This is the published version:


Available from Deakin Research Online:

http://hdl.handle.net/10536/DRO/DU:30014403

Every reasonable effort has been made to ensure that permission has been obtained for items included in Deakin Research Online. If you believe that your rights have been infringed by this repository, please contact drosupport@deakin.edu.au

Copyright : 2005, SAMPE Europe
MELDING: A NEW ALTERNATIVE TO ADHESIVE BONDING

Tim Corbett a, Mark Forrest a, Haydn Law b, Bronwyn L. Fox a
a School of Engineering and Technology, Deakin University, Victoria 3217, Australia
b Quickstep Technologies Pty Ltd, Canning Vale, Western Australia 6155, Australia

ABSTRACT

Melding, a novel method for joining composites is examined in this paper. The method uses Quickstep™ technology to retain partially cured areas of a composite laminate, enabling subsequent bonding operations. The effect of melding on the mechanical properties of the composite has been investigated. Flexural testing of HexPly 914 indicates consistent properties throughout a melded section. Flexural strength values of 1.36±0.03 GPa compared to 1.35±0.03 GPa for a standard laminate were recorded. In order to achieve sufficient bond strength, the portion of the composite to be joined must have a significant proportion of uncured matrix. The ability of Hexply 914 prepreg to retain sufficient bonding potential to form a strong joint was also investigated. HexPly 914 Lap Shear results indicated no significant variation in strength values between co-cured and melded joins, with a recorded strength value of 15.0±0.7 MPa.

INTRODUCTION

Adhesives are increasingly being used in industrial applications to replace and/or complement traditional fastening methods such as welding, bolts and rivets. In automotive and aerospace applications, weight reduction is a key factor; hence the rapidly expanding use of lightweight adhesives. The use of adhesives in these applications has the additional advantage of reducing the number of potential stress concentration sites caused by the presence of rivets [1]. However limitations of adhesives are well known, such as susceptibility to peel forces and environmental attack by hydrolysis [2,3].

Melding purports to overcome the limitations of adhesives by retaining a chemically active surface to react and form a bonded joint [4]. Surfaces are left partially cured so that chemical cross-linking can occur between joined surfaces to create a structure without secondary adhesive bonds that are prone to failure [2]. Using the Quickstep process, hot fluid cures designated areas of a laminate and cold fluid prevents cure in areas to be joined later (Figure 1). Partially cured regions to be
bonded are brought together in a desired arrangement and the cure is completed, creating a seamless join.

Two key areas of the process have been studied to assess the viability of melding. Firstly, the matrix changes from cured to partially cured in the initial transition zone (Figure 1). The mechanical properties of the initial transition zone were evaluated after curing the complete part via flexural testing. Secondly, the retained adhesive potential of the partially cured sections was assessed. Melded lap shear joints were used to compare variations of co-cured and adhesively bonded samples.

![Diagram](image)

**Figure 1:** A schematic diagram depicting the melding procedure

**MATERIALS, SPECIMEN DESIGN AND TESTING PROCEDURES**

**Evaluation of the Initial Transition Zone**

Flat panels were used to evaluate the mechanical strength of the initial transition region. A Quickstep QS 5 curing machine was used to cure half of the panel using hot fluid while the other half was actively cooled with re-circulated room temperature water (Figure 1). A channel was machined on the underside of the mould between the hot and cold halves to prevent heat conduction and thereby creating a sharp temperature transition.

The laminated panels consisted of 12 plies of unidirectional HexPly 914 orientated in the 0° direction. Thermocouples were placed in 40mm increments along the panel, at the mid-plane between the 6th and 7th plies during lay-up, to monitor temperature during the initial cure stage. The samples were envelope
vacuum bagged and debulked for 1 hour prior to cure taking place using an edge bleed arrangement. The laminates had cured dimensions of 300mm x 100mm and a nominal thickness of 1.65mm.

The cure cycle consisted of a half hour dwell at 120°C followed by a one hour cure at 175°C. During this stage the temperature was recorded and logged at each thermocouple. The cure cycle was completed using the same temperature cycle, completing the cure of the partially cured portion.

Flexural specimens were prepared according to ASTM D790 M. Sections were cut from the laminate with a diamond saw and trimmed using a Struers Accutom 50 cutting machine. The final dimensions of each specimen were 38mm x 6mm x 1.65mm. Specimens were loaded in three-point bending to failure in a Lloyd LR30K testing machine using a span to depth ratio of 16:1 and a cross-head displacement rate of 0.6mm/minute.

Investigation of the Adhesive Potential of a Melded Joint

The ability of the process to retain a suitable degree of the partially cured matrix for bonding was investigated using lap shear testing. A melded specimen was compared to an adhesively bonded and a co-cured lap shear specimen. Lap shear joins were produced in accordance with ASTM D 5868-01 and mechanically tested using a Lloyd LR30K testing machine. 18 plies of unidirectional HexPly 914 were laminated in the 0° direction to achieve the required nominal thickness of 2.5mm.

