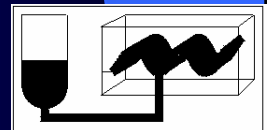
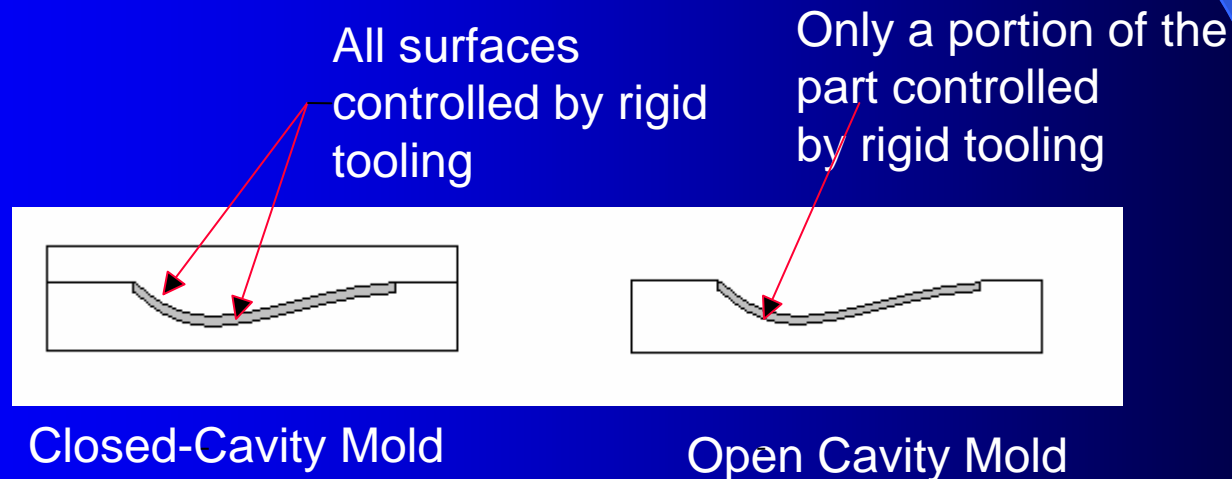


Guidelines for the Development of  
Process Specifications, Instructions,  
and Controls for the Fabrication of  
Fiber-Reinforced Polymer  
Composites by Liquid Molding

Larry Gintert &  
John Bayldon

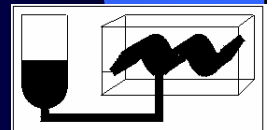
# Liquid Resin Molding

- Liquid Resin Molding (LRM) processes are classified as any processes where liquid resin is infused into a dry fiber perform.

