Experimental Characterisation of Composite T-joints Under Shear Loading

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Introduction

SailGP is a one-design sailing yacht racing series. The current yacht class used, the F50, is primarily formed from Carbon Fibre-Reinforced Polymer (CFRP) and structural foam or honeycomb cored sandwich structures. To join these sandwich structures, taped joints in a 'T' formation are used. These joints are formed by bonding layers of woven CFRP over an epoxy fillet at ±45°. This bonding arrangement has been effective for SailGP's applications, but the mechanics of their failure are completely not understood. Consequently, the onset of failure of the joints is difficult to predict and therefore modifications to the joint arrangement cannot be assessed.

The joint design in the F50 differ from the previous investigations undertaken on the behaviour of T-joints in shear [1-3]. These studies provide useful insight into the distribution of strain in this joint topology, and how failure might initiate. They also made use of a similar test arrangement as that used in this investigation.

This investigation tested the constituent materials of the T-joints, developing a test method to induce shear loading in T-joint samples, and finally testing varying lengths of the current T-joint design, and an alternative using pre-impregnated CFRP tape rather than the current wet-laminated tape. The outcomes of this testing will be used to inform crashworthiness and performance-related developments to the F50.

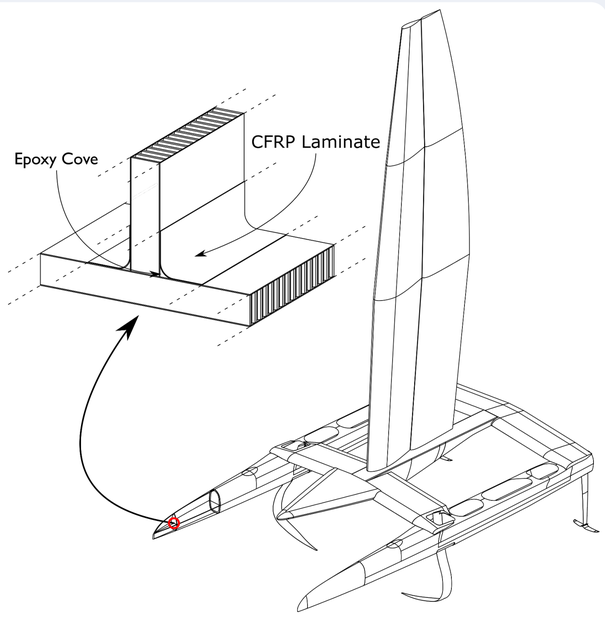


Figure 1: F50's moored at Lyttelton Harbour [4], and a diagram of the T-joints used in the F50's construction

T-Joint Specimen Design and Manufacture

A novel specimen design was developed to induce shear loading in T-joint samples. This design comprises two substrate plates bonded using two T-joints. Gripping regions at the end of each substrate allow the application of a tensile load, inducing shear loading in the joints. The joints were manufactured using the standard process used by the boat builders at SailGP Technologies, who assisted with the manufacturing of these joint specimens. The manufacturing process is as follows:

1. Substrate plates are sanded and cleaned
2. HPR 25 epoxy adhesive is piped onto the plates
3. The 18mm diameter fillet is formed in the epoxy, and then covered with peel ply
4. The two-layer laminate is applied, including 100GSM glue film for pre-impregnated laminates
5. Specimens are cured under vacuum
6. A speckle pattern for Digital Image Correlation is applied