For the melded specimen, two panels - each retaining a partially cured region, were produced using Quickstep. As a chemically active surface was retained, no surface preparation was required prior to bonding. The partially cured portion of each panel was assembled together to create the join of lap shear specimen. The cure cycle was then completed after the specimen was vacuum bagged and debulked.

For the adhesively joined specimen, two fully cured panels of the HexPly 914 were bonded using Redux 322 epoxy film adhesive. In accordance with the Redux 322 product data sheet [5], the surfaces to be bonded were abraded with a surface finisher (120 grit), solvent cleaned with acetone, and oven dried prior to bonding. The adhesive lap shear joint was vacuum bagged and cured at 175°C for 1 hour [5].

For the co-cured specimen, the second (upper) panel was laminated over a fully cured panel of HexPly 914 that had been abraded and solvent cleaned in preparation for the join [2,5]. Excess resin from the upper laminate was utilised as the adhesive for the lap shear joint [6].
A control specimen was also produced where the entire lap shear join was laminated and cured in a single operation to ensure a molecular join at the lap shear interface.

RESULTS AND DISCUSSION

Figure 2 shows the temperature variation across a melded sample during the initial cure stage. The first 3 thermocouples (t1, t2 and t3) positioned on the cooled portion of the laminate show a slow rise in temperature before a significant increase at the initial transition zone, illustrating the effectiveness of the machined channel in the mould. However, each of t1, t2 and t3 remained below 40°C for the duration of the cure cycle, preventing significant cure progress in this area. When inspected, the partially cured portion was still tacky and pliable indicating little or no cure had taken place. Keeping the resin at room temperature for the initial cure is important in order to gain maximum benefit from melding in terms of both cure and handling qualities for lay-up.

![Figure 2: Temperature profile of the initial cure. The insert picture is of the panel produced showing the location of thermocouples](image)

A similar trend is also observed for thermocouples 4, 5 and 6. Less than 2°C variation was noted between t5 and t6, showing values of 173.7°C and 175.6°C respectively. While the temperature at t4 was somewhat lower at 169°C, this was not considered to be a significant variation. Any material not fully cured would be
completely cured during the following cycle. The flexural strength was not affected, as can be seen in figure 3, which shows the flexural strength values recorded across the melded panel. While the average value at each position varies marginally, each sample is within experimental deviation of the panel’s average strength of 1.36GPa. This also indicates the initial transition from cured to partially cured matrix has not affected the final strength of the laminate. A flexural strength value of 1.36GPa from the initial transition region, compared to 1.35GPa at either end of the laminate further indicates variation in flexural strength is minimal.

An inspection of porosity using X-ray imaging indicated no significant porosity in the tested laminates. Images were collected using a Feinfocus Microfocus FXE225.20 x-ray source and tungsten target onto image pates 200 x 250mm and scanned with a Fuji BAS5000.

![Figure 3: Flexural strength at various positions along a melded panel.](image)

![Figure 4: Lap shear strength of various bonding arrangements.](image)

Figure 4 illustrates the lap shear strength of each of the bonded variants. The melded and co-cured variations recorded similar strength values of 15.0±0.7 MPa and 15.2±0.6 MPa respectively. While the control specimen had a 6% lower value of 14.1±0.6 MPa, no significant difference can be seen as this is within experimental error. A cohesive failure mode was observed in each case, along with a small degree of fibre pull-out.
The adhesively joined sample provided the largest lap shear strength of 17.8±2.0 MPa. This sample also failed cohesively, suggesting that the adhesive performs better under the combined loading conditions created in lap shear samples. This is to be expected as the adhesive is specifically designed for this purpose.

However, the melded bond is expected to out perform adhesive bonding where other failure modes preside. Boeing wedge testing is currently being performed to investigate and assess the environmental durability of melding. These results will be presented at the conference.

CONCLUSIONS

In this study, a new bonding procedure for composite materials, Melding, has been investigated. Flat laminate and lap shear specimens were produced and evaluated to demonstrate the merits of the process. The following outcomes are noted:

(1) Negligible loss of mechanical properties was observed. The flexural testing of a melded laminate indicated no significant losses due to the uncharacteristic cure conditions needed to achieve a melded joint; and,

(2) Lap shear testing indicated that successful joints can be achieved with the melding process. Melded strength was equivalent to conventionally cured and co-cured arrangements, returning lap shear strength values of 15.0MPa, 14.1MPa, and 15.2MPa respectively.

ACKNOWLEDGEMENTS

The author would like to acknowledge the financial support of the Victorian Centre for Advanced Materials Manufacturing in this project.

REFERENCES

5 - Redux 322 Product Data Sheet, Hexcel Composites Publication RTC020a (2002)