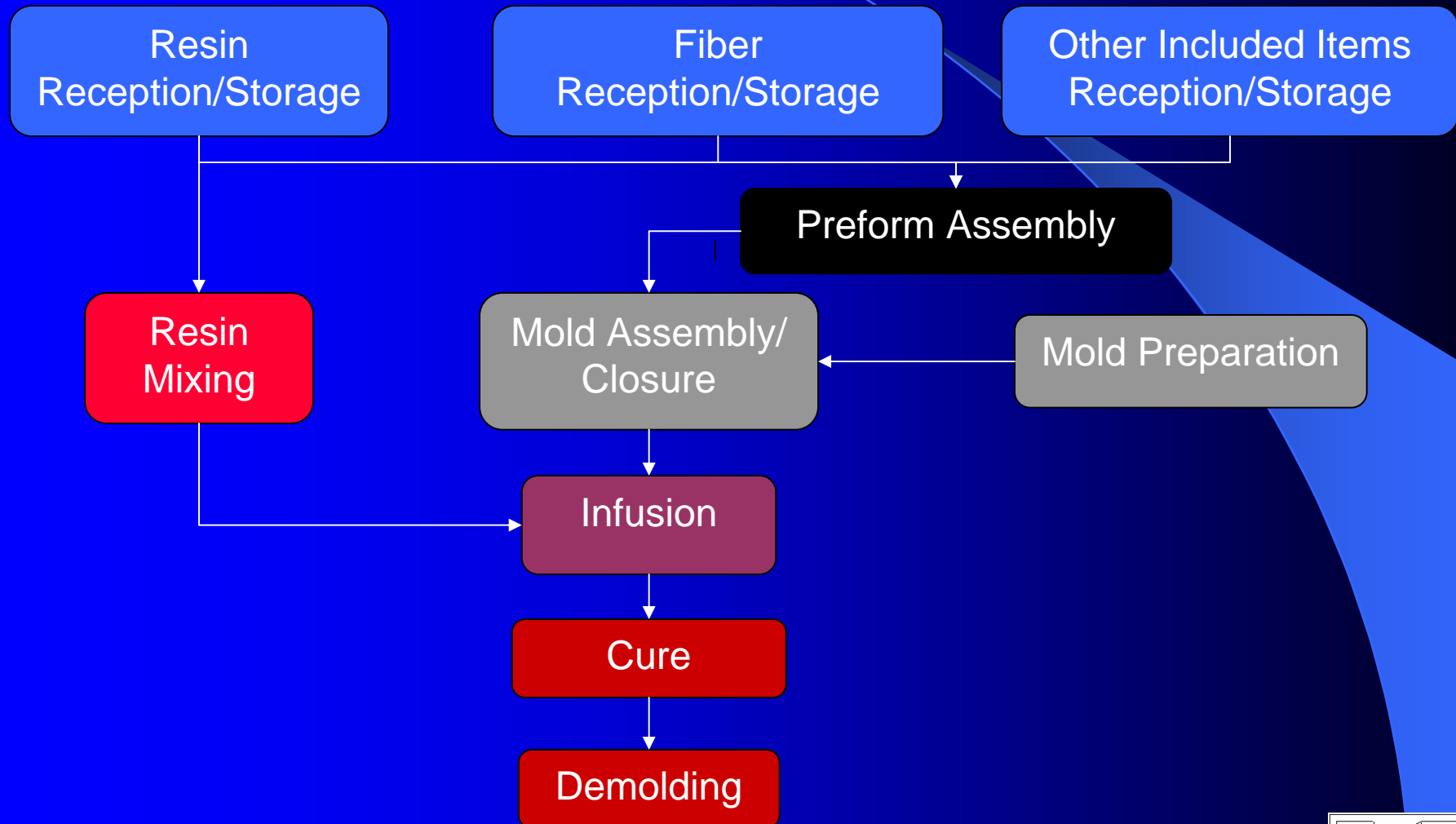


# Objective

- Guidelines for the development of liquid resin molding (LRM) process specifications for the fabrication of continuous fiber-reinforced polymer composite test panels used in the generation of mechanical properties
- An approach for the validation of composite LRM fabrication processes used during the certification of composite aircraft structure

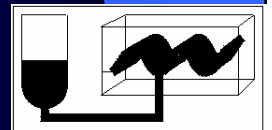


# LRM Process Flow



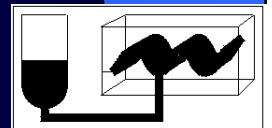
17<sup>th</sup> Sept 2003

Larry Gintert  
John Bayldon



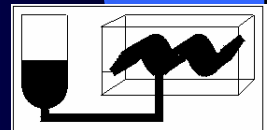
# Certification Process

- Design validation process: to establish by proof, is accomplished through
  - Verification (to prove by evidence) and
  - Qualification (to define attributes or characteristics) of the materials, processes, and analysis tools.



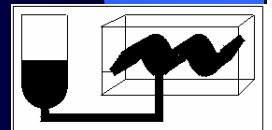
# Material Qualification

- Qualification tests are planned and conducted to
  - Establish key material attributes
  - Establish material performance properties
  - Verify material characteristics will work in the intended application.
- The objective in defining material attributes is to establish the constituent material property limits.



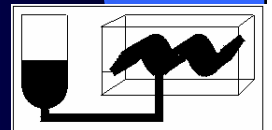
# Preform Attributes:

- Fiber pedigree
- Ply dimensions, alignment and stacking sequence
- Shaped preform contours
- De-bulked preform fiber volume
- Fiber sizing level and type,
- Quantity of tackifiers and/or binders used, and
- Compatibility of constituent materials with each other



# Liquid Resin Attributes

- Initial mix viscosity (at a defined temperature)
- Initial mix heat of reaction ( $\Delta H_{\text{ult}}$ )
- Mix chemistry (e.g. ratio of epoxide:amine groups in some epoxy chemistries)
- Amount of entrained air or solvent
- Thermal conductivity



