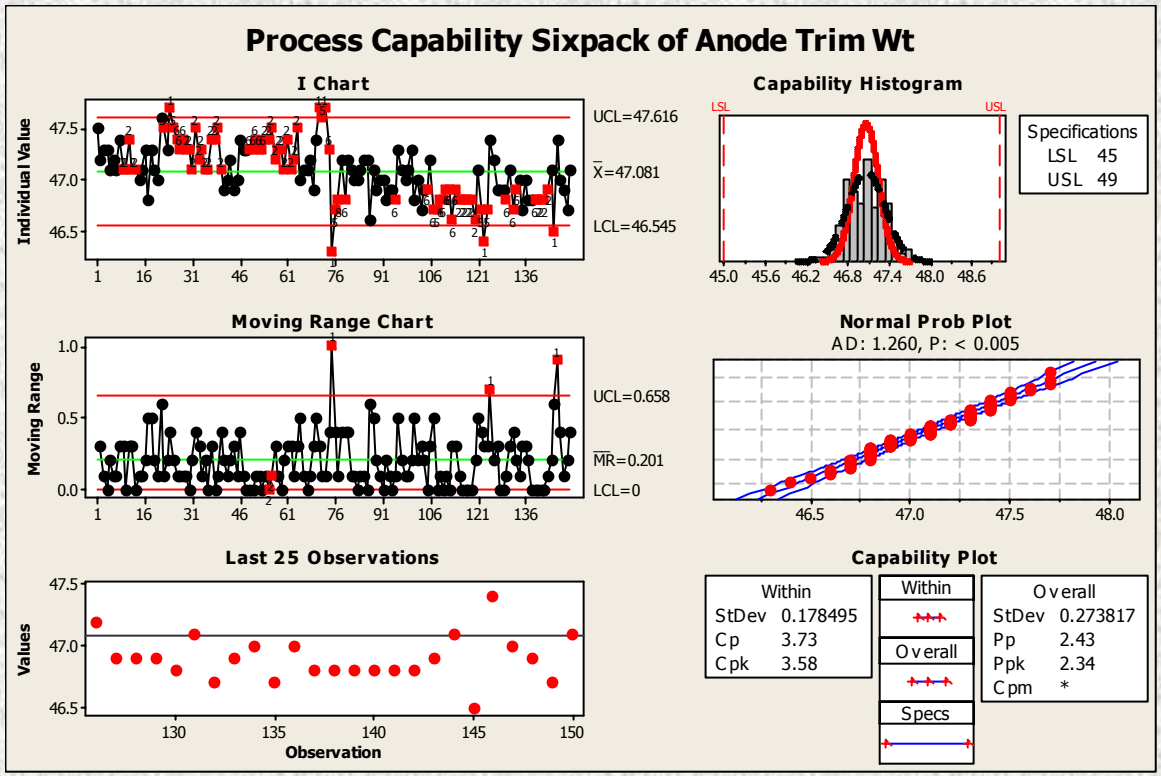
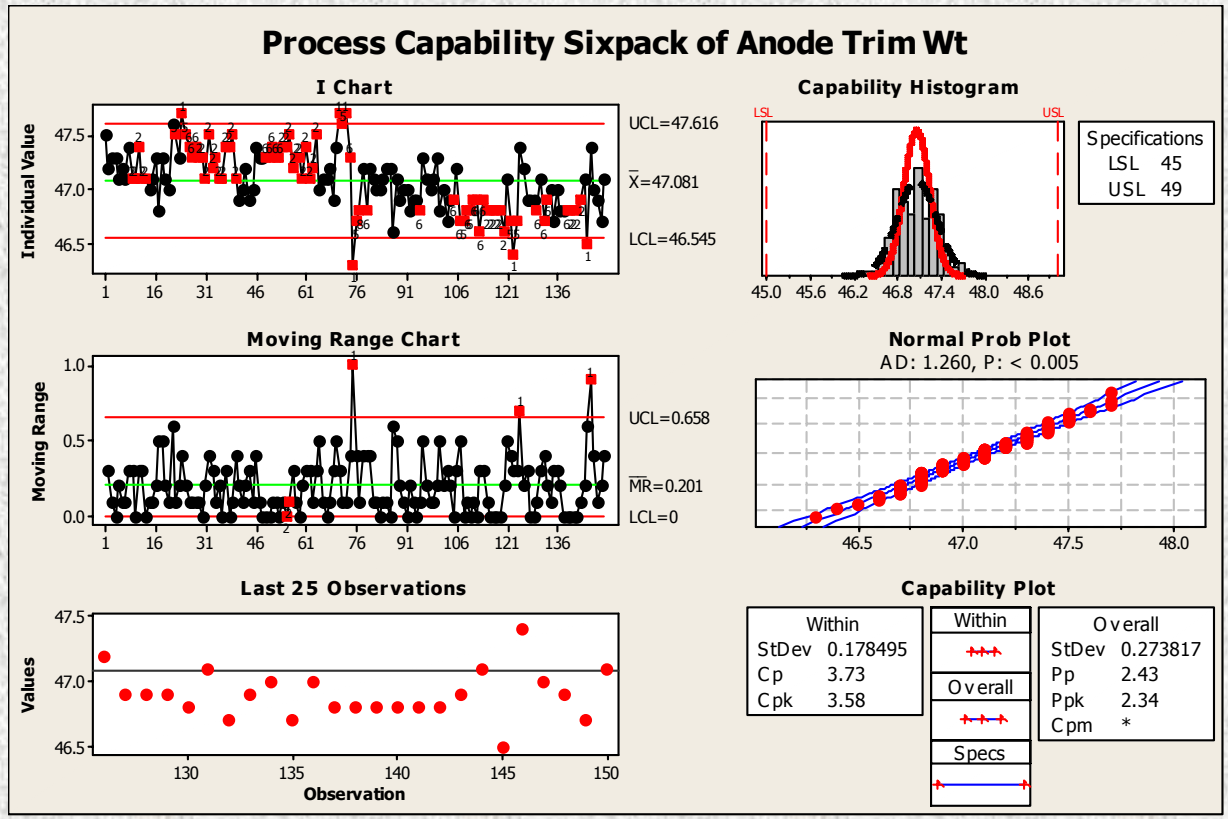
Late 2005 Capability

