

Composite Structure Engineering Safety Awareness Course

Process Specifications for
Composite Manufacturing

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Agenda

Process Specifications for Composite Materials

- ◆ What is a process specification versus a material specification
- ◆ Fabrication processes
- ◆ Cure cycles
- ◆ Nondestructive inspection
- ◆ Sandwich structure
- ◆ Tooling
- ◆ Process qualification, validation, change

References

- ◆ DOT/FAA/AR-02/110, Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites
- ◆ DOT/FAA/AR-06/25, Preliminary Guidelines and Recommendations for the Development of Material and Process Specifications for Carbon Fiber-Reinforced Liquid Resin Molded Materials
- ◆ DOT/FAA/AR-03/19, Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure
- ◆ CMH-17 Composite Materials Handbook, Rev G

Process Specifications

- ◆ Not very exciting by themselves (like most legal documents), until:
 - Different sites (or the same sites over time) experience varying quality “following the exact same process”
 - 6 months of parts called into question by incomplete cure data
 - Parts approaching \$1M each experience quality changes
- ◆ Big difference between processing issues that can be validated (nondestructively) after the fact (porosity) and those that can't (bond strength).
- ◆ Process conformance and control is the ultimate validation for many composite structure conditions, especially concerning adhesive bonding.

Process Specification Questions

- ◆ Why have process specifications?
 - Because the ultimate properties and quality of composites are very dependent on processing (you are finishing making the material while it's being shaped). Unlike metals where material formulation and properties are largely fixed when procured.
- ◆ What does the process specification do?
 - It controls all of the critical aspects of manufacturing composite structure ("documented controls").
- ◆ Why are there different kinds?
 - A process specification covers general process requirements.
 - A "Process Bulletin" (or similar names) covers part or class specific processing requirements.
 - An example would be a process bulletin for wing spars with more stringent processes and quality requirements, but that would unnecessary (and uneconomic) compared to a general process spec when making access doors and fairings.

What is a process specification?

- ◆ Material specifications are used to “buy stuff” – once you’ve bought it, the process specifications takes over.
- ◆ May be little or no connection between processing under material specification used for receiving inspection and processing of the same material as controlled by the process specification
 - Layup and bagging process for making test panels may need to differ from that used for full scale parts
 - Cure cycle in a material specification may be only one of several developed for process specifications
 - Classified (or very proprietary) projects may deliberately alter material spec processing to hide what they actually doing with the material under their process spec
- ◆ If the specification you’re using is not for buying stuff (not services, e.g testing), then it’s a process specification

Process Specifications

- ◆ Proprietary versus industry process specifications
 - Composite fabrication
 - Testing (ASTMs)
- ◆ Go through a simpler process and specify all the steps and materials used:
 - Cookies
 - Pizza
 - Pencil
- ◆ Process specification may also have requirements on what not to do (e.g. no paint strippers on composite and bonded structures).
- ◆ Testing is its own composite manufacturing process: laminate layup and cure, specimen tabbing, machining, fasteners, gaging, conditioning and test

Materials Used in Process Specs

- ◆ Primary (flyaway) materials should already have their own materials specifications (e.g. prepreg, film adhesive, core).
- ◆ Many materials used in a process specification may not be part of completed structure (e.g. vacuum bagging materials) but still have great potential for affecting the quality of the structure - "Consumables"
- ◆ All materials called out in a process specification should be called out by material specification, or at least tradename and source, or (if it really doesn't matter) specifically state any source.
- ◆ A compromise for some materials like bagging - the consumables spec which primarily controls sources with minimal testing.