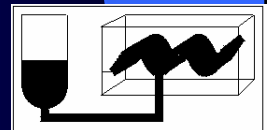


# Process Specification Guidelines

- Process specifications
- Material specifications
- Planning
- Work instructions
- Test plans

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Larry Gintert  
John Bayldon

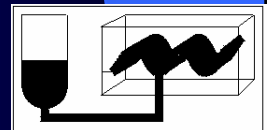


# Fabrication Specification Sections

- Work Instructions
- Personnel
- Materials
- Equipment Description
- Facility Description
- Tooling
- Panel Lamination
- Panel Acceptance
- Process Monitoring

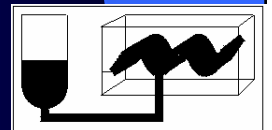
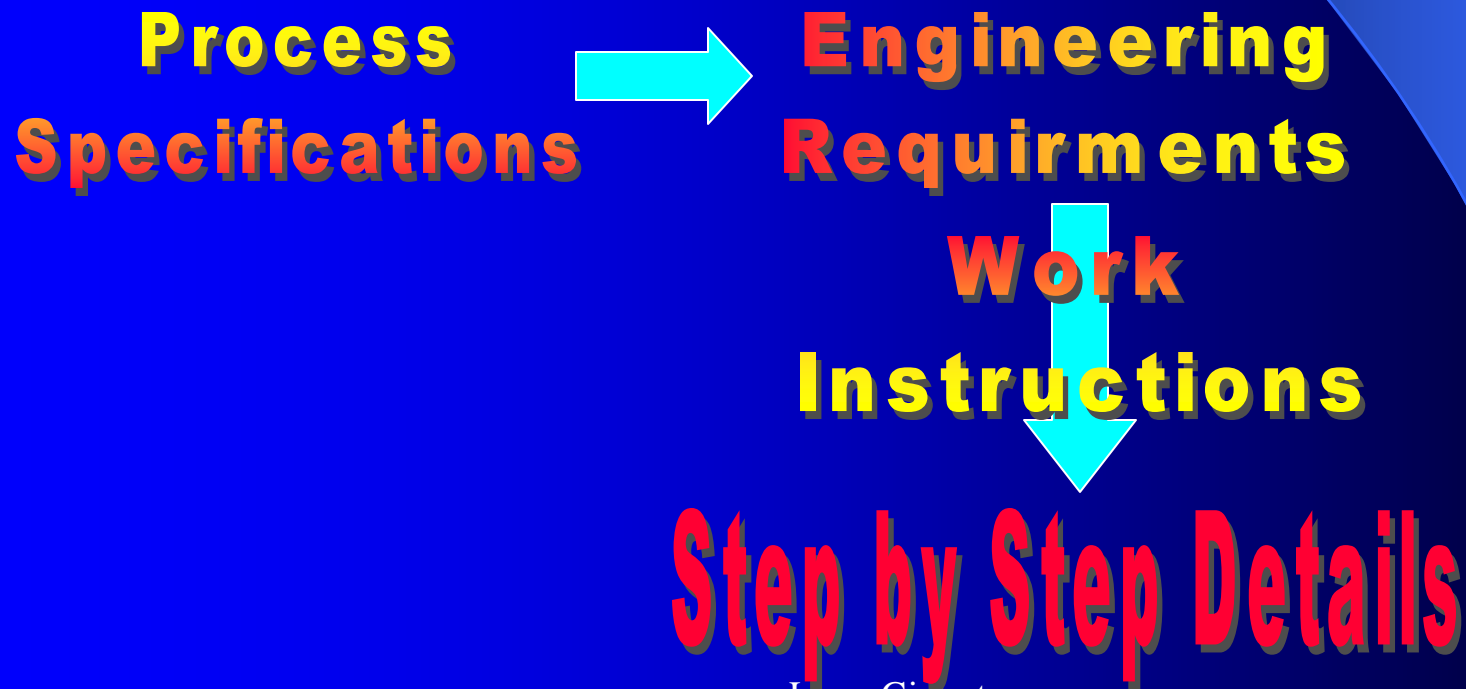
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Larry Gintert  
John Bayldon



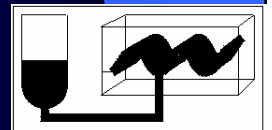
## 2.1 Work Instructions

- Requirements and procedures to be used in the fabrication process.
- Detailed step-by-step work instructions in conjunction with process specifications



