DIRECT ELECTRICAL CURE OF CARBON FIBRE COMPOSITES

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Abstract

Direct application of electricity to the ends of carbon fibre panels has been used to cure them, giving similar mechanical properties and void content to conventionally cured panels. The application of electricity to the panels causes rapid heating of the fibres themselves, even deep within the composite. The effect is that they locally heat the resin, with a resultant viscosity drop simultaneously throughout the panel. As the resin viscosity quickly drops within the centre of the panel, void removal is efficient and low void contents are obtained. Heating is also rapid, allowing controlled but short cure cycles, as the heating is direct and is dependent on the flow of electricity, not on conduction in to the panel from the surface. In this paper, results are shown from the cure of both flat panels and shaped stiffeners, showing that the technique has the versatility to produce a wide range of composite parts.

1. Introduction

Out of autoclave techniques for the manufacture of composite components has gained increasing attention in recent times, due to the lower energy requirements and the convenience of the process in comparison to the use of an autoclave. One of the key concerns has been the minimisation of voids within the structure. Resins that are designed for use out of autoclave have been developed, with lower viscosity to cope with processing only under vacuum, while new processing techniques have also been developed. Quickstep, in which liquid filled bladders are used to both heat and press the panel has been developed, as have microwave processing techniques. Both of these have been developed to improve the quality of out of autoclave composites and to speed up the manufacturing cycle [1,2].

Void removal in these techniques is simplified as the resin heats quickly due to better thermal conduction in Quickstep and internal heating in microwave processing. Thus, resin flow from the centre of the part to the surface can happen more easily and voids are readily removed. Heating rate can also be increased, as the part heats more uniformly through the thickness and also the temperature of the part can be more rapidly controlled due to lower thermal mass than ovens or autoclaves. Therefore, exotherms can more readily be avoided, and the heating rate can be increased to over 10°C per minute without the part being compromised.

The use of directly applied electrical current to cure carbon-fibre composites has been investigated by several authors, although the technique has not been widely studied. Ramakrishnan et al. [3] added strips of carbon-fibre material to a preform for resin transfer moulding and showed that by the application of electricity the cure process was accelerated. Joseph and Viney [4] however, used the composite itself as the conductive element. Using copper blocks as the contacts, enclosing the end of every ply, they obtained acceptable mechanical performance from their process. This was not a practical implementation, due to the complexity of the contact arrangement.

Athanasopoulos et al [5] resistively heated fibres in both liquid processing and pre-preg materails using a dc power supply attached to contacts incorporated in to the composite part. Panels of up to 40 cm by 20 cm were manufactured using this technique and the results from the panels compared favourably with those produced by conventional cure.

Athanasopoulos et al. [6] have also used resistive heating to directly heat the surface of a mould tool produced from carbon fibre composite. This method, however, uses the mould as the heating element, not the part itself, making beyond the scope of this work.

As can be seen, the use of directly applied electricity is an approach that can be used to cure composite materials. However, the practicality of the approach to manufacture larger parts has not been demonstrated. In this work the practicality of the approach is studied and the potential advantages of the system are explored, in relation to other out-of autoclave manufacturing techniques.

Direct electrical cure offers similar advantages as it heats the part internally and has low thermal mass, so control of temperature can be rapid. It therefore presents an interesting alternative processing route that is worthy of further investigation.

2. Experimental

2.1 Materials

All composites in this study were produced using CYCOM 950-1 plain weave composite. Electrical contacts were made using either Rogers R-Flex 20FRNP flexible circuit board or copper foil 0.1 mm thick. Vacuum bagging materials were supplied by Tygavac ltd.

2.2 Manufacture

This study examined flat panels and stringers in order to produce a range of composite components.

Flat panels consisting of 4 plies of composite were produced and cured in sizes measuring up to 40 cm wide and 70 cm long. L-shaped stringers were produced using 8 or 16 plies with sides measuring 2.5 cm and in lengths up to 88 cm. All composites were simple 0/90 plain weave laminates. Contacts were applied to the panels in the manner shown in Figure 1.

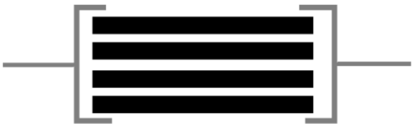

Figure 1. Schematic illustration of the contact arrangement used in the study

Rapid Electronics power supplies (Rapid Electronics SPS-9602-209G capable of producing 30V and 30A, and a Rapid Electronics SPS-9400-209MG capable of producing 15V and 40A) were connected to the contacts at the panel ends and current was controlled using the controls at the front of the supplies. During cure, the voltage and current were recorded to determine the power used to cure each panel. Thermocouples were connected to a Pico Technologies TC-08 thermocouple logger that was connected to a PC in order to record the temperatures within the panel during cure.

In addition to the electrically cured panels, panels were conventionally made in the same geometries using oven cure. These were used to compare with the electrically cured panels in order to determine the suitability of electric cure to manufacture composite components.

