TESTS TO MEASURE THE MATERIAL PROPERTIES RELEVANT TO THE MODELLING OF PROCESS INDUCED DEFORMATIONS IN COMPOSITE PARTS

Nuri Ersoy, Tomasz Garstka, Kevin Potter, Michael Wisnom

University of Bristol, Department of Aerospace Engineering
Outline:

• Introduction to process induced distortions
• The Development of the Degree of Cure
• Frictional Stresses Between the Tool and the Composite
• The Development of Cure Shrinkage During the Cure
• Conclusions
Stresses that arise during the cure can cause significant distortion of polymer matrix composite structures

- Bowing of the arms
- Twist of the web
- Bowing of the web
- Spring-in
- Twist of the arms
A successful model of process induced distortion requires good understanding of material behaviour throughout the cure cycle.
The Development of the Degree of Cure and the Glass Transition Temperature
Material:

The prepreg used in this study is a unidirectional carbon/epoxy, produced by Hexcel Composites designated as AS4/8552.

The nominal thickness of the prepreg was given as 0.250 mm.
The development of the degree of cure, $\alpha$, was modelled using the cure kinetics model proposed by Cole

$$\frac{d\alpha}{dt} = \frac{K\alpha^m(1-\alpha)^n}{1+e^{C[(\alpha-\alpha_c)]}}$$

The constants of the model were calculated by QinetiQ using dynamic DSC tests performed in a TA Instruments DSC 2920.
Cure kinetics model predictions for degree of cure plotted versus time throughout the cure cycle.
Gel point and the Frictional Stresses Between the Tool and the Composite
Ply Pull-Out Testing Setup

- insulator
- plate
- heater
- sample
- spring
Specimens

(a) Aluminum Plate

(b) Aluminum Plate
Inter-ply shear stresses during the MRCC

Actuator movement is continuous

Interrupted actuator movement

Shear Stress (MPa)

Time (min)

Temperature (°C)
Tool interaction shear stresses during the MRCC

actuator movement is continuous

Interrupted actuator movement
The Development of Cure Shrinkage During the MRCC
Experimental set-up used for cure shrinkage measurements

- Heating plate
- 4 mm thick steel plate
- Composite sample
- Targets
- Video extensometer
- Thermocouples
Through-thickness strain induced by consolidation and cure shrinkage

UD laminate

![Graph showing through-thickness strain over time and temperature]
The effect of preconsolidation on the through-thickness strain

UD laminate

- jig preconsolidated
- vac preconsolidated
- not preconsolidated

Gelation

Strain %

Time s
Through-the-thickness cure shrinkage strains after gelation for unidirectional and crossply composites

- Sample #1: 0.54, 1.12
- Sample #2: 0.47, 0.87
- Sample #3: 0.42, 0.96
- Average: 0.48, 0.98

Legend:
- UD
- XP
Relation between cure shrinkage and the degree of cure

\[ \varepsilon = 2.1557\alpha^3 - 1.6209\alpha^2 - 2.6972\alpha + 0.9275 \]

Zeroed at gelation
Thermal expansion strains

Temperature C degrees

Strain %

Liquid CTE 373 \times 10^{-6}

Rubbery CTE 202 \times 10^{-6}

gelation
Conclusions:

The development of cure during the manufacturing cure cycles was investigated using the model proposed by Cole. The model takes into account a shift from kinetics to diffusion control. An excellent agreement was achieved between the model predictions and the experimental measurements of degree of cure and glass transition temperature.
Conclusions:
The maximum shear stress during the cure cycle is rate and lay-up dependent.

The interfacial shear stress varies within the range of 0.01-0.1 Mpa in tool/prepreg interfaces and 0.02-0.25 MPa in prepreg/prepreg interfaces up to the point of vitrification.

It was found that when the resin approaches 30 % degree of cure, the magnitude of force required to shear plies increases, which was taken as the beginning of gelation.
Conclusions:

A novel approach has been developed to measure through thickness consolidation strains of epoxy laminates during the whole cure cycle.

The technique captures the thermal expansion during the heating stages, the laminate consolidation throughout the cure process, and also the cure shrinkage.

The new method proved to be reliable and sensitive therefore it could be applied to a wide range of materials.
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