- **Process Demonstration**
  - **Net-shape molded bipolar plates – anodes and cathodes**
  - **Data shows key variable process capability**



TECHNICAL ACCOMPLISHMENTS

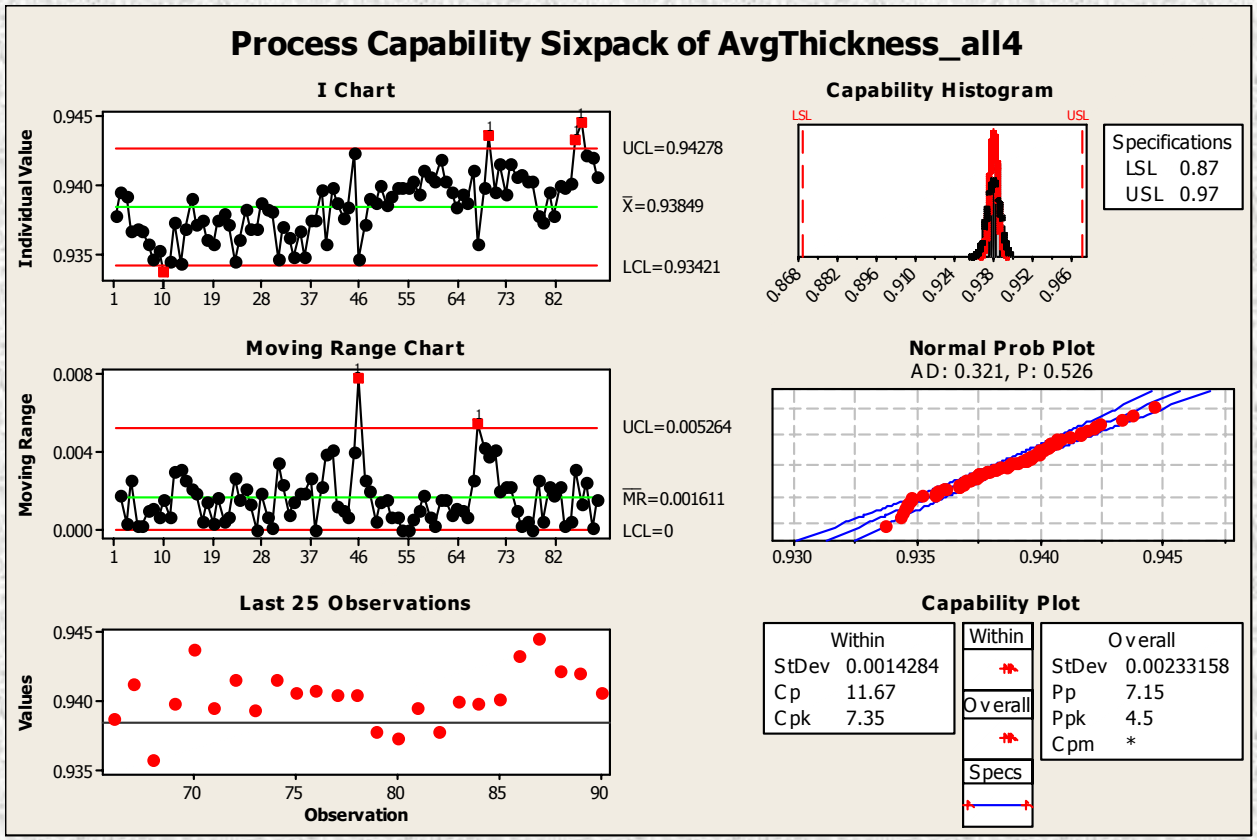
- **Final Preform Trim Weight – Key Process Variable**



