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THROUGH-THICKNESS MELDING OF ADVANCED CFRP FOR AEROSPACE APPLICATIONS

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SUMMARY: T. Corbett *et al.* have successfully melded lap joints and it has been shown that the transition zone between the cured and uncured regions is less than 40 mm. [1] This work aims to manufacture a 160 ply (20 mm) by melding through the thickness of a laminate by joining two half cured 80 ply (10 mm) panels. Unidirectional Hexcel 8552 CFRPs were partially cured along the *z*-axis using a modified hot press, then joined using the Quickstep chamber. The fully melded panel was shown to have similar degree of cure (between 88% and 98% cured) as a panel cured by traditional methods. Although the panel was fully cured, a great deal Work is also underway to design a Quickstep chamber that will allow for through-thickness melding.

KEYWORDS: Quickstep process, melding, through-thickness melding

INTRODUCTION

As fuel prices rise and the need for lower weight materials increases, modern aircraft design relies more and more on composite materials. However the conventional joining methods used for metallic airframes, rivets, leave stress concentrations that significantly weaken composite structures. Adhesive bonding of carbon fibre reinforced polymers is difficult, time consuming and comparatively unreliable. The Quickstep rapid manufacturing process allows a laminate to be partially cured due to the temperature control that is inherent to the system. Melding, a portmanteaux of melting and welding, offers a promising alternative to creating seamless bonds by partially curing two laminates and combining them.

QUICKSTEP PROCESSING

Quickstep is a novel out-of-autoclave polymer composites processing technology. The technique utilizes a glycol heat transfer fluid (HTF) to conduct heat to the uncured laminate stack more efficiently than is possible in the autoclave. This precise temperature control, in conjunction with increased heat transfer, allows for a significant reduction in the cure-cycle time [3].

Advanced carbon fibre reinforced polymers (CFRPs) have not been used as widely within manufacturing as would be predicted from their superior mechanical and structural performances because of complexity, time and energy costs required to create the consistently uniform parts available with most processing techniques [3]. Therefore the use of advanced CFRPs has been essentially limited to industries that already have a high product cost, such as the aerospace industry, or industries in which cost is not as much an issue, such as high-end sporting equipment.

For Quickstep, the uncured laminate stack is prepared using a vacuum bagging technique similar to that used in autoclaves or composites processing ovens. A silicone bladder contains the HTF and provides a flexible membrane that conforms to the shape of the vacuum bagged laminate. Precise temperature control is maintained by circulating HTF through the bladders from one of three storage tanks: one tank full of HTF at room temperature, one full of intermediate-dwell temperature HTF and one of full of HTF at cure temperature.

Typically, the consolidation pressure is about 10 kPa, which is much lower than that produced in autoclave. As the viscosity of the resin can be reduced to its working viscosity which is much quicker during the initial stages of cure, this low pressure is sufficient to enable consolidation with a minimum of voids [5]. Laminates produced by the Quickstep process have been shown to compare favourably with those produced in autoclave [1, 6-8].

HOT PRESS PROCESSING

A hot press applies heat and pressure through two hot platens that are controlled by a hydraulic ram. This is the simplest method to process high quality composite parts with low void content. Its major limitation is that pressure may only be applied uni-axially. While shaped moulds are often used to process shapes with simple curves or bends, complex shapes are all but impossible to make. Further, the heating and cooling rates are dependent on the hot press' capability to heat and cool the platens [9]. For this work, the top platen was heated as normal while the bottom platen was water-cooled.

LINEAR MELDING

Melding is a novel method of producing seamless joins in CFRPs without the use of adhesives. Utilizing the precise temperature control of the Quickstep machine, it is possible to partially cure composites. That is, it is possible to fully cure one part of the laminate stack while leaving the remainder completely uncured and chemically active. Uncured parts are then co-cured together without adhesive so that chemical crosslinking can occur. In this regard, melding is a specialized form of co-curing. This creates a seamless join without mechanical fasteners or adhesive bonds.

