SMARTMolding UPDATE

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# SMARTMolding Update

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Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
Outline

- Review of new VARTM process variations
  - Channel-Assisted Resin Transfer Molding (CARTM)
  - Interlaminar Flow Media
    - Verdant Polybeam™

- New Features of SMARTMolding Software Suite
  - Design Tool
    - Incorporated commercially available Distribution Media into Database
  - Intelligent Process Control System
    - Added Intranet connectivity
    - Automated Vacuum Debulking
    - On-line Work Instructions
    - Virtual Checklist of all Processing Steps
    - Sensor Test
  - New Data Review Graphical User Interface
    - Allows on-line reporting on all recorded data over Intranet
    - Export to Excel, Printing Capability
Outline

- **New Features of SMARTMolding Software Suite**
  - Recipe Definition GUI (In Progress)
    - Complete Process Flow Description (Recipe) is automated
    - Checks on Database and Process Consistency
  - Automated Statistical Analysis Tool (In Progress)
    - Detects Outliers
    - Ranking of Important Process Variables

- **New Features of SMARTMolding Hardware Suite**
  - Wireless Tool-Mounted Sensors (In Progress)
  - Tool-Mounted Time-Domain Reflectometry

- **Technology Transfer**
  - Important Conference Participation
    - SMARTMolding Demonstration at SAMPE ‘03 Long Beach, CA
    - Invited Lecture “Intelligent Process Control For Automated VARTM Processing” Composite Fabricator Association (CFA) Liquid Molding Conference in Dayton, OH
  - In Progress of Updating Beta-Sites with new Software Components
    - NSWC Caderock has been updated
  - Strong Interest in SMARTMolding from several Companies
    - Boating
    - Wind Energy
The CARTM Process I

- Channel-Assisted Resin Transfer Molding Process
- Patented and Commercially Licensed
- Similar attributes compared to FASTRAC, but flow media and completed double bagging systems are commercially available

Courtesy of [Image]
The CARTM Process II

- System can be modeled as a typical VARTM process with distribution media
  - Permeability is a function of CARTM media (channel pattern) and differential vacuum pressure
  - Opportunity to optimize surface flow for complex structures by designing the CARTM layer (off-line control)
  - On-line flow control possible by adjusting differential vacuum pressure
    - Zones
    - Vacuum gradient
    - Delay Lines

- Establishment of a CARTM workcell at UD-CCM in July with help of “Why not Composites”
Interlaminar Flow Medium

- Resin introduced through the preform via an integrated inter-laminar distribution media
- Peel ply not necessary
- Thick preforms can be divided in multiple laminates
Polybeam Flow Media™

- Patented Polybeam technology increases permeability during infusion due to spring-back and reduces porosity after infusion due to unique compaction behavior.

- Talks initiated with Verdant to evaluate compaction behavior and mechanical performance.
  - Bonding to cored structure
  - Inter--laminar shear
SMARTMolding Software Suite

- **Design Tool**
  - Simple Interface, Limited to simple geometries
  - Predicts Flow Times, Lead Length
  - Optimizes # of Seq. Injection Lines
  - Database with Material Properties

- **IPC System**
  - Automates the VARTM Process
  - Records the processing steps
  - Reporting of collected data
  - Enables statistical analysis
  - Guidance Software to define process recipe

- **Data Review**

- **Statistical Package**

- **Recipe GUI**
Added Permeability Data to Database of Commercially Available Distribution Media

- Database includes now 5 Distribution Media (4 more in progress)
- Design tool chooses DM based on lead length and flow times

Data Courtesy of Gaetan Denis
Recipe Definition GUI

- **Supports Definition of**
  - Process Set Points
    - Vacuum Leak Level
    - Resin Volume
    - Debulking
      - Cycles
      - Vacuum Level and Cycle Time
    - Infusion Setup
    - Sensors
    - Valves
    - Sequential Injection Script
    - Dwell Time and Dwell Vacuum level

- **Material Selection**
  - Materials and Material Sequence during Lay-up
  - Resin
  - Bagging
  - Mold

- Validates complete definition of recipe
- Review Recipe Definition
New IPC Graphical User Interface
Features 1/2