## 2.2 Personnel

- Recommended Personnel Selection Factors
  - Experience
  - Inspection personnel, ratio to manufacturing personnel
  - Level of training
  - Personnel status identified (qualified or unqualified)

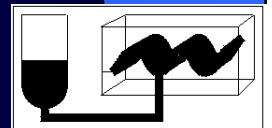


# Materials Controls

- Traceability
  - From raw fiber, or basic raw materials
- Storage Requirements
  - Humidity
  - Temperature
- Records

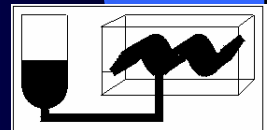
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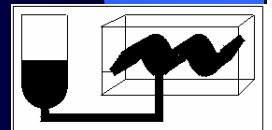
## 2.4 Equipment Description

- Equipment Calibration
  - Ovens
  - Liquid resin delivery devices (such as pumps)
  - Thermocouples
  - Vacuum gages, and ply-warming devices (e.g., hot-air guns)



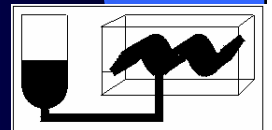
## 2.6 Tooling

- Flat, closed-cavity mold with a uniform thickness cavity, for closed-cavity LRM
- Flat base plate and perhaps a reusable bladder for open-cavity LRM processing
- Engineering Performance:
  - Assembly procedure, infusion parameters/pressures, cure temperature and packing pressure, surface finish and flatness requirements should be defined
  - Thermocouples should be placed at the coldest and hottest locations



## 2.6 Tooling Cont.

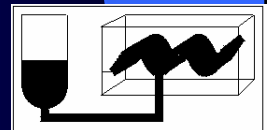
- A method for accurately positioning the plies is required
  - Control of ply orientation
  - Transfer of the tool zero direction to the panel and then to the machining equipment e.g.
    - Scribe lines on the tool
    - Thin metal strips embedded along one edge of the panel
- Tool preparation procedures
  - Tool inspection
  - Verification that all tooling details are available and in good working condition





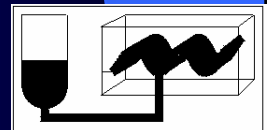
## 2.6 Tooling Cont.

- Method of cleaning, solvents, cleaning cloths
- Mold release agents
- Tool heat survey results (location of coldest and hottest thermocouples)
- Scribe marking
- Templates
  - Inspection intervals
  - Surface conditions
  - Material
  - Quantities



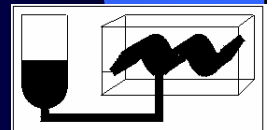
## 2.6 Tooling Cont.

- Heat-up rate
- Surface conditions
- Method of moving, transportation
- Condition (mold release applied, and no mold release)
- Configuration (flat, vertical)
- Status identified (approved, unapproved)
- Storage conditions and locations
- Expansion and contraction rate
- Material
- Repair procedures
- Inspection intervals
- Location and number of vacuum ports
- Orientation rosette



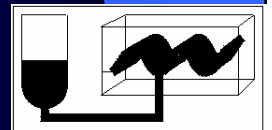
## 2.7.1 Preform Fabrication

- Frozen reactive materials warmed to room temperature prior to opening
- Materials should be cut on surfaces specifically dedicated to cutting
- Individual materials should be identified and marked at the time of cutting
- Preform tooling
  - Inspection step with a translucent shaped caul
- Accurately align the materials with respect to the tool zero-degree reference direction



# 2.7.1 Preform Fabrication Cont.

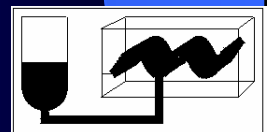
- Mold assembly repeatability
  - Positive location features and methods that ensure that the preform is not distorted or damaged
  - Inspection features with acceptable limits for measured gaps in the case of closed-cavity molds
  - Thickness gages and templates in the case of open-cavity molds
- Thermocouples
  - Direct measurement of the panel temperature
  - Thermocouples placed against the preform to ensure the material is heated to the specified temperatures
  - At least two thermocouples should be used for each panel



# Larry

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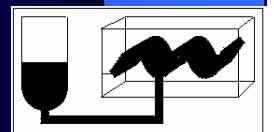
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John Bayldon



# John

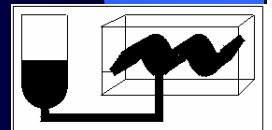
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## 2.7.2 Resin Mixing

