THE IMPROVEMENT OF CARBON FIBRE COMPOSITES USING NANOFIBRE INTERLEAVING VEILS

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ABSTRACT

Revolution Fibres have developed Xantu.Layr®, the world's first commercially available nanofibre interleaving veil. Xantu.Layr® has been shown to improve the fracture toughness (delamination resistance), compression after impact strength (damage tolerance) and fatigue resistance of composite laminates. The Xantu.Layr® nanofibre veils act as nano-scale reinforcements of the brittle resin matrix in the interlayer region, resulting in a tougher resin (even when used with toughened resin systems) which is less prone to micro-cracking when stressed or impacted.

Keywords: carbon fibre composites, fracture toughness, compression after impact, fatigue, electrsopinning.

1. IMPROVING TOUGHNESS IN COMPOSITE MATERIALS

Composite materials have experienced a period of dramatic technological development over the past decade, and are increasingly becoming the materials of choice in weight-critical structural components due to their high specific strength and stiffness. Despite these attributes, composites generally suffer from poor impact resistance, poor fracture toughness and poor delamination strength, particularly when brittle thermosetting resins are used. Currently, these problems are addressed by adding thermoplastic toughening particles to the bulk resin or by inserting tough polymer films or microfibre interleaving veils into the interlayers between the plies of the laminate. However, these toughening methods are not without their drawbacks.

Toughening particles added to resins often suffer from poor dispersion, and can form regions of high and low particle concentrations which can lead to reductions in composite performance. In addition to this, toughening particles are also free to flow with the resin during the curing process resulting in further uneven particle distributions. Toughening particles are also known to increase resin viscosity, making them particularly unsuitable for laminates fabricated using out of autoclave processing methods [1], and can increase laminate thickness, decrease in-plane stiffness and strength and potentially lower the glass transition temperature (Tg) of composite laminates [2].

Composite toughening techniques using a polymer film in the interlayer region can result in poor resin flow, porosity and poor adhesion between the resin and the film, and this method is not generally suitable for use in conjunction with liquid moulding techniques. In addition to this, prepreg materials that incorporate interleaving films tend to be stiff, tack-free and are difficult to use.

Microfibre interleaving veils used in laminates can improve impact resistance but often have detrimental effects on other composite mechanical and physical properties. Furthermore, the addition of bulky microfibreveils can result in undesirable increases in weight and thickness of the laminate.

2. A NEW SOLUTION TO AN AGE-OLD PROBLEM

Revolution Fibres, an AS9100c certified advanced materials manufacturing company based in New Zealand, has developed an electrospun polyamide (PA66) nanofibre interleaving veil that addresses some of the problems associated with traditional composite toughening systems. This product, marketed as Xantu.Layr**®**, is a non-woven web consisting of kilometre long nanofibres (Figure 1), and is currently the only commercially available nanofibre veil on the market for use in composite materials. Xantu.Layr**®** has been shown to improve the interlaminar fracture toughness (ILFT), compression after impact strength (CAI) and fatigue resistance of composite laminates.

Xantu.Layr**®** nanofibre veils have the advantage of being highly porous and thus do not impede the flow of resin during cure. They have very high specific surface areas to promote good bonding with the matrix resin and are thin and lightweight meaning they do not significantly affect laminate thickness and weight. The nanofibres do not move once inside a laminate, and do not increase the viscosity of the matrix resin. Nanofibre veils can also be easily cut to size and placed in critical areas of a laminate that require localized toughening.

And unlike some of the other commonly used toughening systems, the physical and mechanical properties of the composite such as glass transition temperature (T_g), interlaminar shear strength, flexural strength and modulus, and tensile strength and modulus are not negatively affected by the inclusion of Xantu.Layr®.

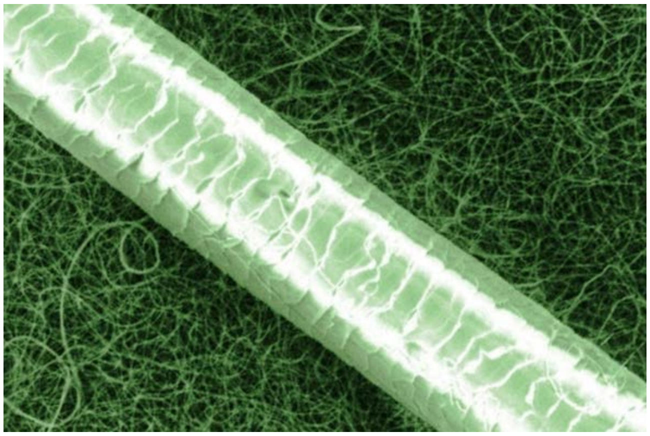

Figure 1: Scanning electron micrograph of Xantu.Layr® nanofibres in relation to a human hair.

