Systematic Evaluation and Transformation of Uncured Aerospace Prepreg Offcuts

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Introduction

The utilization of composite material, and more especially carbon fibres, in aerospace industry has been under a spectacular growth these last 10 years in order to reduce the parts structural weight to mainly increase the fuel efficiency and reduce the costs associated to the production of aeroplanes. However, the manufacturing of these parts from resin pre-impregnated carbon fibres (prepreg) induces a loss from 30 to 50% of materials mainly because of limited production schedules, fixed width of master roll, limited out-time, etc.… These scraps are usually disposed or reduced to low cost fillers leaving their potential for efficient sustainable manufacturing unfulfilled. With the proper staging (thermal treatment to reach an optimized degree of cure) these prepregs offcuts could be used to manufacture high quality tertiary structures simply by compression moulding.

To achieve a proper consolidation of the part by shear and percolation flow, the degree of cure of the processed offcuts most be well known. However, as there is no thermal control between the offcuts production and there recovery, the material will age and its degree of cure will uncontrollably evolve.

The objective of this project is to have a better understanding of the prepreg's evolution with ageing and staging in order to build and compare several inspection methods based on Differential Scanning Calorimetry (DSC), Fourier-Transform Infrared Spectroscopy (FTIR) and tack tests to allow a direct and reliable inspection of the prepreg's degree of cure.

Objectives

- Thermochemical validation of the resin's cure kinetic model
- Development of inspection methods based on DSC, FTIR and tack tests
- Validation of the best inspection method with another epoxy system

Materials

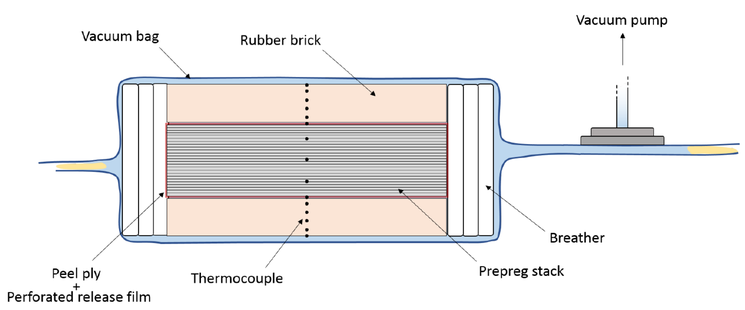
- CYCOM® 5276 – 1 : development of the inspection methods
- CYCOM® 5329 – 1 : verification of the best inspection method
- Reinforcements: THORNEL® T – 650/35 carbon fibre 3k woven ($196\ g/m^2$)

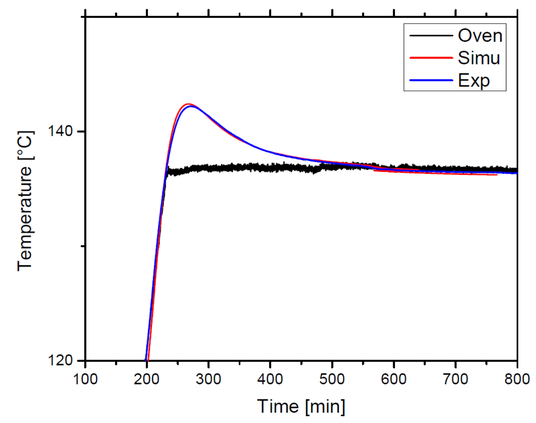
Thermochemical validation

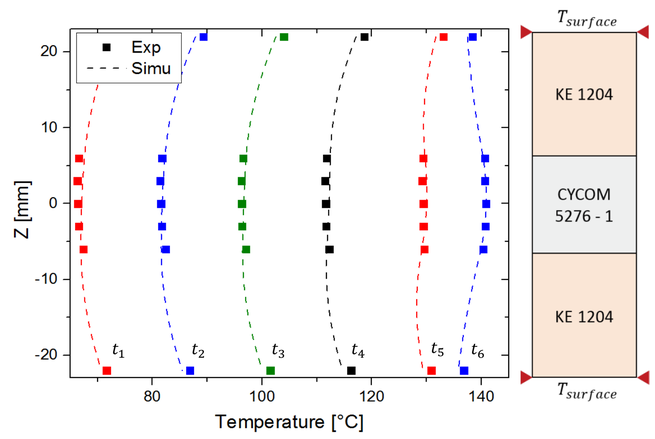
Concept : record the thermal exotherm of a thick laminate (50 plies) during cure by constraining it between to rubber bricks to ensure a 1D through thickness heat flow. The recorded profile was then compared to the simulated one to verify the resin cure kinetic model.

Cure kinetic model: $\frac{d\alpha}{dt} = k_1\alpha^{m_1}(1-\alpha)^{n_1} + K_2\alpha^{m_2}(1-\alpha)^{n_2}\ , K_i = A_i \exp\left(\frac{-\Delta E_i}{RT}\right)$

Experimental setup





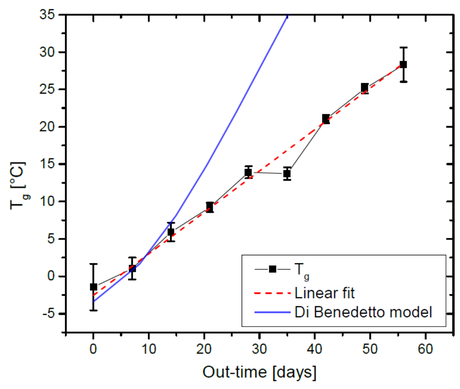


Good agreements between the experimental and simulated thermal profile, the cure kinetic model of the resin is then validated and can be used to simulate the evolution of the degree of cure while staging