2.3 Testing

Dynamic mechanical analysis (DMA) (Perkin Elmer DMA8000) was performed on samples taken from the manufactured panels in order to determine the glass transition temperature, as an indication of the level of cure that had been obtained.

Flexural testing was also performed at room temperature (Zwick Roell Z050) in order to compare the mechanical properties of the composites manufactured using each technique. Specimen dimensions were 7 cm by 1 cm, with the specimen thickness being 1 mm.

3. Results

Studies of the effect of sample length and width on the power requirement showed that as the sample length increased, the power requirement increased, but at a significantly slower rate than as the sample width increased (Figures 2a and 2b). Doubling the sample length gave an increase of approximately 1.6 times the power requirement, whereas doubling the width doubled the power requirement. Therefore, long thin specimens are more suitable to manufacture using this technique. This is in-line with the findings of Athanasopoulos (2010) [5].

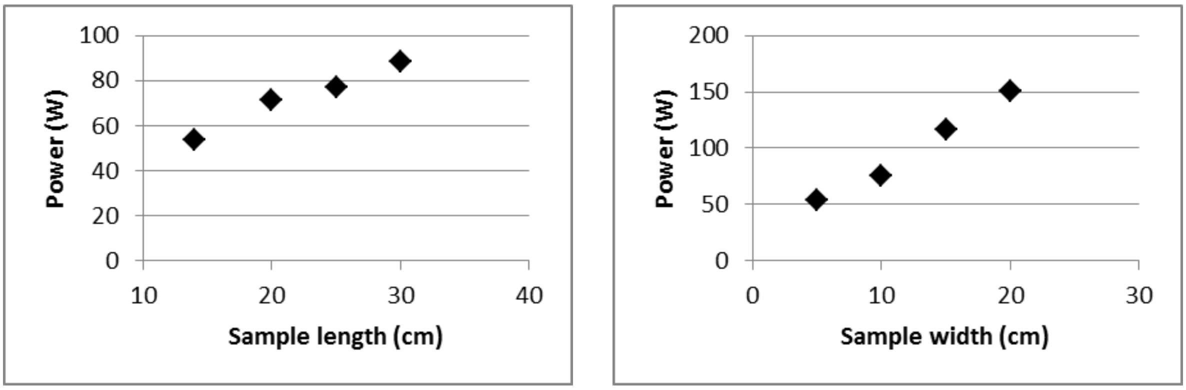

Figure 2. Showing a) the change in power requirement as sample length increase and b) the change in power requirement as the sample width increases.

DMA testing of these panels showed that curing either flat panels or L-beams for 1 hour gave a glass transition temperature that was identical to that obtained when cure was performed conventionally (Figure 3). Flexural testing showed that the mechanical properties were slightly lower than for conventionally cured specimens, but they exceeded the values given in the manufacturers datasheet [7] (Figure 4).

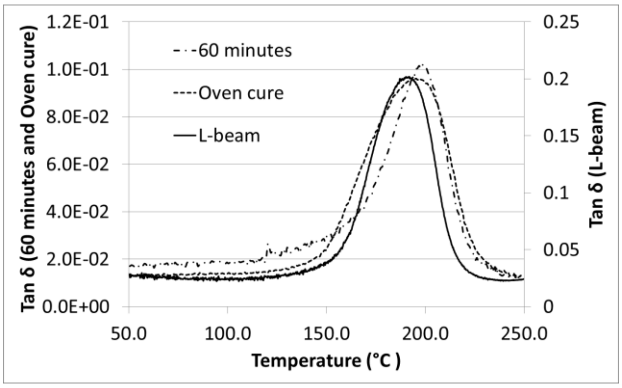

Figure 3. Showing the comparison between the glass transition peaks for electrically cured specimens of a flat panel cured for 60 minutes and an L-beam cured for 1 hour and oven cured specimens.

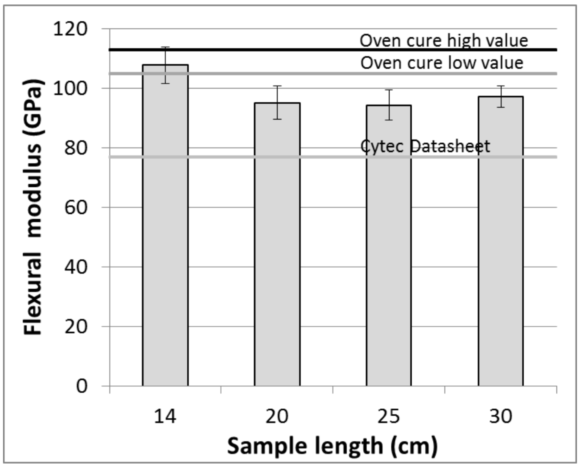

Figure 4. Showing the comparison between the flexural modulus of electrically cured and oven cured specimens and also the manufacturers datasheet values.