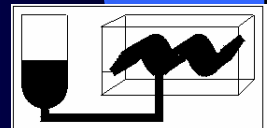
- One Part Systems
  - Controlled by supplier, and verified by fabricator, large batches allow for comprehensive testing of final resin
- Formulated System
  - Supplier can verify chemistry of components, and mixing quality of separate parts, but fabricator has to carry out final mixing. Verification of mix ratio and mix quality required
- Other
  - Fabricator must verify chemistry of components, (before or after mixing,) and then verify mix ratios, and mix quality



## 2.7.2 Resin Options

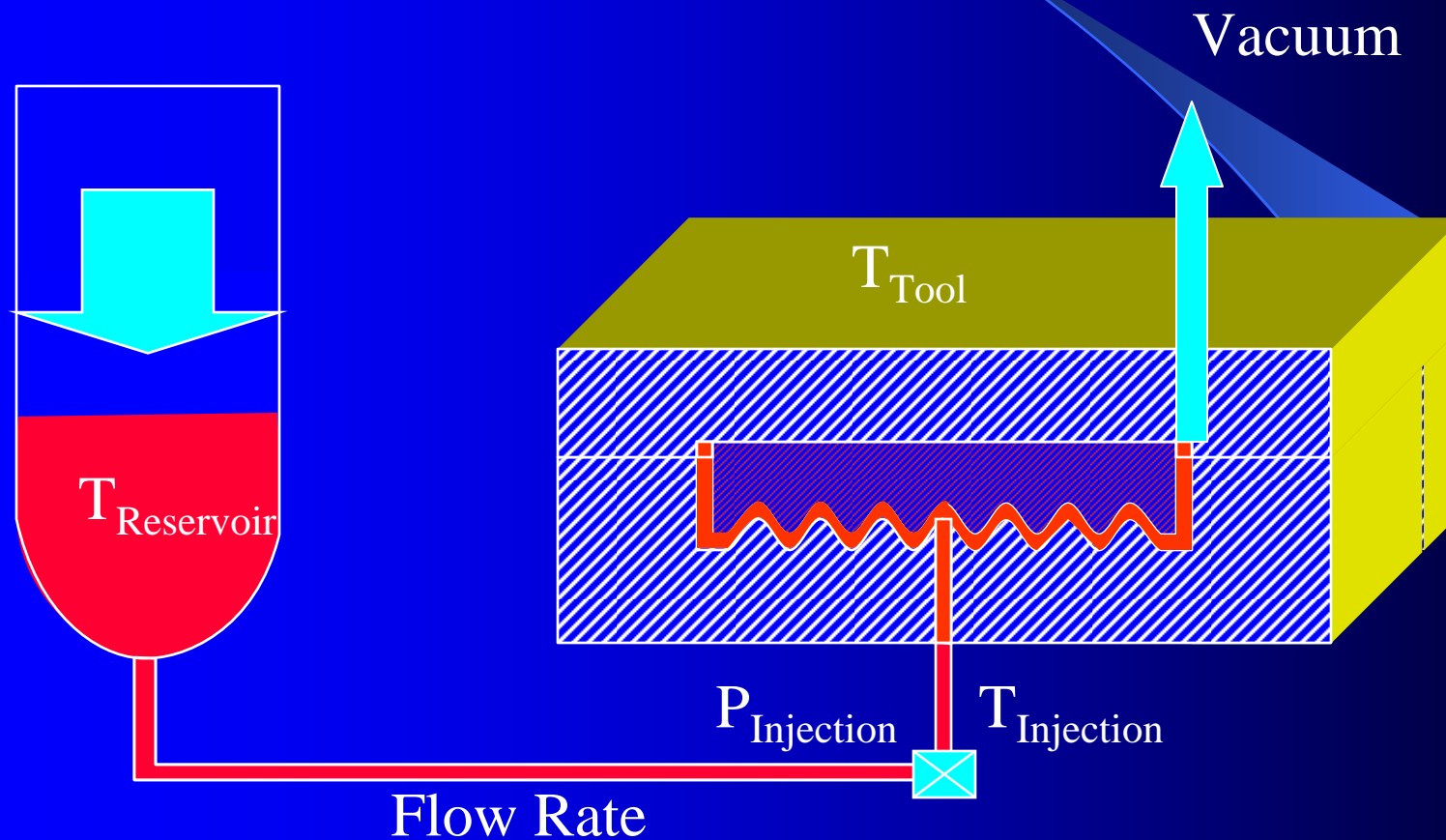
	One part	Formulated	Other
Well Mixed	✓	⊘	⊘
Mix Ratios	✓	✓	⊘
Cure State	⊘	✓	✓
Contamination	✓	⊘	⊘
Compatibility	Test	Test	Test