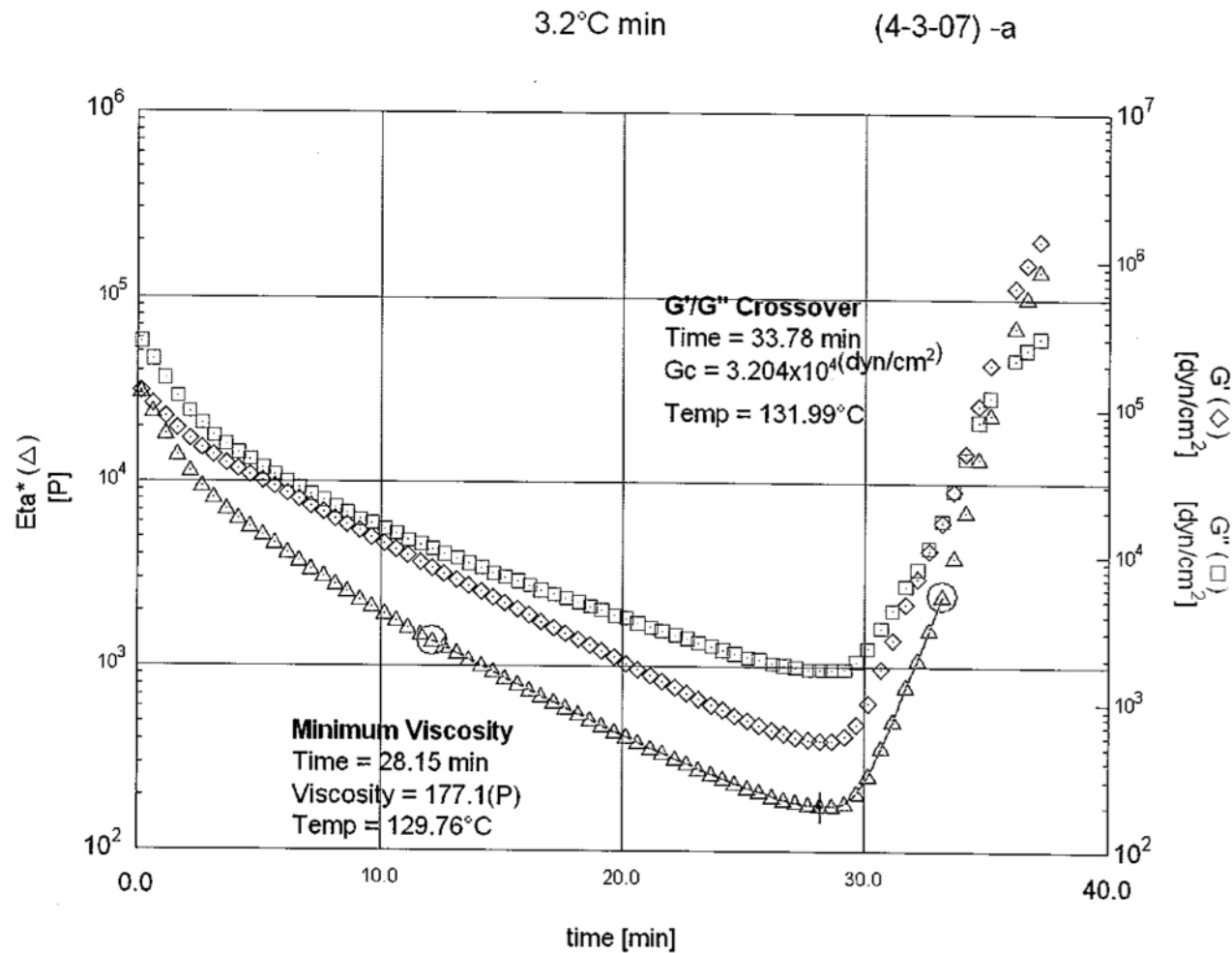
Fabrication Processes

- ◆ Fabrication up to cure: hand layup, resin infusion, filament winding, fiber placement, tape laying
- ◆ Tooling and vacuum bagging can still differ dramatically with “same” fabrication process
- ◆ Cure (heat, pressure, time) Processes: autoclave, oven, press, trapped rubber, room temperature
- ◆ Materials may only be suitable for a given fabrication and/or cure process, or some small window of a general process

