COST REDUCTION IN AUTOCLAVE PROCESSING II: CURING RESIN INFUSED COMPOSITES

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Introduction

There is increasing interest across the range of composites manufacturing processes for cost reduction with a current focus on out-of-autoclave (OOA) processes. However, for the highest performance composites, the maximum fibre volume fraction is limited by the compressibility characteristics of the reinforcement. For any specific reinforcement, vacuum-only processes cannot achieve fibre contents as high as those where additional external pressure is applied. Compression moulding in a hydraulic press creates limited compaction perpendicular to the line of action of the press. The autoclave is good for complex three-dimensional components. Autoclave processes normally use pre-impregnated reinforcements which carry a premium price for the impregnation process and the associated quality issues. The use of dry reinforcements infused with liquid resins should lead to significant cost reductions.

This paper will report a feasibility study for autoclave cure of resin-infused [1-3] composite plates referenced to equivalent systems manufactured by hand-lamination, or by resin infusion without autoclave cure.

Methodology

Experiments were conducted using an unbalanced (470 and 410 tows/m) 270 gm^{-2} plain weave glass fibre fabric. The matrix polymer was Easy Composites IP2 polyester infusion resin (initial viscosity 1600 mPas at 25ºC according to the manufacturer's data sheet) with 2% Butanox M50 MEKP catalyst by weight. Laminates were manufactured using:

- hand lamination with edge dams to constrain flow of the infusion resin (Plate A),
- resin infusion under flexible tooling with a flow medium (RIFT II) and 300 mbar (Plate B), 600 mbar (Plate C) or 900 mbar (Plate D) net pressure, or
- RIFT II outside the autoclave, followed by autoclave consolidation. The autoclave experiments were conducted with either an equivalent area of peel ply (Plate E: 5860 mbar total net pressure) or of bleeder cloth (Plate F) reservoir on the vacuum-side of the laminate. Laminate F was discarded due to over-bleeding of the resin.

The pressure in the vacuum bags was constrained to never exceed the target level (even during vacuum checks). The laminates were characterised by (a) resin burn-off for fibre volume fraction (V_f), (b) tensile properties (BS EN ISO 527-4), (c) flexural properties (BS EN ISO 14125 Class III), (d) inter-laminar shear strength (ILSS, BS EN ISO 14130), and (e) surface-breaking voids (SBV), by filling voids with carbon dust followed by image processing and analysis with ImageJ software. Measurement of void volume fraction by Archimedes principle generated negative values due to the constituent material densities being uncertain. Optical microscopy to establish the size and distribution of resin-rich volumes (RRV) was planned but abandoned due to insufficient contrast between the fibres and the matrix for automated image analysis.

Results

The laminate performance data is presented in Table 1. The fibre volume fraction, elastic moduli, tensile and flexural strengths all increased with increasing net pressure during manufacture. The ILSS decreased with increasing fibre volume fraction. Surface breaking voids (as an indicator of "laminate quality") decreased with increasing net pressure during manufacture. Table 1 also includes predictions of moduli based on the rule-of-mixtures and laminate analysis (Autodesk Simulation Composite

Design 2014) together with predicted strength using the Kelly-Tyson [4] model with no consideration of the transverse fibres. The strengths are over-predicted by just 16-29% even though virgin fibre strengths were input to the calculations.

Table 1: *The measured properties of the respective laminates (predicted values in italics).*

Property	*Units*	*A*	*B*	*C*	*D*	*E*
Process		HL	RIFT II	RIFT II	RIFT II	Autoclave
Net pressure	mbar	0	300	600	900	5860
Plate thickness	mm	2.34±0.06	2.09±0.04	2.03±0.05	1.94±0.02	1.93±0.03
V_f (thickness)	%	40.8	45.7	47.0	49.3	49.6
V_f (burn-off)	%	42.0	46.5	46.7	48.1	50.9
R-o-M modulus	*GPa*	*17.9*	*19.6*	*20.1*	*20.9*	*21.0*
Laminate analysis	*GPa*	*19.0*	*21.2*	*21.8*	*22.8*	*22.9*
Young's modulus	GPa	21.9±0.6	23.7±0.3	24.5±0.6	24.9±0.4	25.0±0.2
Flex. mod. 40 mm span	GPa	18.7±0.4	19.8±0.5	19.8±0.5	21.1±0.5	22.4±0.4
Flex. mod. 48 mm span	GPa	17.3±0.2	19.0±0.3	18.8±1.0	20.4±0.3	20.9±0.7
K-T strength	*MPa*	*489*	*541*	*551*	*574*	*581*
Tensile strength	MPa	384±15	466±20	426±26	452±31	478±24
Flexural strength	MPa	558±7	578±13	586±11	599±21	608±13
ILSS 10.0 mm span	MPa	56.4±0.8	53.5±1.3	54.1±1.4	53.4±1.6	52.5±1.1
ILSS 11.4 mm span	MPa	52.5±1.7	49.9±1.7	51.2±0.6	46.6±0.9	48.7±1.0
SBV area	%	1.9	2.4	1.4	0.3	0.02

Discussion and conclusions

This work was conducted as a brief initial feasibility study using only a single panel for each condition. Having established that the resin infusion/autoclave process can produce sensible laminates, future work should seek to optimise the volume of the reservoir on the vacuum-side of the laminate. The minimal gain in fibre volume fraction for Panel E is probably due to insufficient volume for resin bleed. There may be a greater increase in fibre volume fraction for an optimised process.

The process was conducted without identifying an optimum resin viscosity at which to impose the autoclave pressure. Stringer [5] identified 7500-16500 mPas as an optimum processing window for application of the vacuum for void-free high fibre volume fraction composites manufactured by wet lamination and vacuum bagging. The additional pressure imposed for autoclave cure, may require a different processing window.

It may be practical, subject to some adaptation of the pressure vessel to load the bagged dry composite into the autoclave, then infuse and cure *in situ*. However, preparation outside the autoclave would permit shorter autoclave cure cycles and hence better utilisation of the pressure vessel. The use of resin infusion with heated tooling [6], brought to temperature before loading the autoclave, would further enhance process efficiency.

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