A specialized Quickstep chamber allows hot fluid to cure half a laminate stack while cold water is circulated through the other half to create a half cured laminate with the Fig. 1 configuration. The two laminates are then joined in a traditional Quickstep chamber to create a seamless bond.

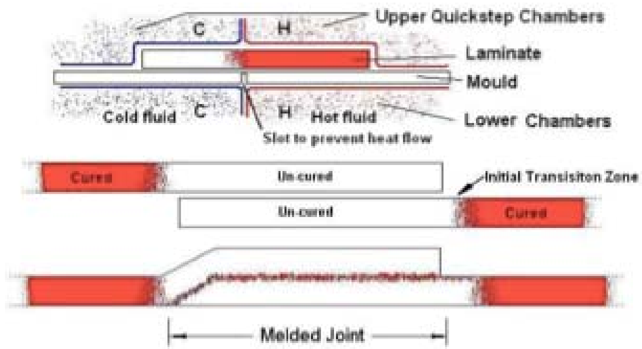

Fig. 1 Schematic of the melding process. Two half cured laminates are processed as shown on the top, and then joined in the Quickstep chamber [1].

THROUGH-THICKNESS MELDING

The current research into melding deals with linear melding along the *x*-*y* plane of the composite laminate. This work explores the feasibility of melding perpendicular to the *x*-*y* plane through the thickness of the laminate. The intention is to build up a thick laminate stack by combing two laminate stacks that have been half cured along the *z*-axis. The material used for this work, Hexcel 6376 unidirectional CFRP with a 12k tow and 33% resin weight, was chosen because it has been extensively studied for use in the Quickstep process and its properties are well understood. The cure cycle chosen for this work is shown in Fig. 2.

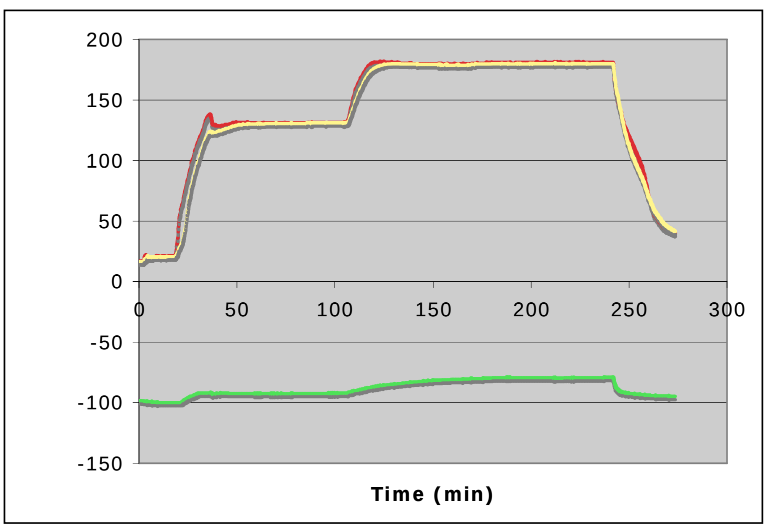

Fig. 2 Chosen cure cycle for Hexcel 6376. The top curves represent the top and bottom mould temperature, respectively. The bottom curve is the vacuum pressure [4].

THROUGH-THICKNESS MELDING IN THE HOT PRESS

The through-thickness melding process was taken out of the Quickstep chamber and into a hot-press. For the final full joining cure, the two half cured laminate stacks will be processed using the Quickstep chamber. The rationalization for using the hot press was that too much heat would transfer between the contacting areas of the flexible bladders. A laminate stack was made to be closer to the size of the platens, but thicker to encourage a greater temperature differential through the thickness (100 plies at 200 mm x 200 mm). The platens were 0.126 m^2, leaving only 0.086 m^2 of hot and cold platens exposed. The final cure thickness was 25 mm, leaving the hot and cold platen surfaces relatively far from each other. The layup was similar to that of traditional vacuum bagging. However, the over-pressure in the hot press was 1.3 MPa; far superior to the over-pressure seen in vacuum bags. The ramp rates were 5˚C/minute with a 30 minute dwell at 120 ˚C and a one hour dwell at 150 ˚C.