Trim sheet weight consistency drives product consistency, and is the single most important measurable in our process. We demonstrated Cpk's ~2.

TECHNICAL ACCOMPLISHMENTS

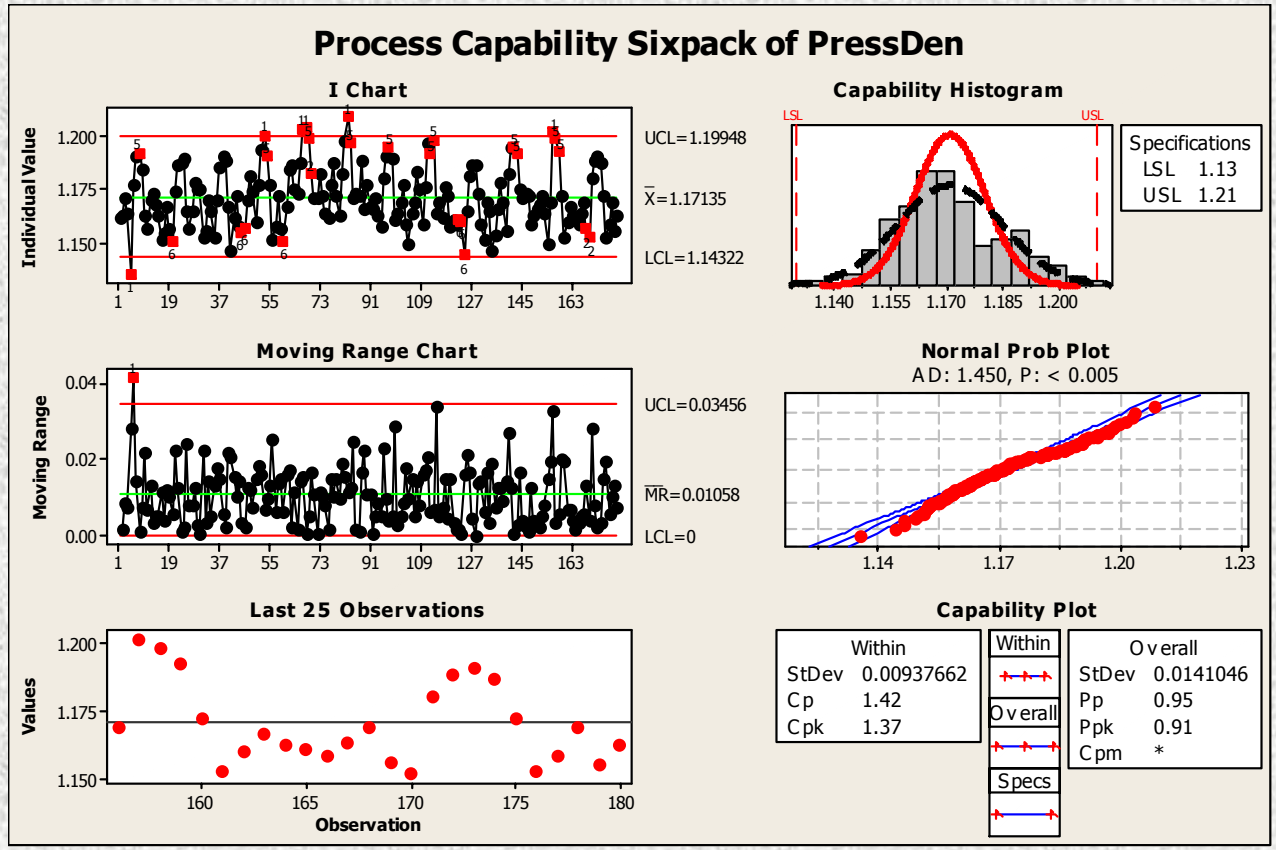
- **Plate Geometry – Final Thickness**



Final plate thickness. Measured in 10 positions on plate. Capability is very good relative to specifications, but off center. Adjustment made to re-center part thickness.

TECHNICAL ACCOMPLISHMENTS

- **Within Plate Uniformity**



Data shows coupon consistency from as-molded plates (15 equal size coupons measured per plate evaluated). This data shows that we have ~0.8% standard deviation in our product (which exceeds our long-term goal of 1%).