Supporting Processes

- ◆ Clean room control
- ◆ Shelf life and out-time control and extension

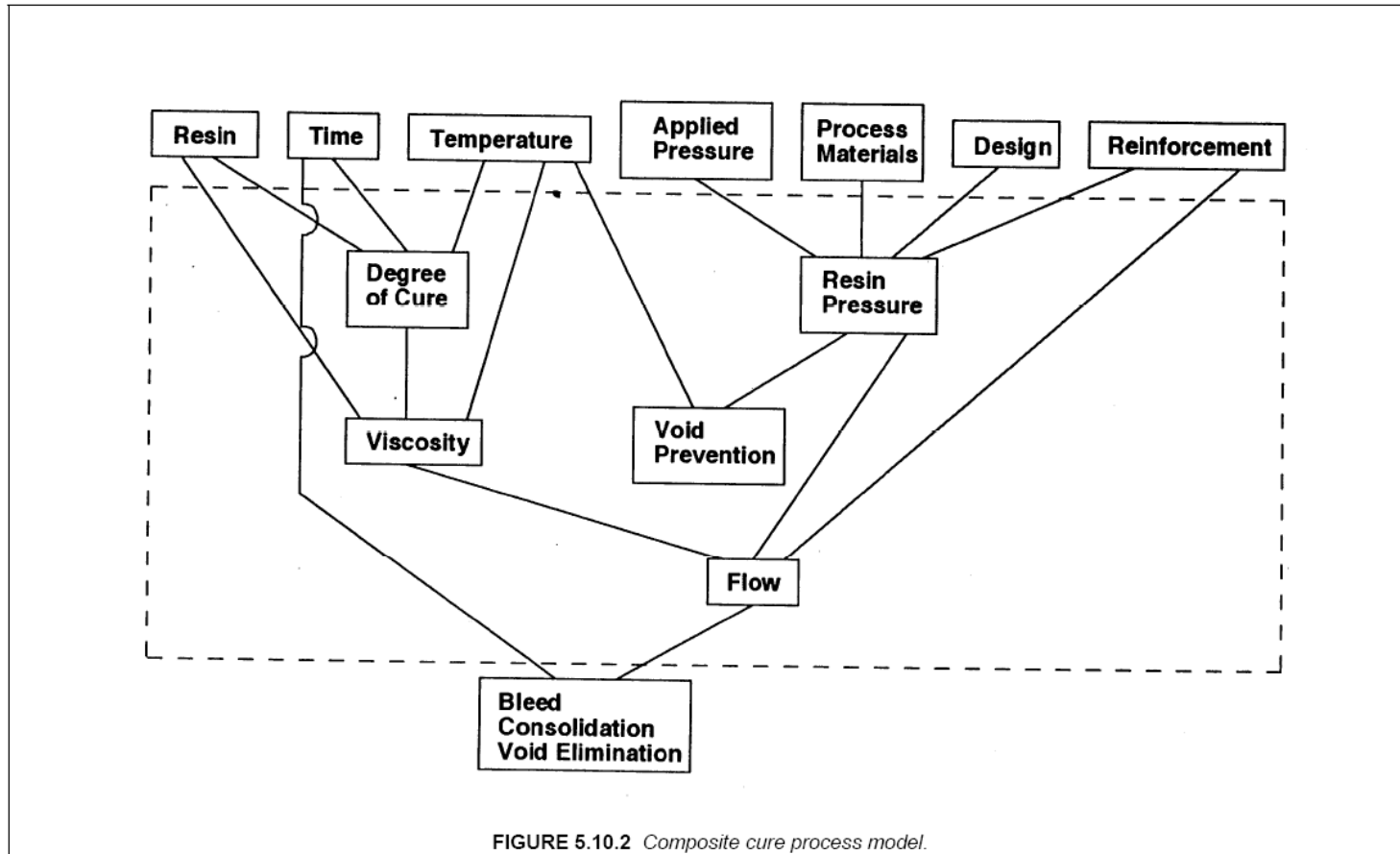
Cure Cycles - Temperature and Time



Cure Cycles

- ◆ Cure cycle primary factors
 - Time
 - Temperature (applied by vessel and/or tooling)
 - Pressure (applied by vessel and/or tooling)
- ◆ Dependent factors
 - Temperature (actually experienced throughout part)
 - Pressure (mechanical versus resin pressure)
- ◆ Autoclave load diagrams, heat survey of cure vessels
- ◆ Potential of path dependence of cure cycles
- ◆ What will you do when (not if) parts do not experience the intended cure cycle?

Cure Factors Interdependent



Cure Models

- ◆ Develop process models for various outputs just like use FE models to predict/simulate how a part will respond
- ◆ Use cure models to determine how material will respond to different cure parameters (time, temperature, pressure)