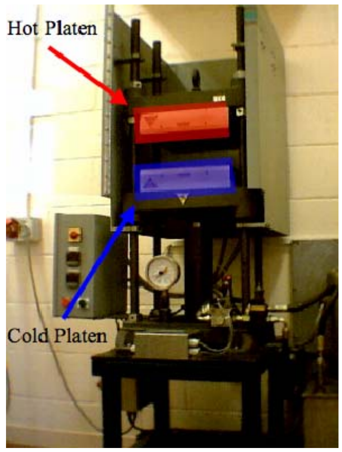

Fig 3. Standard hot press modified so that while the top platen operates as normal, the bottom platen is cooled by air and water.

RESULTS AND DISCUSSION

Sufficient heating was observed in the material exposed to the hot platen, while the side exposed to the cold platen was not exposed to a temperature above 65 ˚C. The half-cured laminate stack was rigid on the side exposed to heat and tacky, or workable, on the cold side.

As shown in Fig. 5, optical microscopy revealed the portion of the half cured panel that was exposed to heat appears similar to a fully cured panel. As the viewer progresses through the thickness of the half cured panel from the hot to the cold, individual laminates that are not fully cured become more evident. In Fig. 5c the individual laminates can be seen at an intermediate stage of curing and in Fig. 5d, resin flow has yet to occur. The two half cured panels were then joined together using the traditional Quickstep method, with the cure cycle shown in Fig. 2.

As shown in Fig. 6, while the entire melded panel appears fully cured, a good deal of porosity formed around the bond line. While Fig. 6a and 6b show a great deal of porosity towards the edges of the panel, Fig. 6b displays voids that are on the scale of 1-2 mm in diameter. It is believed that this occurred because trapped gasses were unable to escape through their normal routes, as the upper and lower bounds of the panel were already cured. Further, as the outer edges of the panel cured, all routes of escape for gasses were closed, as shown in Fig. 7. Towards the edge of the panel, the bond line was well sealed and had very few voids. Future work aims to solve this problem with the addition of glass fiber strips and/or cork edge dams to allow escaping gasses to leave the panel prior to being trapped.

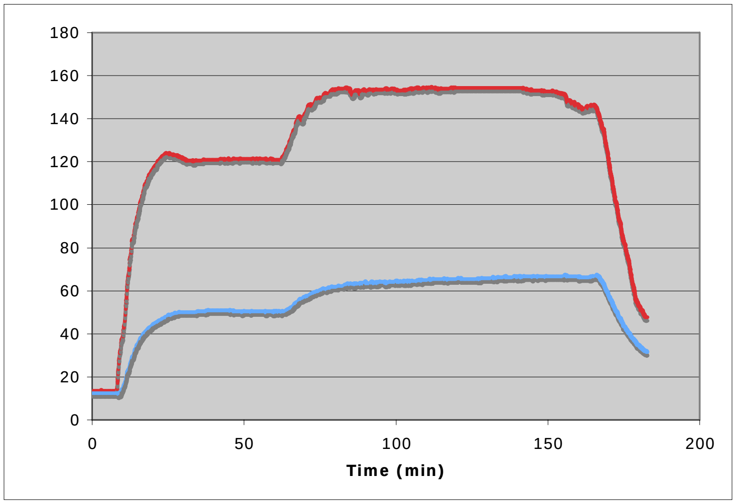

Fig. 4 Cure cycle profile observed in the hot press used for through-thickness melding. The top curve was exposed to the hot platen while the bottom curve was exposed to the cold platen.

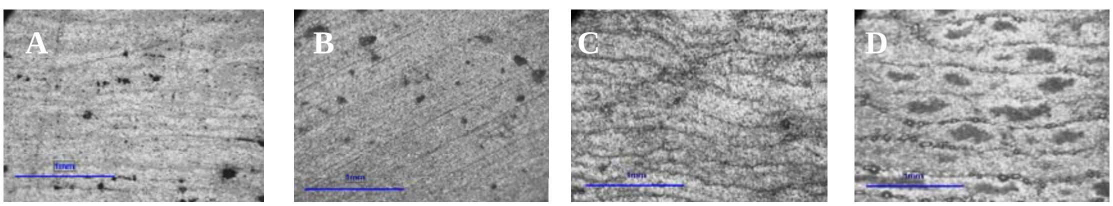

Fig. 5 Optical micrographs of a) fully cured panel; b) portion of the half-cured panel exposed to heat; c) midpoint of the half-cured panel; and d) portion of the half-cured panel exposed to cold.

