

A NOVEL METHOD OF TUBE MANUFACTURE FOR VEHICLE CRASHWORTHINESS UTILISING THE QUICKSTEP™ PROCESS

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SUMMARY

A novel method of composite tube manufacture was developed for potential use in automotive crash structures. Tubes were crushed axially under quasi-static conditions and highly repeatable behaviour was observed with an average specific energy absorption of $\sim 85\text{kJ/kg}$. DMTA results indicated that the tubes were fully cured, even when the cycle was reduced to 7 minutes, giving this process huge potential for high-volume production.

INTRODUCTION

Vehicle safety is of considerable interest to both the public and auto-manufacturers and not surprisingly, numerous studies in this field have been undertaken and reported [1-4]. The combined requirements for manufacturers to improve vehicle crashworthiness, reduce vehicle weight and provide features such as air conditioning and power steering have forced investigations into less conventional materials. Composites are capable of providing both reduced weight and improved crashworthiness simultaneously. Consequently, composite materials in crash structures have been the focus of a number of investigations in recent years [5-10].

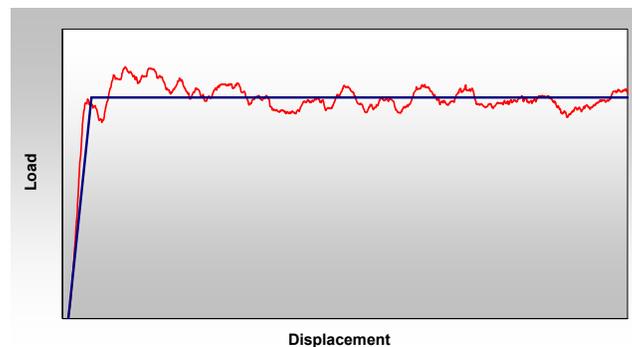


Figure 1. A typical composite tube load-displacement response compared to an ideal response.

Composites have displayed an ability to provide almost ideal crashworthiness characteristics, a bilinear load-displacement relationship, an example of which can be seen in Figure 1 [11]. Furthermore, these materials regularly surpass the energy-absorption of similar metallic structures with a fraction of the weight [12]. However, significant prototyping costs and relatively expensive processing costs have hindered the use of composites in all but the most expensive vehicles. The provision of a suitable production technique and computer based model for the impact behaviour of composite materials is crucial for the cost-effective implementation in widespread automotive applications. Current methods of tube manufacture are pultrusion, filament winding and autoclave mandrel wrapping. This paper is focussed towards the results of a novel manufacturing technique for composite tubular structures which offers faster production for high volume manufacture.

Quickstep¹ is an advanced composite component manufacturing process for out of autoclave processing of high quality, low cost, low weight components using faster cure cycles. This process utilises a unique fluid filled mould to provide exceptional temperature control and phenomenal cure times. These attributes together with significantly lower capital, tooling and operational expenses make Quickstep an attractive process.

A novel manufacturing technique has been developed and validated which makes best use of the faster cure cycles possible with the Quickstep process. The manufacturing technique will be discussed in detail during the authors' oral presentation.

EXPERIMENTAL DETAIL

The tubes have been manufactured from TORAY G 83C (5 Harness Satin Weave) pre-impregnated carbon fibre. To demonstrate the concept of the manufacturing process, a simple [0/90°] lay-up of four layers was selected. This produced tubes of a 2.1mm (± 0.1) thickness with an inner diameter of 59.6mm (± 0.08).

An initial cure cycle was chosen based on the manufacturers recommended time at full temperature. This cure cycle is five minutes at a dwell temperature of 100°C, then full temperature of 155°C for three minutes. This resulted in a total cure cycle time of 14 minutes. Subsequent tests varied the cure cycle from a maximum of 30 minutes to a minimum of just 7 minutes.

¹ www.quickstep.com.au

Initially, the tubes were prepared using a conventional perforated release film, N10 breather and vacuum bag but in further testing, various other approaches were tried. Combinations of vacuum bag with various thickness breathers, both with and without shrink tape, were tested. The various tubes and their production techniques are shown in Table 1.

Tube Sample	Layers	Bagging	Lay-up	Cure Cycle
#1	4	Perforated Release Film Breather N10 Vacuum Bag	0/90	Standard ⁺
#2	4	Shrink Tape	0/90	Standard ⁺
#3	4	Perforated Release Film Light Weight Breather N4 Vacuum Bag	0/90	Standard ⁺
#4	4	Shrink Tape Light Weight Breather N4 Vacuum Bag	0/90	Standard ⁺
#5	4	Perforated Release Film Breather N10 Vacuum Bag	0/90	20 min dwell, 3 mins full temp -30 min cure
#6	4	Perforated Release Film Breather N10 Vacuum Bag	0/90	no dwell, 3 min full temp. 7 minute cure

Table 1. Bagging arrangement of the manufactured tubes

⁺ Standard cure is as discussed above

In order to determine the energy absorption of a sample, it was necessary to axially crush the tubes and record the load-displacement relationship. Each tube was cut into 100mm sections and a 45° chamfer was turned into one of the ends (in order to produce a progressive collapse mode [7]). Tubes 1-4 were crushed in a 385kN MTS with Teststar 2s control software. Tubes 5 and 6 were crushed in a 100kN MTS 20/G with Testworks 4 (V. 4.01) control software. Both devices were calibrated prior to crushing and all tests were conducted at a rate of 10mm/min for 60mm. The Specific Energy Absorption (SEA – energy absorbed per unit mass [kJ/kg]) was then calculated and compared. Similarly, the glass transition temperature (T_g) and degree of cure of each tube was measured by Dynamic Mechanical Thermal Analysis (DMTA) on a polymer laboratories Mk2 instrument at 1kHz using 2mm thick specimens in single cantilever mode.