2.1 Mode I Interlaminar Fracture Toughness

Fracture toughness is a property which describes the ability of a material containing a crack to resist fracture, and is used as a measure of delamination resistance in composites. One common mode of delamination failure, referred to as Mode I, involves a crack opening up as a result of a tensile stress normal to the plane of the crack. In this evaluation, the Mode I crack energy release rates (crack onset) were obtained for 12 ply unidirectional laminates made from MTM57/T700S (24K)-300-35%RW using the Double Cantilever Beam test and the Modified Beam Theory in ASTM D 5528.

The effect of nanofibre veil areal weight on the Mode I ILFT of composites interleaved with various Xantu.Layr® veils can be seen in Figure 2.

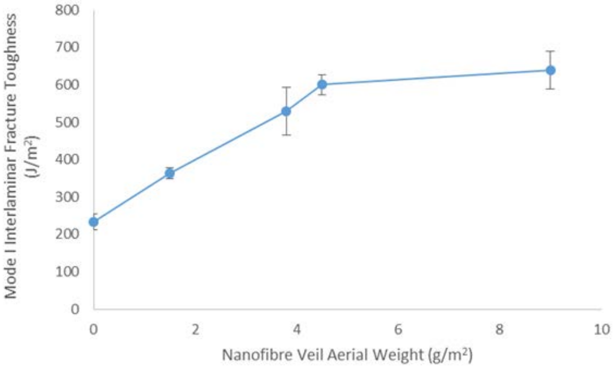

Figure 2: Mode I interlaminar fracture toughness (onset) for composites interleaved with different Xantu.Layr® veils. Error bars represent ±1 standard deviation.

It can be seen that the nanofibre veils had a dramatic effect on increasing the Mode I ILFT, with 4.5g/m^2 veils showing an improvement of 156% over the control. PA66 has a high elongation to break in relation to epoxy resin (30% and 4%, respectively) and it is thought that the plastic deformation of the nanofibres in the interlayer region diminish the crack energy and thus increase the Mode I ILFT [3]. In other words, the nanofibre veils reduce the brittleness and increase the crack energy absorbing characteristics of the epoxy resin in-between the reinforcing layers of the composite.

2.2 Mode II Interlaminar Fracture Toughness

A second mode of delamination failure, referred to as Mode II, is characterised by a crack sliding through the laminate as a result of a shear stress acting parallel to the plane of the crack and perpendicular to the crack front. In this evaluation, the Mode II crack energy release rates (crack onset) were obtained for 12 ply unidirectional laminates made from MTM57/T700S (24K)-300-35%RW using the End Notch Flexure test and the method stated in ASTM D7905.

The Mode II ILFT of composites interleaved with various Xantu.Layr® veils can be seen in Figure 3. It can be seen that all of the nanofibre veils resulted in significant increases in fracture toughness, with the 4.5g/m^2 nanofibre veils resulting in improvements of 69% over the control.

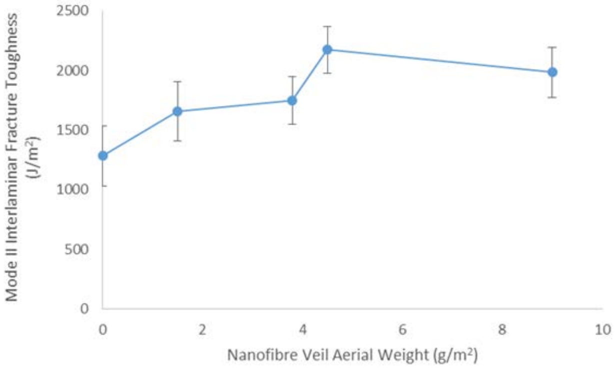

Figure 3: Mode II interlaminar fracture toughness for composites interleaved with different Xantu.Layr® veils. Error bars represent ±1 standard deviation.