Larger panels were produced, with Figure 5 showing a panel measuring 30 cm by 20 cm that has been cured electrically, along with the temperature profiles obtained during the cure process. Table 1 shows panel dimensions and voltage, current and power used to cure panels measuring 30 cm by 20 cm and 20 cm by 30 cm and 40 cm by 20 cm. The power requirement in each case is presented in Table 1, it was necessary to use multiple power supplies in the case of the 30 cm and 40 cm wide panels, hence the multiple values of current and voltage.

L-shaped stringers have also been produced. Measuring 2.5 cm by 2.5 cm by 88 cm these have taken 160 W to cure, regardless of the thickness of the part (2 mm or 4 mm). Initial ramp to temperature took approximately 10 minutes and the cure cycle was completed with a dwell of 1 hour. Measurements of the void content and mechanical performance are on-going, however significant resin bleed has occurred indicating that consolidation of the panel is likely to be good. Figure 5a shows a stiffener following cure and Figure 5b shows a close up of the cropped end of the stiffener.

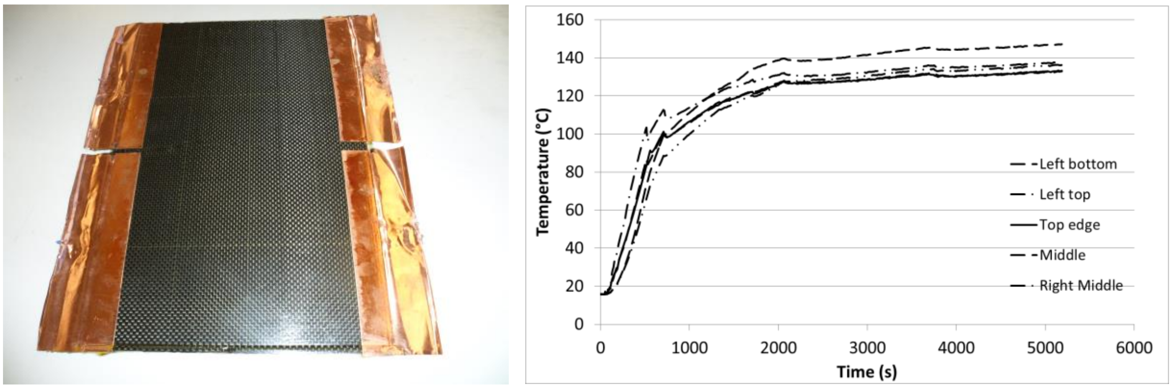

Figure 5. Showing an electrically cured panel measuring 30 cm by 20 cm, and the temperature variation in the panel during cure.

Sample size (width * length) (cm)	Current (A)	Voltage (V)	Power (W)	
20 * 30	38.0	6.2		235.6
30 * 20	32.8	3.8	124.6	242.7
	31.9	3.7	118.03	
40 *20	32.9	3.7	121.7	352.1
	32.9	3.5	115.2	
	32.9	3.5	115.2	

Table 1. Power requirements for curing panels measuring 20cm, 30 cm and 40 cm wide.

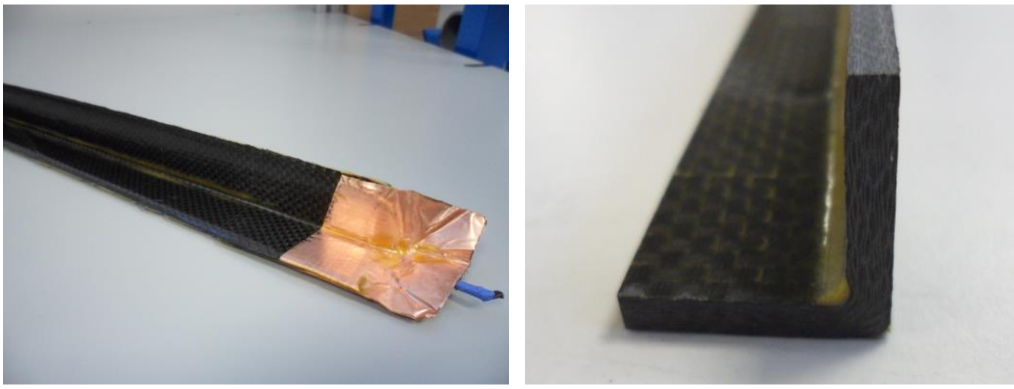

Figure 6. Showing an image of the electrically L-shaped stiffener, detailing the contact arrangement, and showing the consolidation and degree of resin bleed via the image of a cut end.

4. Conclusions

Flat panels and shaped composite stringers up to 4 mm thick can be produced using the direct application of electricity to the panel. The temperature of the panel can be readily and rapidly controlled by varying the electric current and thus rapid heating can be obtained throughout the panel. The power requirements increase as both length and width of the panel increase, but the increase with length is significantly lower than for the increase in width. This suggests that longer thinner panels are more suitable for manufacture in this way. While optimisation of the process is still on-going, the level of consolidation and performance of the composites seem to be in-line with conventional manufacturing routes.

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