TECHNICAL ACCOMPLISHMENTS

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- **Channel Dimensions**

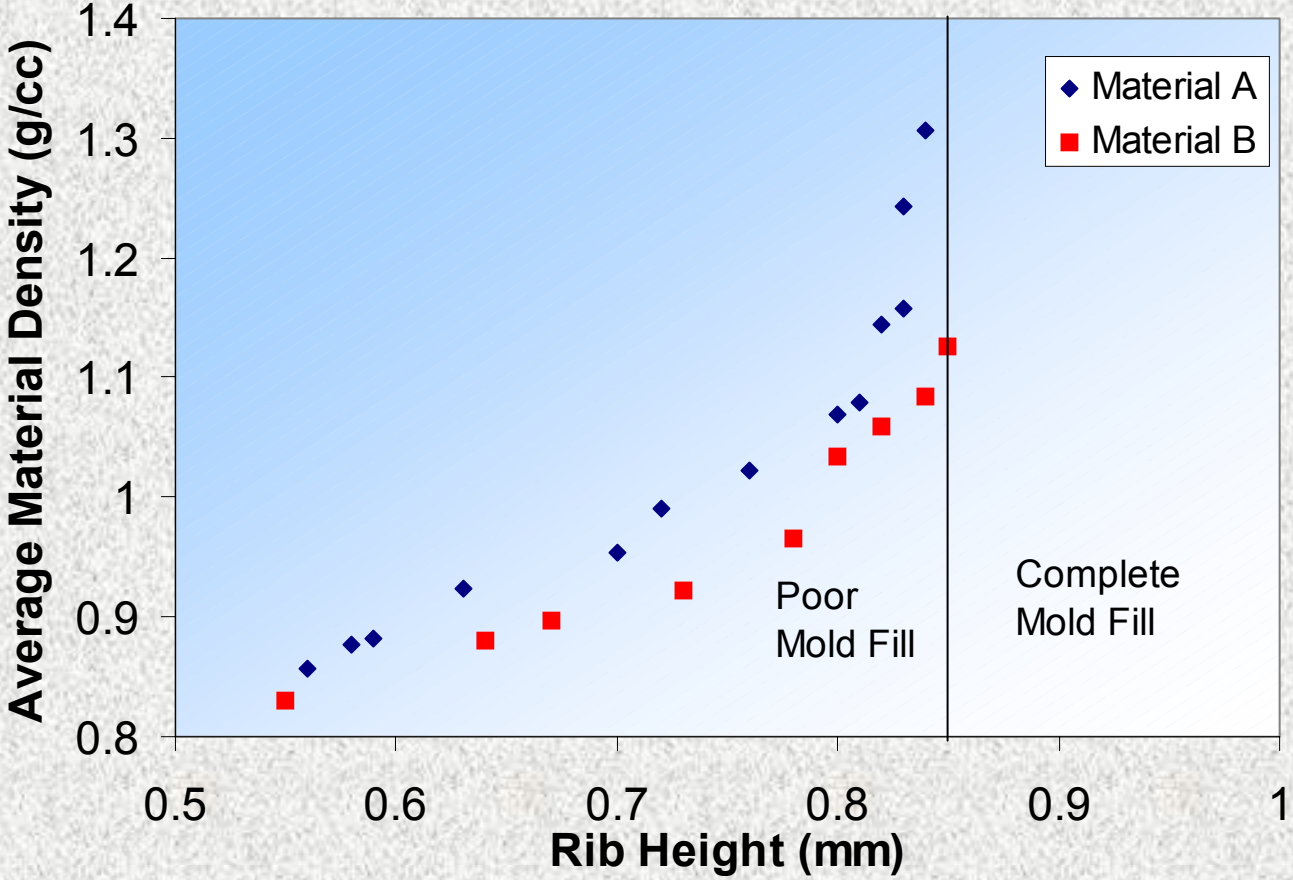

Chart shows rib height vs. material density. Materials development resulted improved mold fill at lower overall product density – better mold fill at lower molding pressures.

TECHNICAL ACCOMPLISHMENTS