- ◆ Cure models can just focus on material (chemical) changes which manifest as mechanical or other property differences which are difficult and/or expensive to characterize for a given part (hot/wet compression)
- ◆ Process control coupons vs. cure models

Information Provided by Cure Models

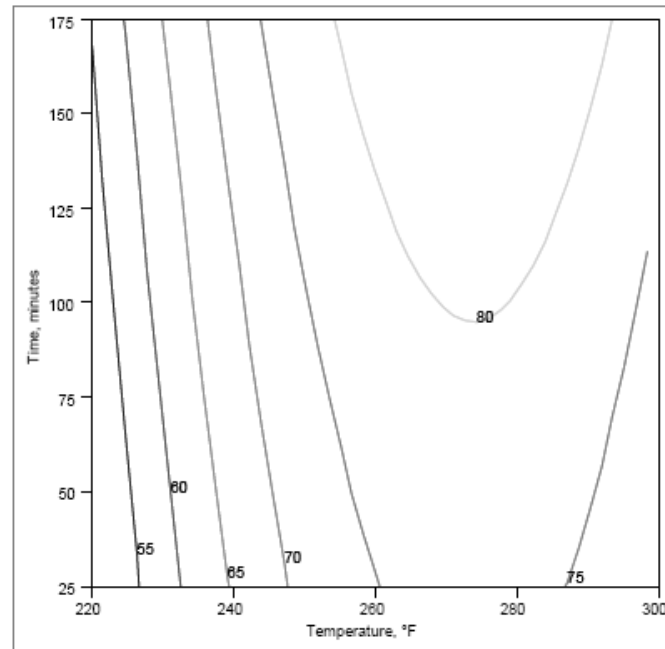


FIGURE 6.4.6.2(j) *Example of quadratic response surface (adhesive peel strength in psi as a function of cure final dwell time and temperature).*

Many ways of achieving same cure state (for a given property)

Vacuum Bagging Process

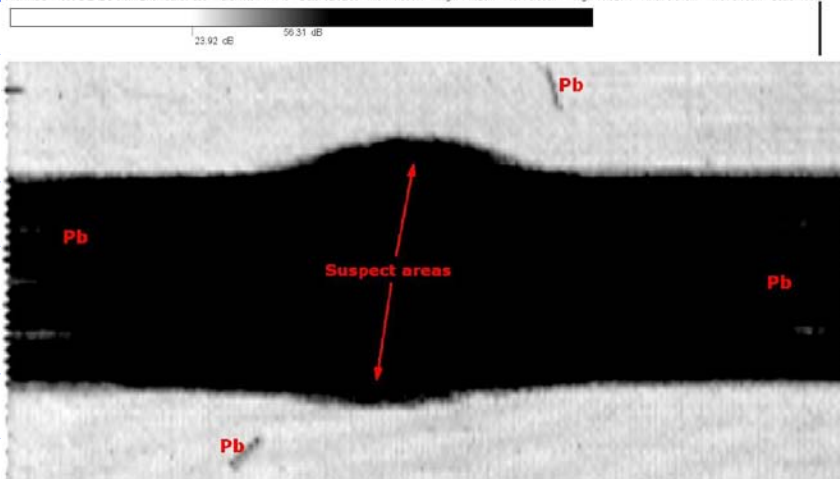
- ◆ Consequences of differences in bagging
 - Changes in bag bleed result in fiber volume (and laminate quality) variation
 - Reduced path for trapped gas results in rejectable voids and porosity
 - Bag failures - minor bagging issue can scrap part (e.g. bag bridge over radius ruptures under pressure)

