A FEASIBILITY STUDY OF QUICKSTEP PROCESSING OF AN AEROSPACE COMPOSITE MATERIAL

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SUMMARY

A novel out-of-autoclave polymer composite material processing technology is described. The Quickstep manufacturing technique uses a liquid to transfer heat to the uncured laminate stack, enabling precise control of the stack temperature and a considerable reduction of cure-cycle times. Plant and tool structural requirements are significantly reduced compared to those of an autoclave process by eliminating the need for high consolidation pressures. This paper assesses the suitability of the Quickstep technique for the processing of a typical aerospace composite material, 914/40/G703 carbon epoxy prepreg. Laminate test specimens have been manufactured using various Quickstep process cycles and a conventional autoclave cycle. Physical and mechanical properties of the specimens have been measured and are reported. Comparable physical and chemical property data were obtained for the Quickstep and autoclave processed composites with the Quickstep process achieving a significant reduction in the overall process cycle time and estimated manufacturing costs.

INTRODUCTION

Advanced fibre reinforced polymer composite materials have not been as widely used within manufacturing industry applications as would be predicted from their structural performance characteristics. The main reasons for this aversion are the complexity of their processing techniques and the associated high costs. The use of

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advanced composites has therefore, largely been restricted to industries with already high product costs and low volume production, *viz* the aerospace and high-performance automotive industries. Currently, most high performance composite components are produced by hand or machine lay-up of prepreg laminates followed by curing in an autoclave at elevated temperature and pressure in order to obtain the required structural properties. This manufacturing process is expensive and time consuming, with a typical process cycle time of up to 16 hours and an estimated cost per kilogram part of $640 [1]. There has been an increase in the development of alternative composite manufacturing technologies, with the aim of producing materials of similar quality to aerospace grade composites, but in a shorter processing time and at a lower cost *e.g.* RTM, RFI, VARTM [2, 3]. Although many of these techniques benefit from a shorter process cycle time than autoclave curing, they tend to produce material with inferior mechanical properties whilst still retaining a high manufacturing cost [1].

Quickstep Technologies Pty Ltd (Perth, Australia) has developed a balanced pressure, heated mould process, that can be utilised for the out-of-autoclave manufacture of advanced composite materials [4, 5]. The process benefits from versatile production facilities, fast cure cycles and reduced capital, tooling and operational costs [6, 7]. The technology enables the fabrication of large composite components to aerospace standards, together with the flexibility to co-cure or meld parts to produce complex components with superior structural integration.

QUICKSTEP MANUFACTURING PROCESS

The Quickstep process utilises a heat transfer fluid (HTF) to apply heat and pressure to the uncured component during processing. The HTF has a higher heat capacity and thermal conductivity than air, therefore, a greater degree of control over the processing temperature can be achieved compared to of an autoclave. Additionally, since the Quickstep processing system has a lower thermal inertia than an autoclave, shorter process cycle times are possible.

The laminate part is assembled on a single-sided tool using conventional lay-up, sealed in a vacuum bag and processed in a pressure chamber containing the glycol based HTF. The tool and laminate are supported between two flexible membranes in the pressure chamber (see Figure 1). Temperature control is maintained by circulating the HTF through the pressure chamber, enabling rapid heating/cooling rates and precise control of the resin viscosity. The resin in the entire laminate can be rapidly brought to its minimum viscosity during the initial stages of the process, thereby enabling good consolidation to be achieved at low applied pressures (typically 10 kPa). The HTF also acts as a large thermal sink, which removes the heat generated in the exothermic reaction and thus maintains a constant cure temperature. On top of the mean static pressure, an alternating pressure may also be applied to the HTF in order to facilitate laminate compaction and minimise void content, however, this method was not used in the work reported in this paper.

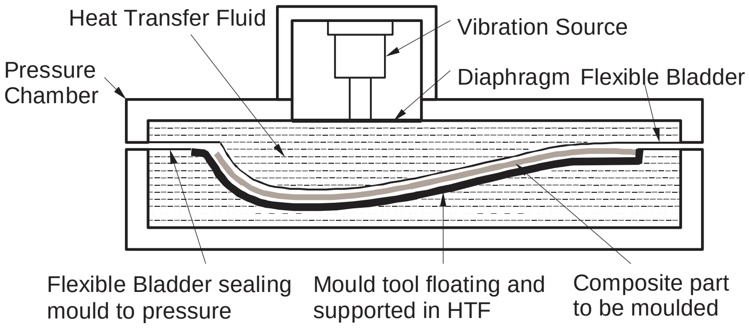

Figure 1. Schematic of Quickstep process

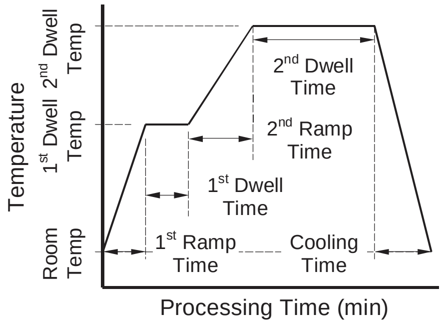

Figure 2. Processing cycle

SCOPE OF STUDY

The objectives of this study were to:

(a) Develop a Quickstep cure cycle for the carbon fibre reinforced epoxy prepreg 914/40/G703 that would minimise cycle time without adversely affecting laminate chemical and physical properties;

(b) Compare the chemical and physical properties of the Quickstep cured material with laminates produced using a conventional (manufacturer recommended) autoclave cure process;

(c) Estimate the manufacturing cost-savings achievable through use of the Quickstep process for simple aircraft components.

MATERIALS & PROCESSING

The material used in the present study was carbon fibre reinforced epoxy prepreg 914/40/G703, which is used extensively in high temperature resistant, primary aerospace structures. The prepreg is a 0° / 90° (5 harness satin) cloth and was provided by Hurel-Hispano (Burnley, UK) from stock acquired directly from Hexcel UK. Quickstep specimens were manufactured by Quickstep Technologies at Deakin University (Geelong, Australia), while conventional autoclave specimens were manufactured at Hurel-Hispano. In order to minimise variation in the laminates compared in the study, all specimens were made using the same batch of prepreg and were laid-up and debulked (every four plies) at Hurel-Hispano. Specimens to be cured using the Quickstep process were vacuum bagged under a light pressure and air-freight couriered to Deakin University, with a typical transit period of one week. All processing consumables were consistent in the two processes. Quickstep specimens, once cured, were shipped back to Hurel Hispano where both Quickstep and Autoclave cured specimens were post-cured for 4 hours at 190°C.

CURE CYCLE OPTIMISATION

The effect of varying Quickstep cure cycle parameters for 914/40/G703 carbon epoxy prepreg was investigated in order to minimize the process cycle time, whilst retaining laminate properties (*e.g.* mechanical, void/volume fraction, consolidation, T_g) equivalent to autoclave cured laminates. The process cycle is shown in Figure 2 and the cycle parameters (ramp times, dwell times, dwell temperatures) together with the total cycle time (including cooling time) are listed in Table 1. The conventional manufacturer recommended autoclave cure cycle (A1) and three Quickstep cure cycles (Q1-3) have been compared. Differential scanning calorimetry (DSC), dynamic mechanical thermal analysis (DMTA) and optical microscopy were performed at The University of Manchester. The average thickness of the 8 ply specimens, the degree of cure calculated from DSC and the glass transition temperature (T_g) determined from DMTA on the post-cured materials for the cure cycles A1 and Q1-3 are reported in Table 1. Optical microscopy revealed significant void content in the Q1-2 specimens. However, the Q3 cycle produced a void content comparable to that of the A1 specimens.

Cure Cycle	1st Ramp Time (min)	1st Dwell		2nd Ramp Time (min)	2nd Dwell		Total Cycle Time (min)	Applied Pressure (kPa)	Average Thickness (mm)	DSC	DMTA
		T (°C)	Time (min)		T (°C)	Time (min)				% cure	T_g (°C)
A1	55	135	30	20	175	60	260	700	2.24 ± 0.05	99.7	200
Q1	10	175	0.02	5	125	120	145	10	2.50 ± 0.05	59.6	208
Q2	10	135	35	5	175	60	120	10	2.32 ± 0.05	84.0	207
Q3	8	110	30	7	180	60	115	10	2.43 ± 0.05	80.3	207

Table 1: Comparison of autoclave and Quickstep cure cycles

The cure cycle optimization process did not look to minimize specimen thickness and only required that the final laminte thickness was within an acceptable manufacturing tolerance (±0.2mm) of the nominal autoclave thickness (2.25mm). Associated work with other bleeder and breather material combinations has produced laminates of comparable thickness to that of the autoclave process. DSC measurements of the Quickstep cured specimens (Figure 3) show two features; a reaction exotherm for the 914 epoxy between 200℃ and 300℃; and an endothermic peak between 70℃ and 100℃, which is most l ikely due to a phase change in either the excess curing agent (DICY) or the thermoplastic toughener included in the pre-preg. The autoclave sample (A1) is almost fully cured, whilst the Quickstep specimens (Q1-3) are significantly less cured. The Q1 cycle produced a material that was significantly unreacted and which had only just reached its gel point and was barely vitrified. Some residual cure was also observed for the Q2 and

Q3 cycles but at a much reduced level to that of the Q1 specimens. After post-curing, all specimens were fully cured and DSC measurements showed only the low temperature phase change peak (Figure 4). Note that the different appearance of the Q3 data in Figures 3 and 4 is a result of regular maintenance on the DSC having been carried out between testing of the A1/Q1-2 specimens and the Q3 specimens.