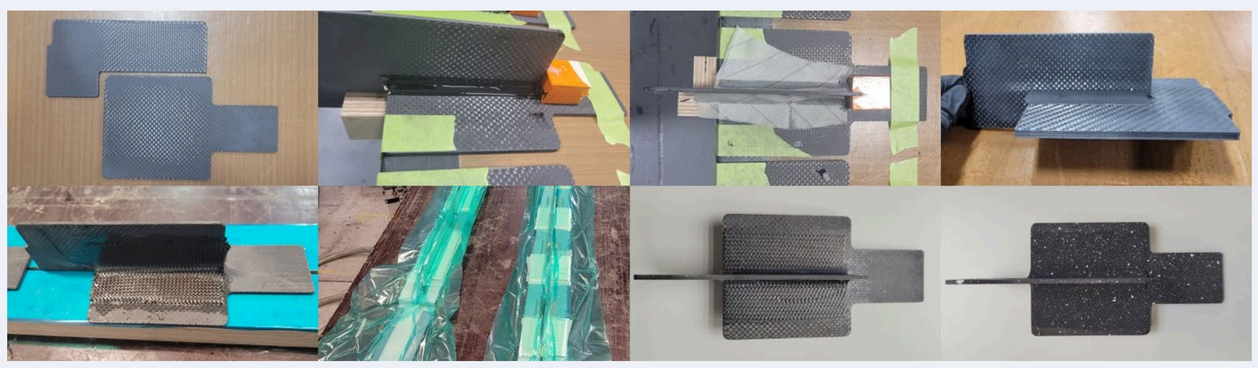


Figure 5: The process of manufacturing the T-joint specimens

Coupon Testing

Material coupon testing was performed to evaluate the strengths of the constituent materials of the joints. The CFRP tape's shear strength was evaluated using V-notch rail shear testing with modified geometry to mitigate grip slippage, and the adhesive bond between the tape and the substrate was evaluated using double-lap shear testing.

Wet-laminated CFRP shear strength: **246 MPa**

- Brooming compressive fibre failure as expected

Double-lap shear strength: **13.07** and **12.47 MPa** for **0/90°** and **0/90/±45°** wet-laminated specimens, respectively compared with **22.05 MPa** for pre-impregnated specimens adhered with 100GSM glue film

- Failure surface bonding surface of wet-laminated specimens indicated presence of voids
- Pre-impregnated failure surface exhibited substrate failure, indicating the laminate rather than adhesive is limiting factor

These results enable the prediction of the strength of a T-joint of **183.34 N/mm** based on overlaminate strength and **784 N/mm** based on adhesive strength for a wet-laminated joint.

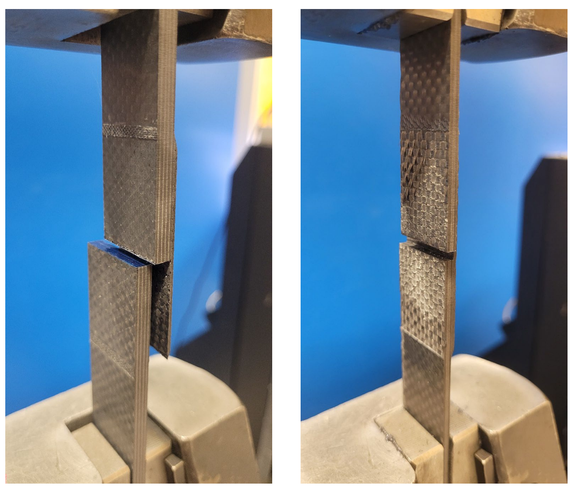


Figure 2: The failure surfaces of a wet-laminated (left) and a pre-impregnated (right) double lap shear specimen. Note rougher surface and fibre pullout for pre-impregnated specimen

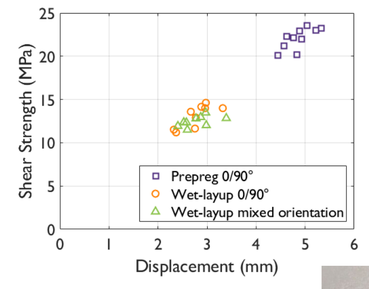


Figure 3: The results of the double-lap shear testing, showing the significantly stronger adhesion of the pre-impregnated specimens

Figure 4: A V-notch shear specimen after testing. Note brooming failure originating from root of V, and extended gripping region

T-Joint Test Results

Wet-laminated joints ranging from 50mm to 400mm in length were tested. 100mm pre-impregnated joints were also tested. Joint failure was the main phenomenon of interest throughout this testing. Initial findings:

- Joint failure mode depended on length. For specimens 70mm and shorter, failure occurred in a single stage as the CFRP tape failed in shear. Above this length, tape debonding preceded tape failure.
- An edge effect was present. This manifested as tape debonding initiating at the edges of the joint.
- Tape failure manifested as a crack oriented with the fibres, consistent with the failures during coupon testing.