Inspection Process Specifications

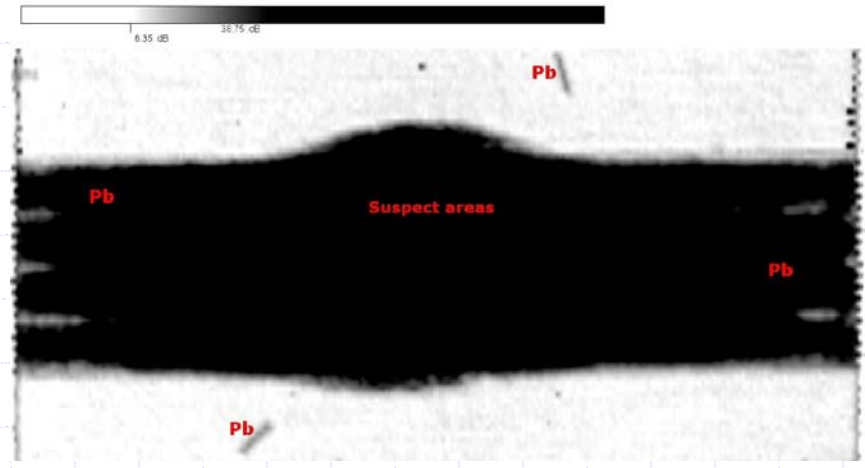
- ◆ Technologies: UT (PE, TTU), radiography, resonance, thermography, shearography, visual
- ◆ NDI does not provide perfect insight into final condition of parts. Cannot see characteristics such as “kissing unbond” (bond strength).
- ◆ Development and validation of quality criteria – start big and work down, don’t start with assumption of perfect parts. They don’t exist – can always find some (perhaps harmless) anomaly with today’s methods.
- ◆ For NDI the quality criteria must be interpreted in the context of the inspection process that is specified. Criteria specified without inspection process are meaningless.
- ◆ Don’t shoot the messenger (NDI didn’t make the part bad)

NDI Data Acquisition & Signal Processing

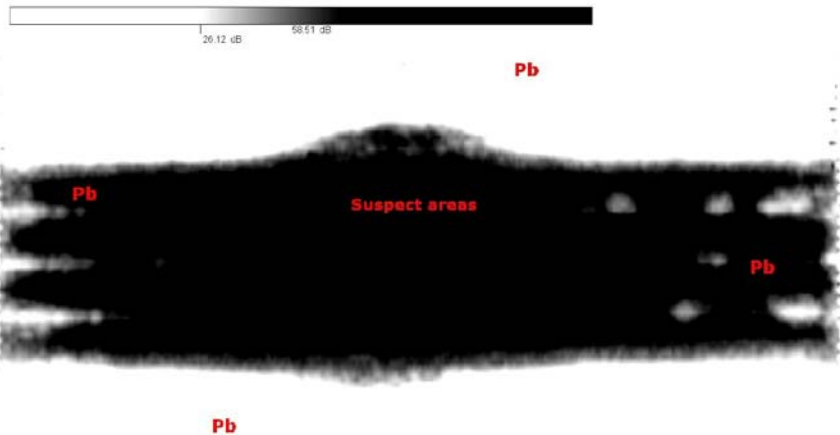
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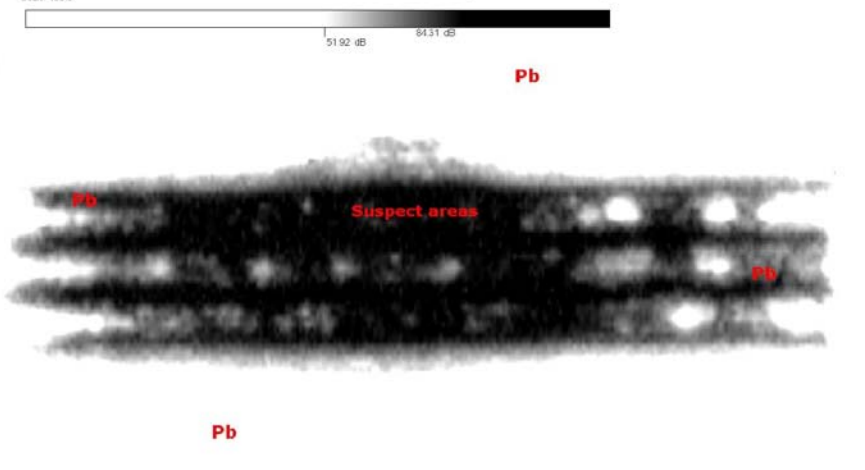
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Adhesive Bonding