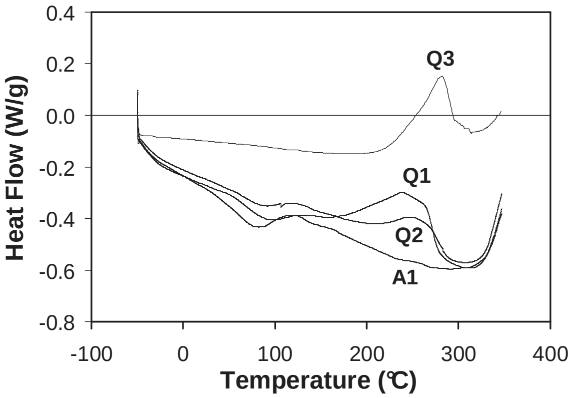

Figure 3. DSC of cured specimens

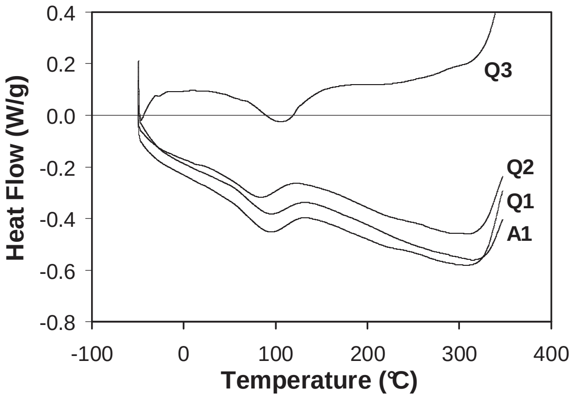

Figure 4. DSC of post-cured specimens

MECHANICAL TESTING

Mechanical testing was performed at the University of Manchester. Specimens were manufactured using the conventional autoclave cure cycle A1 and the Quickstep cure cycle Q3 (4 post-cured specimens for each test and process combination). The mechanical property test matrix was based upon the Hurel-Hispano batch acceptance test matrix. The relevant industry test specifications are summarised in Table 2 (Note that where test standards are for unidirectional laminates they have been used for guidance on the procedures used in this study). Test panels comprising 8 ply laminates were prepared with the 3 fibre configurations listed in Table 2 (Note that the angles refer to a single axis within each woven cloth prepreg lamina).

Mechanical Property	Standard	Configuration	Autoclave	Quickstep
Tensile Strength (MPa)	NF EN 2561	8 plies at 0°	600 ± 50	660 ± 30
Open Hole Tensile Strength (MPa)	NF EN 2561	8 plies quasi-isotropic (0°/±45°/90°)	240 ± 10	270 ± 10
In-Plane Shear Strength (MPa)	NF EN 2561	8 plies at ±45°	226 ± 4	229 ± 4
Interlaminar Shear Strength (MPa)	NF EN 2563	8 plies at 0°	75 ± 4	83 ± 2

Table 2: Mechanical property comparison for A1 and Q3 processing cyles

ESTIMATED PROCESS COST SAVINGS

An estimate for the cost-savings achievable through use of the Quickstep process for manufacture of an aircraft gas turbine engine thrust reverser blocker door was made using the following assumptions: (i) material, cutting, debulking and laminating costs would be the same regardless of curing process and (ii) two components could be made using the Quickstep process in the same time as one batch of autoclave components - reducing tool requirements by half. These assumptions combined with an estimated cost saving of 65% for a Quickstep tool over that of an autoclave tool meant that an 82% cost-saving could be made on tooling alone. Note that these calculations ignored the significantly higher capital and maintenance costs incurred for installation and operation of an autoclave compared to those required for the Quickstep process.

CONCLUDING REMARKS

Laminate samples of 914/40/G703 epoxy carbon prepreg have been successfully manufactured using the Quickstep technique, a novel out-of-autoclave process. A considerable reduction in the overall process cycle time (≈50%) compared with conventional autoclave curing was achieved due to the precise temperature control and high heating/cooling rates (≈8℃/min) that are possible with Quickstep. The Quickstep cured specimens exhibited a higher glass transition temperature and were on average ≈8% thicker than the autoclave samples. The thickness/volume fraction effect may be explained by the lower pressure applied during the Quickstep cure cycle resulting in reduced resin bleed out. Comparable void content and mechanical test data were obtained for the Quickstep and autoclave specimens. The tooling cost for a simple aircraft component was estimated to be 82% cheaper for the Quickstep process compared to that for an autoclave process.

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