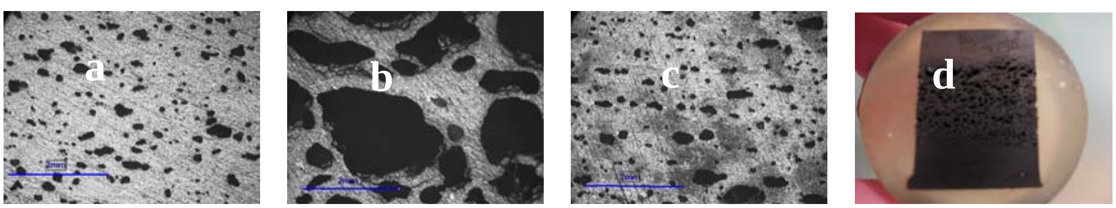

Fig. 6 Optical micrographs of a) bottom of a fully melded panel; b) middle of the same panel; c) the upper section; d) photo of the cross-sectional area of views a, b and c.

Table 1 below shows the degree of cure, as calculated from the heat work measured in a differential scanning calorimeter. For the top and bottom half cured panels, it is clear that the sides exposed to the cold platen remained nearly fully uncured, between 2% and 7%. As the viewer moves through the sample towards the side exposed to the hot platen, the degree of cure increases until the side directly exposed to the hot platen is close to approximately 25%. While not fully cured, this level of crosslinking and material flow makes it easy to handle and unreactive. Once the two half-cured panels are cured together, they can be considered fully cured.

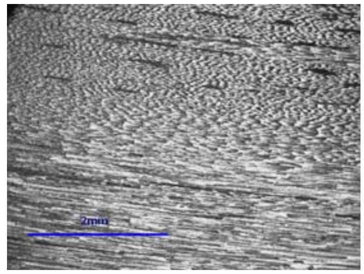

Fig. 7 Bond line near the edge of the fully melded panel.

Table 1 Degree of cure at various locations through the fully melded panel and constitutive parts

Location		Average Heat Work (J/g)	% cured
Parent Uncured		167.6	0
Parent Cured		0.3179	99.81
Full Meld	Top	4.351	97.40
	Middle	2.815	98.32
	Bottom	28.41	83.05
"Top" Half Cured	Top	127.7	23.79
	Middle	149.0	11.12
	Bottom	162.5	2.94
"Bottom" Half Cured	Top	124.4	25.81
	Middle	139.2	16.95
	Bottom	157.6	6.54

CONCLUSIONS AND FUTURE WORK

This work has shown the feasibility of half curing two advanced CFRP panels and then joining them with a Quickstep chamber. The process will be further refined to eliminate voids from the system and to optimize the degree of cure for the cured portions of the half cured panels. Further work will also include thermal characterization through dynamic mechanical analysis to determine the T_g in a similar fashion that degree of cure was determined. Also, the entire curing process (half curing, fully curing and melding) will be examined using Fourier transform infrared spectroscopy to ensure that the curing process in the through-thickness melding process is identical to that of normal curing.

Mechanical tests will be carried out to ensure that the through-thickness melding process manufactures panels that are equal or superior to panels made by various processing methods, including hot press process, autoclave and Quickstep. The short beam strength, ultimate tensile strength will be examined for this cause. Lastly, the mechanical strength of the bond line between the two half cured panels will be examined with double cantilever beam testing.

While the process of half curing a laminate stack was done using a modified hot press, the ultimate goal is to move this entire process into the Quickstep chamber. Work is underway to design a chamber that is capable of allowing a sufficient temperature *z*-axis temperature gradient while minimizing heat loss between the top and bottom chamber.

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