According to Xia and Hutchinson [4], Mode II failure occurs as a result of combined shear and tensile micro-crack growth. While the toughening mechanisms of this type of system are still not fully understood, it is believed that the nanofibres act to bridge the micro-cracks which form in the interlayer during Mode II fracture. Such bridging absorbs crack energy, and it is thought that as long as the nanofibres are well bonded to the matrix resin, a nanofibre veil with a relatively high tensile strength will provide resin reinforcement and will better resist the opening of these micro-cracks, resulting in a higher Mode II ILFT.

2.3 Compression After Impact Strength

CAI has become a key experiment to gather damage performance data for the design or certification of composite materials. Damage tolerance in laminates is usually evaluated by determining the effect of different impact energies on their residual strengths. In this investigation, CAI tests were performed on 16 ply QI laminates made from SE70/VRC/200/400/35+/-3% UD prepreg interleaved with Xantu.Layr® nanofibre veils in accordance with ASTM D7136/D7136M and ASTM D7137/D7137M.

As can be seen in Figure 4, the compression after impact strength of laminates interleaved with Xantu.Layr® was greatly increased over a range of impact energies. It can also be seen that a nanofibre interleaved laminate impacted at 30J exhibited a similar CAI strength to a non-interleaved laminate impacted at 10J, representing a significant increase in damage tolerance.

This increase in CAI strength is due to the toughening effect of the nanofibre veils in the composite interlayers, resulting in reduced delamination of the laminates after being impact damaged. The interleaving nanofibres deflect cracks in the matrix and absorb crack energy during the impact and compression test, thus increasing the amount of energy required for crack growth. Other toughening mechanisms such as fibre bridging, debonding and pull out could also have increased the energy required for crack propagation and reduced the overall degree of damage, resulting in higher CAI strengths.

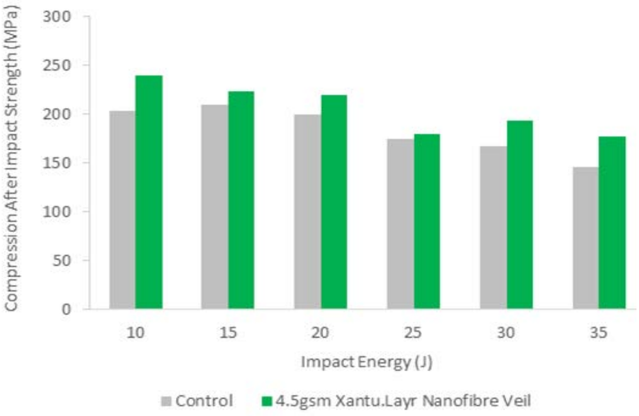

Figure 4: Compression after impact (CAI) strength for composites with and without 4.5g/m^2 Xantu.Layr® nanofibre veils.

2.4 Fatigue Life

Fatigue is the main reason for failure of structural materials in service. Repetitive cyclic loadings of composite components eventually result in extensive damage throughout the material, leading to failure from matrix cracking, delamination, fibre breakage and interfacial debonding. In this investigation, tension-tension fatigue tests were performed on 16 ply QI laminates made from SE70/VRC/200/400/35+/-3% UD prepreg interleaved with nanofibre veils in accordance with ASTM D3479/D3479M.

As can be seen in Figure 5, the fatigue life of composites can be dramatically increased by interleaving the laminates with 4.5g/m^2 Xantu.Layr® nanofibre veils. An improvement of 394% was seen for interleaved laminates tested at a cyclic stress of 450 MPa.

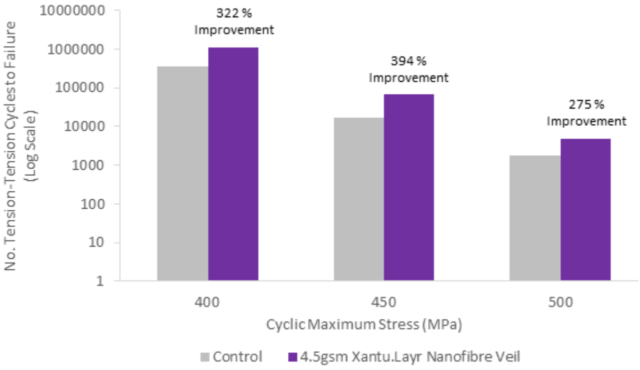

Figure 5: Fatigue life of composites with and without 4.5g/m^2 Xantu.Layr® nanofibre veils.