Inspection methods

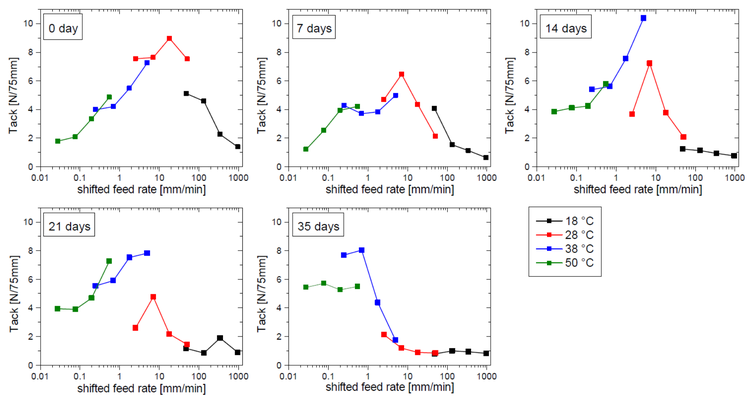
Concept : the evolutions of the prepreg's while ageing and staging were recorded with three different characterization methods. The ageing and the staging were performed, respectively, at room temperature (20°C) for up to 50 days and at 120°C for times corresponding to characteristic degree of cure according to the validated cure kinetic model. The Wiliams – Landel – Ferry (WLF) principle was used to analyze the tack tests and the FTIR results. The Di Benedetto model was used to link the glass transition temperature measured by DSC to the degree of cure and inversely with the FTIR measurements.

DSC



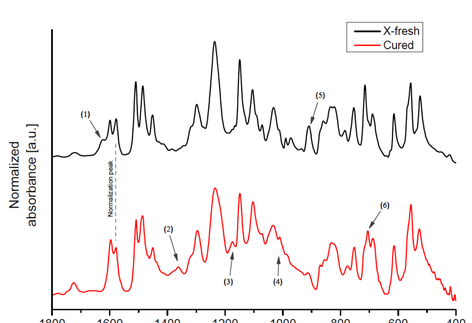
The DSC can be used to work out the out-time from the T_g.
No possibilities to find the degree of cure from the Di Benedetto model…

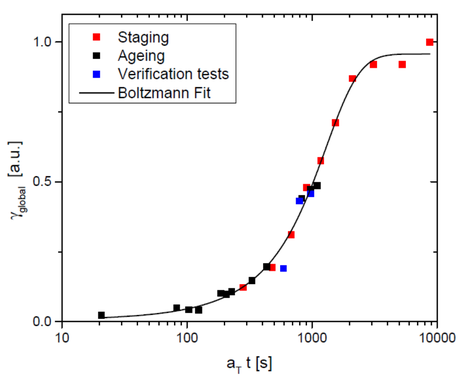
Tack Tests

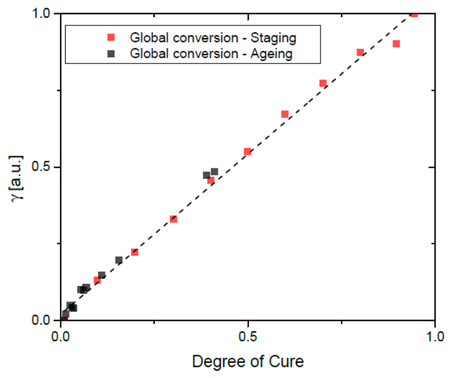


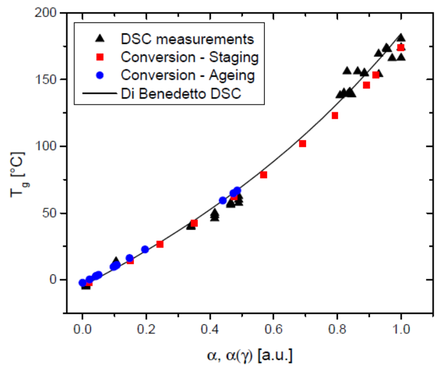
No clear evolution of maximum tack with ageing.
Possible evolution of the shifted feed rate at maximum tack with ageing, but no clear link with degree of cure.

FTIR









Successfully recorded the evolution of prepreg's state while ageing and staging recording the conversion of functional groups typically involved in the cure of epoxy as:

$$\gamma = \frac{A_t - A_0}{A_\infty - A_0}$$

The WLF principle was successfully applied to get a master curve allowing to find the out-time of the prepreg's offcuts.

The conversion showed a one to one relation with the simulated degree of cure obtained from the cure kinetic model. The functional group conversion is then a good measure of the degree of cure. The T_g of the aged resin could also be worked out using the FTIR conversion in the Di Benedetto model.

Conclusions

- Validation of KE 1204 thermal model as well as CYCOM 5276 – 1 cure kinetic model
- Inspection by DSC only gives T_g , no possible link with Di Benedetto model to find the degree of cure
- Inspection by tack tests not adapted for prepreg's offcuts inspection.
- Inspection by FTIR fully operational and allow to get the out-time and required staging time from only one measure of the functional groups conversions.
  This conversion of chemical functional groups was proven to be a reliable measure of the degree of cure.
  Using the conversion as an inputs in the Di Benedetto model allow to directly get the glass transition temperature of the aged prepreg.
- The Inspection method based on FTIR was successfully applied to another epoxy system (CYCOM 5329 – 1) proving its reliability. According to these results and to the simplicity of the method, the inspection method can easily be adapted to industry.

Acknowledgments

Thanks to my supervisors Adam Smith and Prof. Pascal Hubert from McGill university as well as Prof. Véronique Michaud at EPFL for their guidance and support throughout the project.
Thanks to the Zeno Karl Schindler foundation for the financial support.