P106

Practice for troubleshooting a thermal transformation step

Document Type	Practice
Document Identifier	106
Themes	• Thermal management
Tags	• Conductive heating • Cure and crystallization • Heat transfer • Matrix • Thermoset cure kinetics • Thermoset polymers • Cure cycle optimization
Objective functions	**Cost** Maintain **Rate** Maintain **Quality** Increase
MSTE workflow	Troubleshooting
Prerequisites	• Practice • Production Troubleshooting

Introduction[edit | edit source]

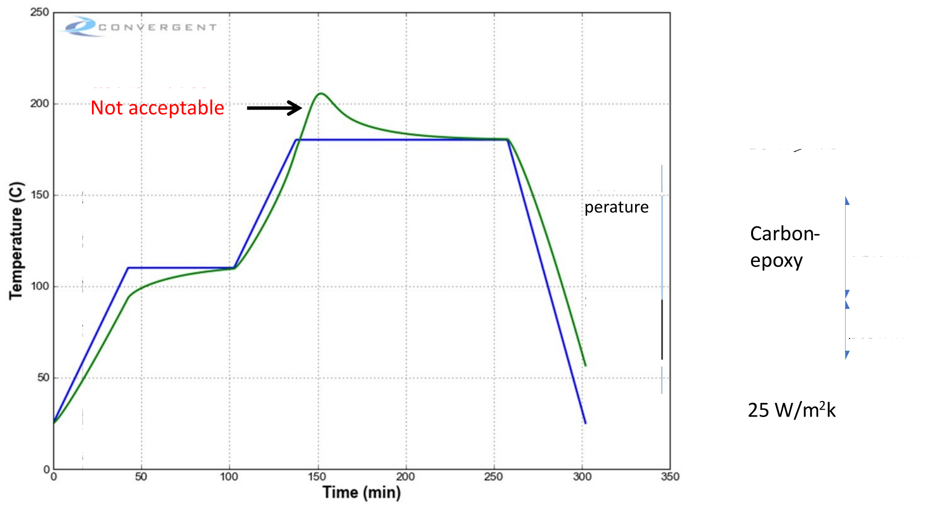
One of the critical aspects to the composites manufacturing process is the proper control of the thermal transformation of the polymer matrix material. This is achieved through careful control of the equipment processing parameters and understanding of the system interactions involved in the manufacturing process (MSTEP (Material, Shape, Tooling, Equipment and Process)). Improper thermal transformation of the matrix can be a root cause for failure of a composite part. Symptoms of this are: unsatisfactory in-service performance (material properties are not as expected); failed inspection(s) during quality control; failed measured process parameters in the production process and/or a reduction in Tg.

Scope[edit | edit source]

This document is to be used when an existing thermal transformation step is not performing as expected. It provides guidance on how to methodically trouble-shoot and fix the problem.

Significance[edit | edit source]

A failed production process can be identified at three possible points in time (listed worst to best case scenario):



Temperature history profile of equipment (blue) and part (green) for a two-step cure cycle. A large exotherm in the part temperature is observed (in excess of 30°C), well outside the typical temperature bounds of an MRCC (manufacturer's recommended cure cycle). Such an occurrence would be considered a thermal transformation step failure.

1. Worst Case - In-service (failure)[edit | edit source]

Part failure due to in-service performance:

- structural performance
- life-cycle performance
- environmental performance
- shape distortion
- visual surface appearance
- etc.

2. Improved Case - Quality control (inspection)[edit | edit source]

Failure during quality control testing:

- traveller coupons
- hardness test
- DSC analysis for degree of cure of matrix sample
- maximum allowable void content
- target fibre volume fraction (V_f)
- etc.

3. Best Case - During process monitoring[edit | edit source]

When an in-process measurement fails due to process control not being maintained:

- measured part temperature history not as expected
- measured tool temperature history not as expected
- measured equipment temperature history (or other process parameter) not as expected
- etc.

Prerequisites[edit | edit source]

Recommended KPDs to review before, or in parallel with this document:

- Systems Knowledge
- Thermal management

Relevant Case Studies[edit | edit source]

Recommended case studies to review before, or in parallel with this document:

- Troubleshooting of a room temperature process for boat hulls

Workflow[edit | edit source]

Troubleshooting workflow for a thermal assessment.

In order to determine the root cause of failure, the best solution is to approach the performance of the process step using a system-based approach (refer to the Systems Knowledge volume). This means checking the performance of the equipment and tooling as well as the parameters of the part and material(s). Moreover, initial conditions of the system should be investigated along with the boundary conditions as a function of time. These latter points are often overlooked but may contribute significantly to the overall response of the system. Examples of common causes of failure during thermal transformation are listed below:

- M - Material chemistry changed
- S - Part geometry/features changed without notice
- T - Initial tool temperature was not as expected, tooling features changed (eg. substructure closed up)
- E - Fan failed, pressure not achieved, airflow obstructed or not behaving as expected

Anyone of these points may significantly affect the final outcomes of the system, thus resulting in failure. This is true whether it is a processing specification failure, inspection failure, or in-service failure.