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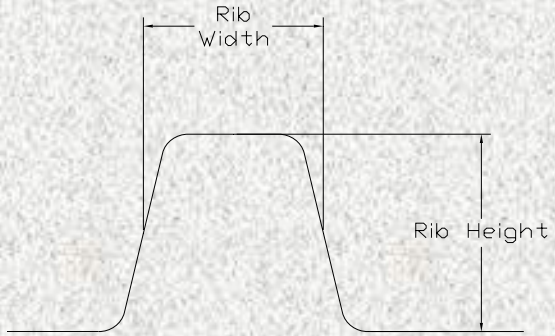
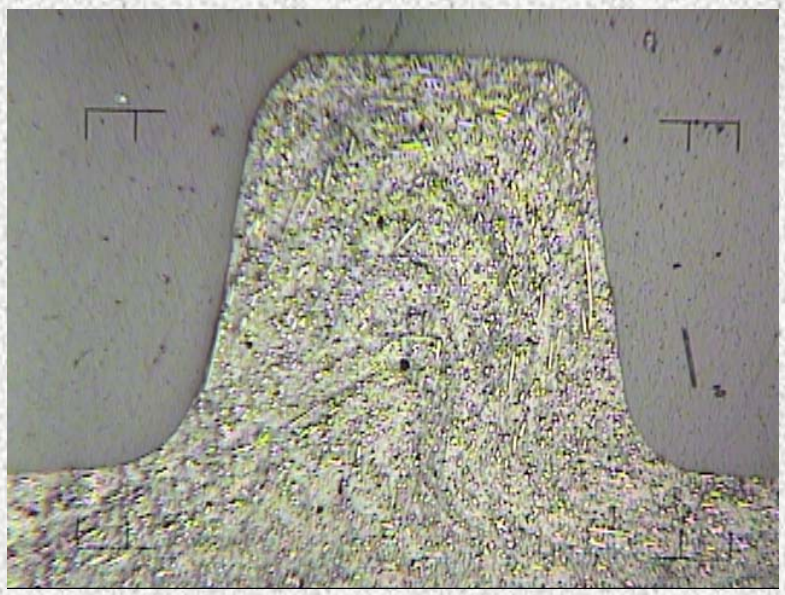
- Channel Dimensions
- Material Shrinkage Characterization
  - Material orientation impacts material shrinkage
  - This shrinkage was characterized for a wide range of channel dimensions
  - Data used to design new mold dies