Intranet connectivity

IPC 1

IPC 2

Server

On-Line Work Instructions

- MSDS
- Pictures
- AutoCAD drawings
- Video

Virtual Checklist of all Processing Steps

- Automatic Backups
- Multiple IPC’s can be connected
New IPC Graphical User Interface
Features 2/2

Automated Vacuum Debulking

- Automatic Debulking
- Improves repeatability and reduces preform thickness prior to infusion

Sensor Test GUI

- Ensures sensor functionality
- Adjust resin arrival threshold for different resin systems
Data Review Graphical User Interface

DEMONSTRATION

SMARTMolding 3.1
Data Review

03-00054

- Resin Weight
- SMARTMolding
- Vacuum
- Temperature Humidity

- Part History
- Lay-up History
PhD student is establishing theoretical and experimental understanding of VARTM repeatability ➔ see presentation of Amoroux

Boeing Corporation is supporting the VARTM repeatability project

> Information will be provided from the AST Wing and CAI program
> POC Boeing: Scott Holmes
  V-22 Affordability
  Integrated Defense Systems, PHL
Statistical Analysis Package

Objective

- Flag outliers based on process parameter values and reduce number of post-inspections
- Rank parameters based on their repeatability
- Identify parameters that relate to quality of part
- Detect quality based on parameter values

Approach

- Iterative statistical detection scheme for outliers
- Repeatability measure to rank parameters,
Data Analysis: Fiber Weight

- **Discrete vs. Continuous**
  - Discrete parameters have one value per part, Ex. Fiber Weight
  - Continuous parameters are time-dependent, Ex. Resin Weight Infused vs. Time

- **Lognormal Distribution**
  - Assuming Lognormal distribution for process parameters (When RV X is lognormally distributed, then ln(X) is normally distributed.)

- **Lognormal Validation**

- **Outlier Detection based on Probability Level**

Lognormal Distribution fits the Fiber Weight Data

- **Lognormal Validation**

- **Outlier Detection based on Probability Level**

Additional Layer was added to part 03-00062 and 03-00063 creating two outlier.
Wireless Sensor Network

Objective:
- Reduce noise due to wiring
- Allow seamless switching of molds without connecting/disconnecting sensor cables

Approach:
- Using existing wireless sensor network technology
- Develop custom DAQ to connect locally to transmitter
  - DC-based flow measurement
  - Other sensors such as temperature and humidity sensor
- Wireless sensor network technology replaces multiplexing technology
- Sensor signal quality is improved due to a reduction in cross-talking and cable noise
- Simple plug & play reduces the setup time. System can be reduced if mold is scrapped
Improved Signal to Noise Ratio 5:1

**Existing SMARTMolding System**

![SMARTMolding SC-15 Curing Curve](image1)

SNR = 10 * log(0.3/0.01) = 4.7 db

**Wireless Single Sensor**

![Wireless SC-15 Curing Curve](image2)

SNR = 10 * log(2.02/0.01) = 23.05 db

**Demonstration!!!**
Tool-Embedded TDR Sensing

**Technology benefits:**

✓ Non-contact sensing;
✓ Sensing through release agent and gel coat;
✓ No post service required;
✓ Low cost manufacturing;
✓ Application for non-conductive polymer based tools with various curvatures.
5m Tall Structure Infusion

![Graph showing location vs. time for 1D Flow Measurement with TDR](image1)

- Tool embedded TDR sensing has been tested during vertical infusion;
- TDR sensor response fits infused resin weight data very well.

- 1D TDR Flow data shows flow progression after fill factor shows no response
- The resin cures in bucket faster and stops injection in the preform
Summary

- New VARTM processes create opportunity for on-line control
- Additions to IPC software creates new capabilities (debulking) and adds to industrial requirements (work instructions, intranet capable)
- Major advances have been implemented to create user-friendly SMARTMolding environment
  - Recipe Definition
  - Data Review
- Data mining software components have been implemented to review automatically large amount of data collected and to detect processing outliers
- New sensor hardware shows promise for industrial environment
  - Reduced wire count
  - Tool-Mounted TDR allows monitoring through gel coat