- ◆ Composite manufacturing of any complexity almost always pulls in (structural) adhesive bonding
- ◆ Metal bonding may be brought in by inserts, fittings
- ◆ Surface preparation for adhesive bonding a science (and art) unto itself
- ◆ Use of peel ply, especially if little or no subsequent surface preparation
- ◆ Film adhesive vs. paste bonding
- ◆ Material compatibility – cobond/cocure vs. secondary bond, use of known interface (film adhesive)
- ◆ Most critical processes – surface preparation for structural adhesive, bonding, process for bond primer application, delay between preparation and application of adhesive or preservation

Sandwich Structure

- ◆ Process changes for sandwich structure
 - Additional processes: Core splicing, edge filling, potting
 - Changes to processes such as cure (pressure may “crush” core)
- ◆ Bonding (almost) always pulled in by sandwich structure.
- ◆ Core stabilization and machining
- ◆ Cure skins at same time as bond to core (dimpling), or cure skins then secondarily bond (extra steps, higher quality, more money)
- ◆ New parts: inserts, close-outs, hardpoints, fasteners

Sandwich Structure Core Crush



FIGURE 5.4.1(b) *Panel exhibiting substantial core crush.*

Until bonded into structure, core may be weak and flimsy

Tooling

- ◆ The manufacturing process, tooling and cure process are all inter-related. Changes in one may necessitate changes in another.
- ◆ In addition to providing shape, tooling affects the temperature and pressure profiles experienced by the part/resin during cure.
- ◆ Example of rotor materials in tool string - 250 vs. 350°F cure prepregs

Process Validation

- ◆ How to ensure that a process was followed correctly: documentation of step by step, inspection, test
- ◆ Initial heat survey, destructive test after NDI
- ◆ Plot process data gathered over time for trends
- ◆ Statistical Process Control (SPC)

Process Qualification

- ◆ Qualification to process specifications for outside companies
- ◆ Generation of engineering data which characterizes the output of given processes, versus the testing that is used to validate that a given processor can reproduce these processes and the resulting properties

Additional Processes After Cure

- ◆ Similar to processing for other materials
 - Checks to make sure processes don't adversely affect composite material - e.g. machining temperatures or fluids
 - Accommodate sensitivities - e.g. poor ply to ply properties
- ◆ Machining/trim/drill, surface filling before paint, sealing, finishing
- ◆ Fastener installation

Process Changes

- ◆ Validation process for process changes
- ◆ Processes changes will happen. First transition - panels to parts.
- ◆ Any transition from material as procured and processed for acceptance to manufacturing process must be understood and validated
- ◆ Repair/rework criteria development and validation



Questions?