TECHNICAL ACCOMPLISHMENTS

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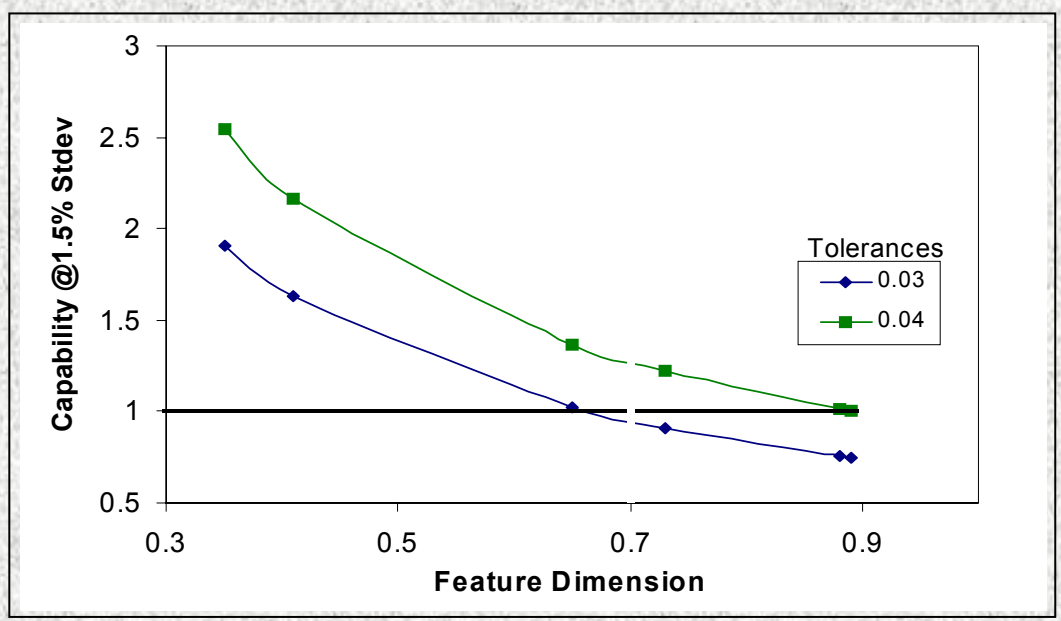
- **Channel Dimension – Capability Analysis**
  - **Better capability at smaller feature dimension**
  - **Capability marginal at larger feature size with typical customer tolerances**



TECHNICAL ACCOMPLISHMENTS

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- **Product Sealing**
  - **Significant work done to improve product sealing**
    - **Defining sealing tests (full plate small sample)**
    - **Reducing contact resistance**
    - **Reducing hydrogen permeability**
    - **Evaluating product durability and lifetime**
  - **Sealing work on-going**

TECHNICAL ACCOMPLISHMENTS

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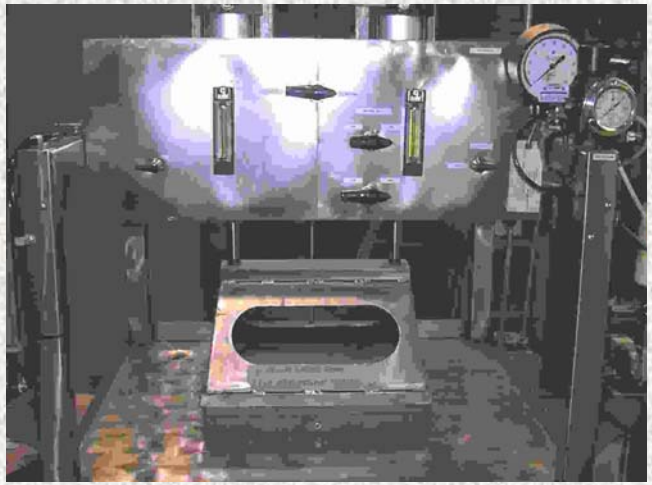
- **Sealing Results**
  - Hydrogen perm ~$2x10^{-5}$ $cc/cm^2/sec$ @ 30 psi, room temp.
  - Seal is stable for more than 500 hours in 0.1M sulfuric acid at 80C
- **Seal Testing**
  - Large scale is coarse test and checks for presence of flow in a fine variable area flow meter
  - Small scale test is hydrogen test following ASTM 1434-82



TECHNICAL ACCOMPLISHMENTS

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- **Wettability Treatments**
  - **Investigations performed on enhancing the surface water wetting characteristics**
    - **Hydrophobic and hydrophilic treatments investigated**
    - **Durability evaluated by high temperature sulfuric acid soak**