⊘ Indicates Fabricator Controls Required. ✓ Indicates generally good



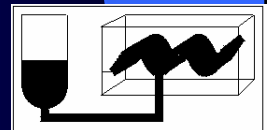


## 2.7.3 Resin Infusion Control

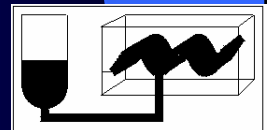
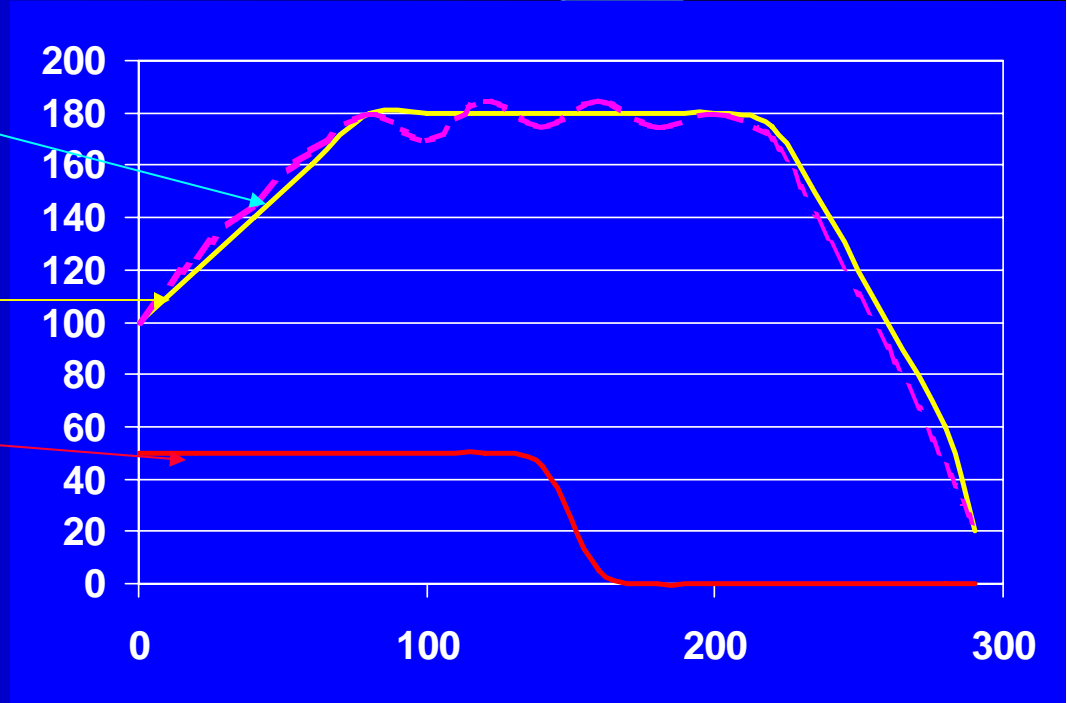
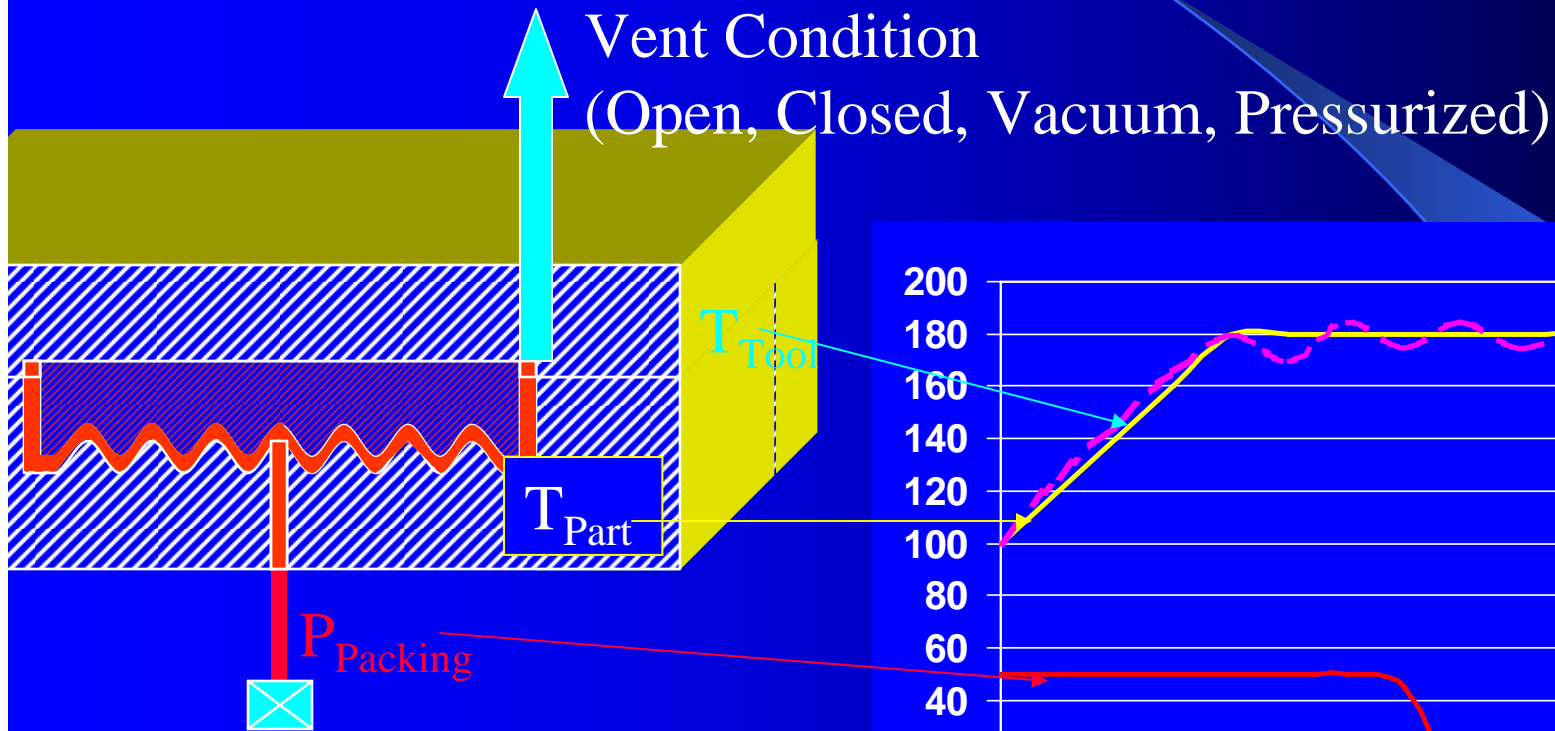