RESULTS

The surface appearance of the tubes varied from very rough to smooth and glossy depending on the preparation technique. The tubes which used breather and vacuum bag possessed a rough appearance with small axial ridges along the length of the tube. It was thought that these would adversely affect the impact behaviour and so, effort was taken to reduce the amount of wrinkling but in the case of tube 3, the smaller ridges were combined to form one large crease (~8mm high) along most of the tubes length, as shown in Figure 1(a).

Shrink tape was then employed which contracts as the temperature increases, applying pressure to the tube. This produced a far more aesthetically pleasing finish with none of the aforementioned wrinkles (Figure 1(b)).

In an effort to further improve the mechanical properties and reduce the void content, a combination of shrink tape and vacuum bag was investigated for tube 6. It became apparent that the shrink wrap effectively sealed the tube nullifying the benefits of the vacuum bag. A good surface finish was produced but voids were still apparent. Modifying the cure cycle appeared to be the solution. However, as will be discussed shortly, the effect of varying the dwell time was not found to affect the tubes mechanical properties.

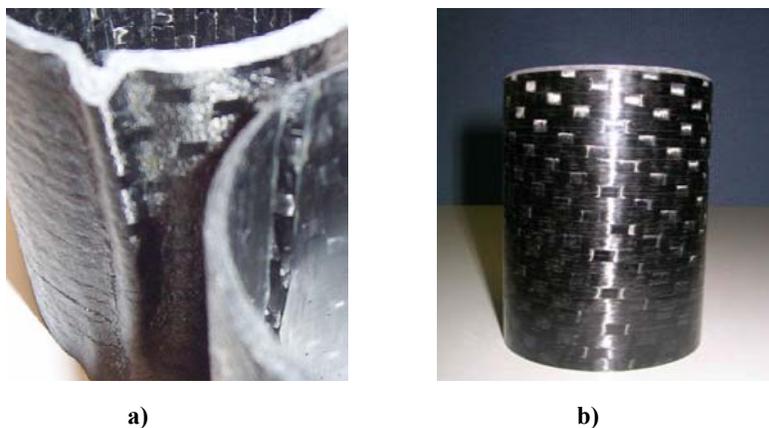


Figure 2. (a) Tube 5 showing the ridge developed during production. (b) Surface finish obtained by utilising shrink tape

In crush testing, all of the tubes failed by the brittle fracture failure mode. The average SEA of each tube is shown in Figure 2.

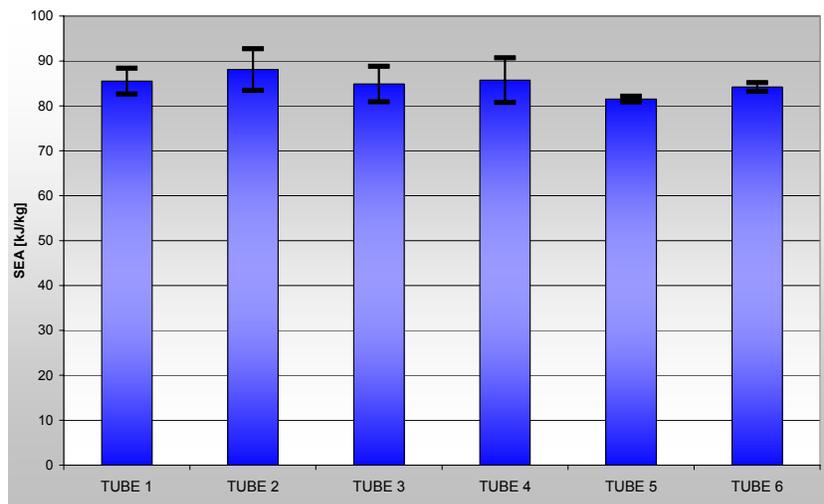


Figure 2. Average SEA for all tubes crushed

It was observed that the changes made through the production improvements resulted in more repeatable crush behaviour, evidenced by the smaller variance in tubes 5 and 6. The changes made to the production process did not appear to have influenced the energy absorption of the tubes. In the case of tubes 2 and 4, the inclusion of shrink tape appears to have decreased the repeatability. Interestingly, tube 3's previously discussed ridge had very little effect on the impact behaviour suggesting that some degree of pre-existing damage is tolerable. These results suggest that there is little influence from surface finish. The largest contributor to the energy absorption is the cure cycle and that the most repeatable values come from a cure cycle of 7 minutes.

The results of the DMTA showed glass transition temperatures (T_g) of $146 \pm 2^\circ\text{C}$ for all cure cycles tested which compares well with autoclave samples which possessed values of $139 \pm 2^\circ\text{C}$ for the same system. This was achieved with a time of 3 minutes at 155°C and a total time of 7 minutes. The average SEA for all tubes crushed is 84.9 kJ/kg, a value that compares well with steel tubes of similar geometry which produce figures of approximately 25 kJ/kg [13]. Significant improvements are possible through fibre-orientation and tube geometry.

CONCLUSION

A novel technique for the manufacture of composite tubes has been developed and tested by DMTA and crush testing. Tubes have been cured in a remarkable 7 minutes with little preparation required to produce an aesthetically pleasing product. This process achieves a higher degree of cure than is possible with autoclave techniques and has produced highly repeatable energy-absorption characteristics in crush conditions.

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