TECHNICAL ACCOMPLISHMENTS

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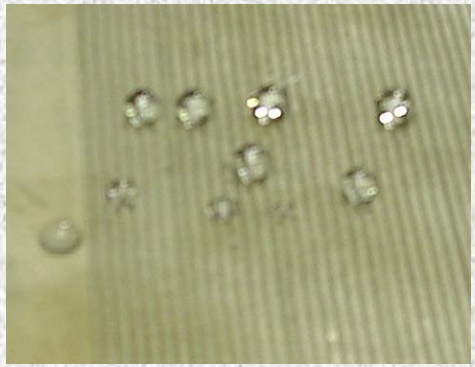
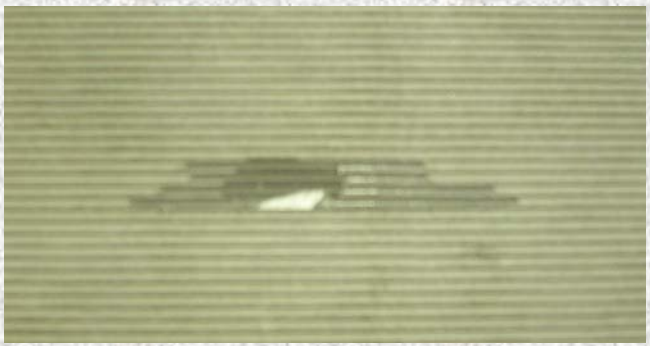
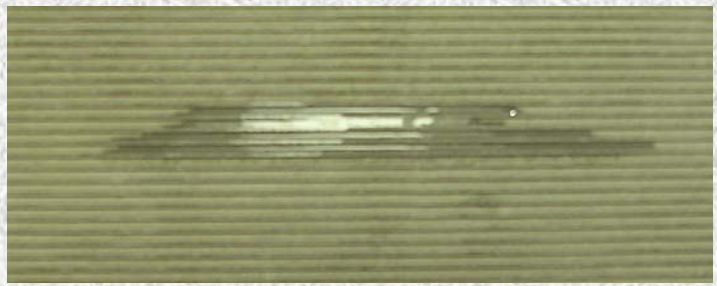


Hydrophobic surface before sulfuric acid soak

Hydrophobic surface after sulfuric acid soak



Hydrophilic surface



Hydrophilic surface after sulfuric acid soak

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FUTURE WORK 2006

- **Investigate Next-Generation Processes**
  - Aimed at reducing process time from minutes per plate to seconds per plate
  - Focused at the molding and final treatment processes
- **Demonstration of Fuel Cell Performance with Net Shape Molded Stack**
  - Stack testing currently underway (approximately 1800 hours accumulated at the time of this presentation)

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FUTURE WORK 2006

- **Complete Process Improvement Activities**
  - Generate final QA plan, FMEA
  - Perform final lean event to eliminate non-value-added steps from process
- **Complete Sealing Development**
  - Finalize evaluation of product durability
  - Finalize development of hydrophobic surface treatment
- **Final Product Cost Analysis**
  - Perform final product manufacturing cost evaluation
  - Evaluate final product capability relative to DOE targets

REVIEWERS COMMENTS

- **Cost Model Not Clearly Explained**
  - Detailed explanation of cost model would have taken longer than the time allotted for the presentation
  - Focused upon results of cost model instead
- **Reliance on single partner will bias the project**
  - Most of our work done with UTC Power
  - Several customers have/are evaluating our sealed plate materials
  - We find FC manufacturers are focusing upon areas other than bipolar plates at present. While there is interest, there is not a strong drive for customers to devote significant resources.
- **Project directed toward commercialization of this technology. Limited public knowledge developed in this project**
  - Our project includes 50% cost share
  - Specifics of program are proprietary

PRESENTATIONS/PUBLICATIONS

- **Other than the 2005 DOE Fuel Cell program review, and the 2005 Tech Team review, no other presentations or publications were made in 2005 from work resulting from this program**

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CRITICAL ASSUMPTIONS/ISSUES

- Relevance of Sulfuric Acid Durability Testing
  - Materials known to be used with success in fuel cells do not pass testing with hot sulfuric acid – is test too rigorous?
- Impact of Moderately Hydrophobic Surface
  - Customers can not clearly indicate impact or difference in performance between a hydrophobic or hydrophilic surface
- Customer Channel Tolerances are Very Tight
  - Typically +/- 0.03 mm (+/- 1 mil)
  - What is the impact of less restrictive tolerances? Wider tolerances may not impact performance, but will make the manufacturing process much more capable