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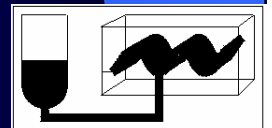


# 2.7.4 Resin Cure



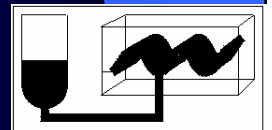
## 2.7.5 Panel Identification

- The identification number will provide traceability to:
  - The requesting document
  - Resin batch number
  - Preform identification number
  - Cure cycle
  - Test type
- Lines can also be drawn at an angle across the panel surface to aid in identifying specimen location within the panel.



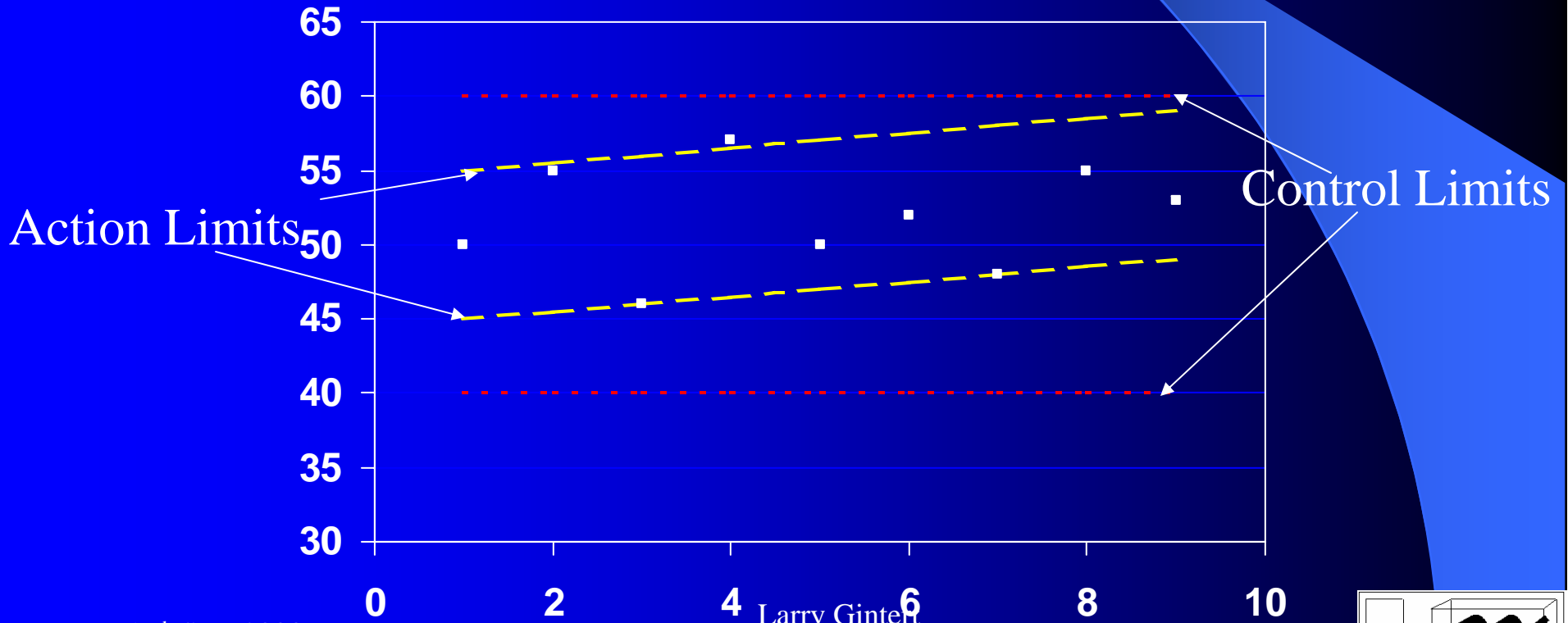
# 2.8 Inspection and Process Monitoring.

- **2.8.1 Responsibility for Inspection**
- **2.8.2 Process Monitoring and Control**
- **2.8.3 Panel Inspection**
- **2.8.4 Use of Prolongs/Cut outs**



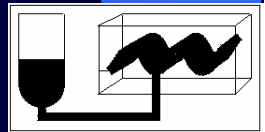
# 2.8.2 Process Monitoring and Control

- Data Collection for Quality Assurance
- Data Collection for SPC



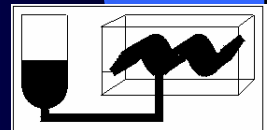
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John Baydon



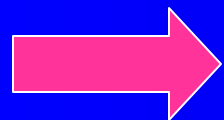
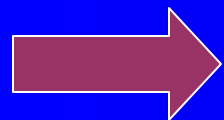
## 2.8.3 Panel Inspection

- Panel thickness
- Surface flatness
- Resin content/reinforcement weight fraction
- Void content
- Composition variations (e.g due to binder migration or resin filtration,)
- Completeness of cure
- Embedded materials



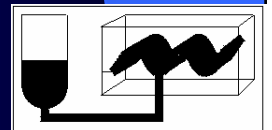
# Resin Composition Variation

- Filtration
- Binder/Tackifier Migration



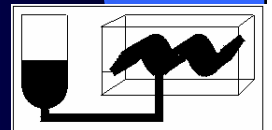
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## 2.8.4 Use of Prolongs/Cut-outs

- Traveler Pieces
  - Quality control
  - Statistical process control
- Must be included at the earliest stage of the process design
- Tests
  - Degree of cure
  - Final Tg
  - Flexural strength.
- Vent/Gate plugs





# 3 Producibility Validation Guidelines

- 3.1 Producibility Qualification Tests
  - Verification of material behavior for complex shapes and full scale parts
- 3.2 Fabricator Qualification
  - Verification of production parts compared to development
- 3.3 Performance Property Equivalency
  - Verification of materials properties for full scale parts
- 3.4 Component Structural Equivalency
  - Verification of structural behavior