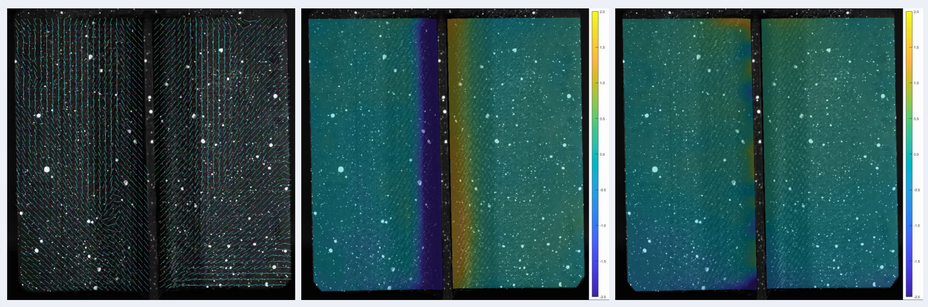


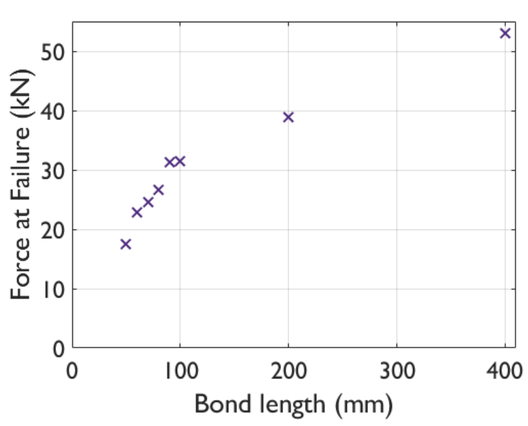
Figure 6: T-joint DIC results for a single (left), XY strain (centre), and YY strain (right).

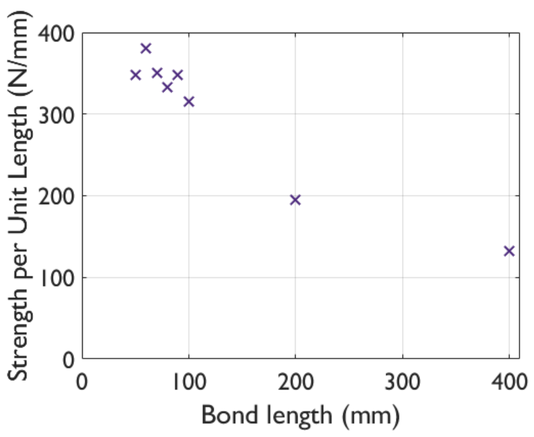
Note shear strain present in the joint shown in the strain vector and XY strain plots, and the strain concentrations present at the ends of the joint shown in the YY strain plot.

Figure 7: A tested T-joint specimen. Note debonding of tape from substrate at the edges of the joint, and the crack travelling along the loading direction throughout the laminate

Discussion and Conclusion

- Key takeaway: the presence of a length effect. This limits strength per length, as stress concentrations in the bond line [5] initiate tape debonding in longer specimens, reducing the area of laminate to carry the load until laminate failure occurs. Not all T-joints in the F50 have ends, and it remains to be seen if this length effect is present for continuous loops of T-joint.
- Unlike the double-lap coupon tests, the T-joint tests showed similar performance between the pre-impregnated and wet-laminated tests. It is thought that the bonding of the wet-laminated double lap shear specimens had defects not present in the wet-laminated T-joints, causing their low adhesive strength. The lack of defects in the T-joint specimens leads to the more favourable comparison between wet-laminating and pre-impregnation for these specimens.
- Analytical predictions of T-joint strength performed using coupon test strength results did not predict joint failure behaviour. Further work is necessary to incorporate the bond line edge effects into analytical methods.





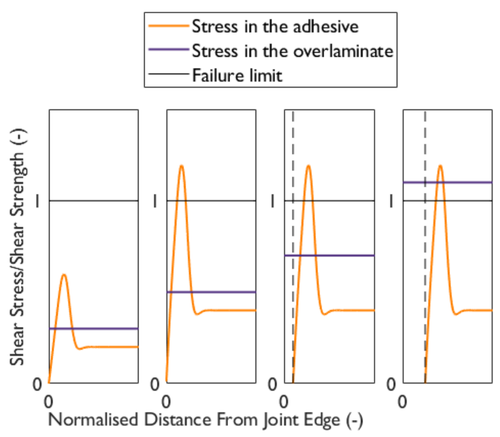


Figure 8: The failure loads and strengths per unit length of the T-joint specimens (left and centre, respectively), and a diagram proposing how failure transitions from adhesive debonding to laminate fracture as the effective length of bond is reduced (right)

Acknowledgements and References

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