SMARTMolding UPDATE

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## SMARTMolding Update

### Report Details

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### Abstract

See also ADM001700, Advanced Materials Intelligent Processing Center: Phase IV., The original document contains color images.

### Security Classification

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### Limitation of Abstract

- **Limitation of Abstract**: UU
- **Number of Pages**: 21

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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
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

Courtesy of
SMARTMolding Software Suite

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

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

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

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

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

Wireless Single Sensor

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.
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