P125

Ensuring quality during curing of thick parts

Practice document

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Themes	• Thermal management • Material deposition management • Flow and consolidation management • Residual stress and dimensional control management
Tags	• Shape • Shape parameters • Thermoset cure kinetics
Objective functions	**Cost** **Rate** **Quality** Maintain
MSTE workflow	Development
Prerequisites	• Effect of shape in a thermal management system

Q:"*I am going to make thicker parts than I have before but with a resin system that I have experience with. How do I ensure I avoid large exotherms and resulting quality issues?*"

A:You can maintain quality while making thicker parts by ensuring that their thermal history does not deviate significantly from the thermal history of your thinner parts. If you find that the thermal history of your thicker parts no longer meets your thermal specifications, you will have to change your manufacturing system, i.e. MSTEP collection.

Overview[edit | edit source]

As explained in Systems Knowledge, composites processing is a complex interaction between material response, part shape and dimensions, tooling choices, and equipment behavior. Any change to the MSTEP collection may affect the manufacturing outcomes. Making thicker parts is likely to not only impact thermal management outcomes but also manufacturing outcomes related to material deposition management, flow and consolidation management, and residual stress and dimensional control management.

Thermal management considerations[edit | edit source]

Link to thermal management

From a thermal management perspective, increasing the part thickness is a major change. As explained in Systems Knowledge - effect of shape in a thermal management system, the thermal response of a part depends on its thickness.

First, the part thickness defines its thermal mass and therefore how much energy must be transferred in-or-out of the part to heat or cool it. For example, the thicker the part, the larger its thermal mass, and therefore the more heat is required to increase its temperature. As the part's thermal mass increases, it will not only take more energy to heat or cool but also more time, as the heat needs time to travel in-and-out and of the part. Ultimately, this means that thicker parts experience larger thermal lag (i.e. larger temperature differences between the part and the equipment) and larger through-thickness temperature gradients, as compared with thinner parts.

Second, a thermoset part releases heat during cure. The thicker the part, the longer the path is for the heat of reaction to travel through the part and escape. This means that the thicker the part, the more heat of reaction is trapped within the part and the more the heat of reaction contributes to increase its temperature which might lead to an exotherm.

Thermal lag, through thickness temperature gradients, and exotherm are common issues faced with thicker parts. While developing your manufacturing workflow, the sooner you consider these issues (at the conceptual screening stage and at the preliminary selection stage) the better. If you wait to confirm that all is well during final production, then you are essentially in troubleshooting mode. You are now constrained by the choices you have made, and the cost and effort to change can be significant.

You can evaluate the thermal history of thick parts using:

1. Thermal Simulation
2. Thermal Test
3. Combination of thermal simulation and test

If you find that the thermal history of your thicker parts no longer meets the given thermal specifications, you will have to change the MSTEP collection.

For example, you might consider changing:

- The temperature cycle of the equipment. As illustrated in in Systems Knowledge - Effect of equipment in a thermal management system, thermal lags and through thickness temperature gradients observed during a ramp can both be lowered by decreasing the ramp rate, while an exotherm can be mitigated by lowering the cure temperature or by using a 2-hold cure cycle instead of a 1-hold cure cycle.
- The thickness, substructure, or material of the tooling. As illustrated in Systems Knowledge - Effect of tooling in a thermal management system, an exotherm can be mitigated by increasing the tool's facesheet thickness with the trade-off of increasing thermal lags. Replacing an

aluminum tool with an Invar one, for example, has such an effect.

Depending on how advanced you are in the development process and what the thermal specifications are that you are failing, you might also consider altering or changing:

- The equipment to maximize the heat transfer coefficient. This allows you to decrease thermal lags but might come with the trade-off of increasing the exotherm when the tool is lagging more than the part (see Systems Knowledge - Effect of equipment in a thermal management system).
- The part design to reduce its thickness as illustrated in Systems Knowledge - Effect of shape in a thermal management system.
- The material system if the exotherm is an issue which cannot be addressed with the above mitigation strategies.

Material deposition management considerations[edit | edit source]

Link to material deposition management

Content coming soon.

Flow and consolidation management considerations[edit | edit source]

Link to flow and consolidation management

Content coming soon.

Residual stress and dimensional control management considerations[edit | edit source]

Link to residual stress and dimensional control management

Content coming soon.

About **Help**

For polymer matrix composites (PMCs), resin refers to the matrix; the continuous material phase that binds the reinforcement together, maintains shape, and transfers load. Resins are divided into two main groups: thermosets and thermoplastics.

Outcomes represent the range of response/sensitivity to factory system attributes. Those that fail to satisfy manufacturing requirements are known as defects. Examples of manufacturing outcomes include process parameter outcomes, material structure outcomes, and material performance outcomes.

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.

Thermosets are a class of polymer that undergo polymerization and crosslinking during curing with the aid of a hardening agent and heating or promoter. Initially they behave like a viscous fluid. During curing, they change from viscous fluid to rubbery gel (viscoelastic material) and finally glassy solid.

If heated after curing, initially they become soft and rubbery at high temperatures. If further heated, they do not melt but decompose (burn)

Comes in two parts: part A (resin) and B (hardener). When mixed, curing reaction starts and is not reversible.

Examples include epoxy or polyester.

Polymerization of thermoset resins is an exothermic reaction and heat is generated during the curing process. A thermosetting resin has the potential to release a certain amount of energy while curing. This is called the total heat of reaction, H_R, with a unit of J/g (SI units).

The heat of reaction during polymerization is measured using a Differential Scanning Calorimeter (DSC) equipment measuring much energy/heat comes out of the reaction for a small resin sample.