This observed improvement in fatigue life is most certainly due to the toughening effect of the nanofibre veils in the resin rich interlayers of the composite, as described previously in this article. Since the interleaving veils delay the onset of matrix cracking and delamination, the strength of the composite is maintained for longer before the integrity of the material is compromised.

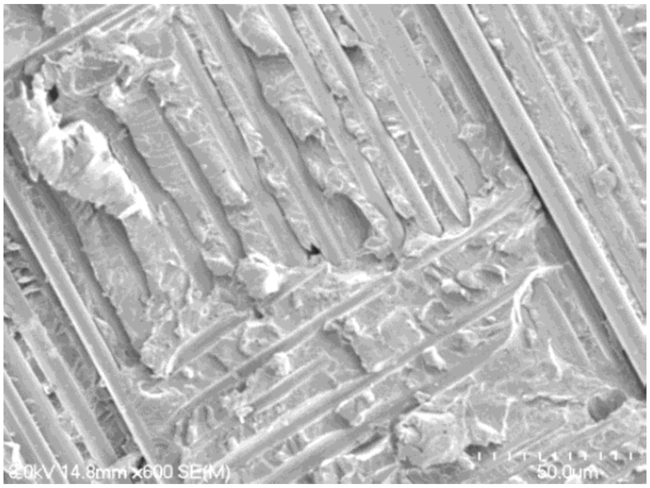

Figure 6: Fracture surface of non-interleaved fatigue test specimen after 350,000 cycles (600x magnification).

Fracture surfaces of non-interleaved and interleaved fatigue test specimens can be seen in Figures 6 and 7. The non-interleaved composite (Figure 6), displays a smooth, shiny but jagged fracture surface that is typical for brittle epoxy matrices.

The Xantu.Layr® interleaved composite (Figure 7), on the other hand, shows a dull, rough but less jagged fracture surface suggesting a more ductile failure mode. It is likely that the fatigue cracks in the interleaved resin were not able to join up to form a continuous and smooth fracture surface, but were instead re-directed in many different directions by the nanofibre veils to form a rough surface. It is also evident that some nanofibre pull-out had occurred, which would have resulted in crack energy dissipation.

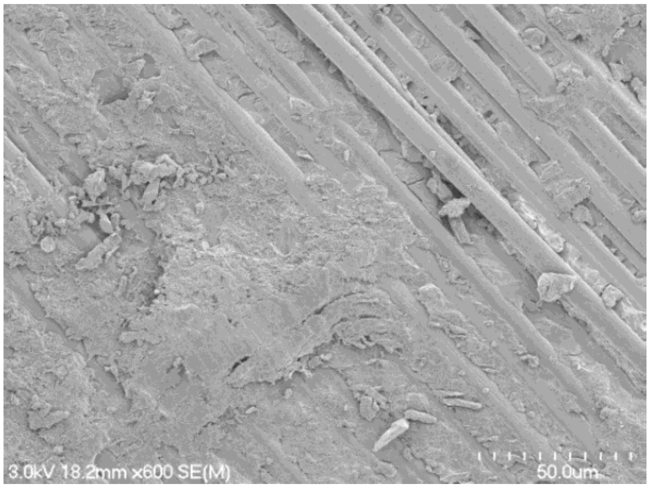

Figure 7: Fracture surface of 4.5g/m^2 Xantu.Layr® nanofibre veil interleaved fatigue test specimen after 1,124,000 cycles (600x magnification).

3. PRACTICAL APPLICATIONS

In summary, Xantu.Layr® is particularly suitable for improving the performance of composite structures that are prone to impact damage, delamination, high flexure or fatigue loadings. There are many examples of products performing better with the inclusion of Xantu.Layr®. One such example is a carbon/epoxy fishing rod manufactured by Kilwell Sports Ltd, where a 100% increase in breaking load was demonstrated with the placement of 1.5g/m^2 Xantu.Layr® veils in-between each ply.

In addition to improvements in mechanical properties, Xantu.Layr® has also been seen to greatly reduce the amount of delamination observed in composites during machining, allowing composite tubes to be finished on a lathe to get a high degree of roundness and high quality finish. Xantu.Layr® has also been seen to reduce visible micro-cracking on the surfaces of flexible composite parts.

Revolution Fibres is leading the way in terms of supplying the composites industry with nanofibre veil toughening solutions, and invites you and your materials suppliers to find out more about how your products can be improved with nanofibre. Xantu.Layr® is available in 1m wide, 100m length rolls (MOQ), but sample packs and custom widths and lengths are available on request.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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