The first step in any thermal management workflow is to define processing specifications if not already done (eg. the intended part quality metrics). From there, for a troubleshooting workflow, there are typically three major steps that must be taken. These are:

- Define the representative production scenario
- Perform a system thermal assessment
- Analyze the system thermal assessment

The first step defines the family of parts that are being manufactured (eg. thick laminates, thin laminates, sandwich panels, etc) and their associated geometry. From this, the lead and lag temperature locations on the part should be determined. The second step refers to setting up the necessary instrumentation to measure the thermal response of the part (based on lead/lag locations), and then running the thermal cycle. Finally, the last step analyzes the results to determine if the part passed or failed spec. An optional step prior to performing the system thermal assessment is to perform a sub-system thermal assessment of just the equipment and tooling. This ensures that the appropriate thermal specifications can be met by the equipment alone and by the equipment with the addition of tooling. In this regard, the sub-system assessment is an analysis of E and TE, whereas the full system assessment is an analysis of MSTE.

If the part passed specifications, the assessment, including all changes and maturations to the system, should be documented. Conversely, if the part failed specifications, then the troubleshooting process repeats, with the necessary changes made. One important realization is that it is possible to measure false positives and false negatives during the thermal assessment. For example, in a high-temperature processing scenario, if a thermocouple reads that the maximum temperature of the part is much higher than desired, it may actually be that the thermocouple is not properly shielded from the environment and is in fact measuring the much higher air temperature; thus giving a false negative. Similarly, if the thermocouple is not properly shielded from the environment and the part temperature is higher than that of its surroundings (during the exotherm for example), the thermocouple may read a lower part temperature than is true; thus giving a false positive. These factors must be considered and mitigated against in order to reliably troubleshoot the thermal transformation step.

Related pages

Page type	Links
Introduction to Composites Articles	
Foundational Knowledge Articles	• Conduction - A118 • Convection - A106 • Cure of thermosetting polymers - A162 • Degree of cure - A104 • Heat transfer - A132 • Thermoplastic polymers - A161 • Thermoset polymers - A105
Foundational Knowledge Method Documents	• How to measure curing time and degree of cure - M100
Foundational Knowledge Worked Examples	
Systems Knowledge Articles	
Systems Knowledge Method Documents	
Systems Knowledge Worked Examples	
Systems Catalogue Articles	
Systems Catalogue Objects – Material	
Systems Catalogue Objects – Shape	
Systems Catalogue Objects – Tooling and consumables	
Systems Catalogue Objects – Equipment	
Practice Documents	• Decreasing Cure Cycle Time - P121 • Practice for developing a thermal transformation process step - P105 • Troubleshooting scale-up issues from thin to thick parts - P140 • Troubleshooting scaling-up issues from coupons to parts - P134
Case Studies	• Troubleshooting of room temperature processes for large recreational and industrial parts - C100

Perspectives Articles

- Composite materials engineering webinar session 3 - Constituent materials - Resin - A122
- Composite materials engineering webinar session 4 - Thermal management and resin cure - A123
- Composite materials engineering webinar session 5 - Manufacturing processes - Introduction - A124
- Composites Process Simulation: A Review of the State of the Art for Product Development - A283
- Dr. Anoush Poursartip's cdmHUB global composites expert webinar - A136
- Effect of cure on mechanical properties of a composite (Part 1 of 2) - A319
- Effect of cure on mechanical properties of a composite (Part 2 of 2) - A320
- Heat Transfer in Composites Processing - A321
- Introduction to the processing of thermoplastic composites - A322
- Resin Behaviour During Processing: What are the key resin properties to consider when developing a manufacturing process? - A257
- Understanding Polyester Resin Processing: The Effect of Ambient Temperature on the Final Part - A286

About **Help**

The continuous material phase that binds the reinforcement together, maintains shape, transfers load, protects the reinforcement from environment and damage, and provides the composite support in compression.

Desirable characteristics:

- Moisture/chemical resistance
- Low density

- Processability

Engineered materials (designed to have specific properties) made from two or more constituent materials with different physical or chemical properties. The constituents remain separate and distinct on a macroscopic level within the finished structure.

Manufacturer's Recommended Cure Cycle (MRCC).

Differential Scanning Calorimetry (DSC).

Degree of cure (DOC) is an indication of how far the chemical curing reaction (crosslinking process) has advanced in a thermoset resin.

DOC is defined with a number between 0 and 1 (or 0% and 100%) where 100% is a fully cured resin. It does not have to fully reach 100% for the resin to become solid or the part to be used. In some aerospace applications, resins are only cured to about 90%. Higher the degree of cure, higher the mechanical properties.

Volume fraction of either matrix or fibres with respect to total composite volume (matrix + fibre).

A central processing theme in the manufacturing cycle. This theme is concerned with managing the thermal response of materials during storage and handling or parts/tools when they are subsequently heated.