EVALUATION OF THE EFFECTS OF TUFTING ON PERFORMANCE OF COMPOSITE T-JOINTS

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1. Abstract

Carbon fibre T-stiffened skin-stringer joints were manufactured with through-thickness carbon fibre reinforcement using a one-sided stitching technique, known as tufting. Untufted control specimens and joints tufted with two different reinforcement configurations were tested in four-point bending to identify the delamination trigger mechanisms. The control specimen showed that delamination initiates at two transitions within the joint: where the stringer flange meets the skin and where the flange transitions into the web. Continued loading of the untufted joint resulted in stringer separation from the skin. Tufting successfully suppressed the initiation of failure at the flange to skin transition. Delamination between the skin and flange occurred, but separation of these elements was delayed, increasing the stiffness and damage tolerance of the joint. The failure mode changed from skin-stringer peeling to web-splitting.

2. Introduction

Delamination remains a frequent failure mode in composite structures and through-the-thickness reinforcement (TTR) is becoming an accepted technique to overcome this problem. The industry requires components which perform in a way that satisfies the design requirements, whilst also being able to tolerate damage, and remain able to sustain loading once initial propagation of cracks has begun. In the case of resin infusion manufacturing processes, the dry preform can be reinforced through-the-thickness by dry thread tufts, with the intention of limiting crack propagation in a loaded structure. The tufting is carried out as an automated process, with a specialised robotic head being used to insert the thread from one side of the preform. The tufts resulting are held in place by friction (1).

Crack initiation and propagation are of particular concern in joints, where out-of-plane loading increases the likelihood of delamination failure between elements. Adding a discrete amount of through-thickness reinforcement to physically link adjacent fibre layers subjected directly to out-of-plane loads has been identified as a potential solution to overcome delamination propagation in structures made by both prepreg and liquid composite moulding routes (2). Stitching has been shown to have some detrimental effect on the in-plane properties of composites structures (3), although there is some disagreement in the literature as to the full extent of such reduction. The tensile and compressive moduli are reduced because the highly aligned in-plane fibre network is disturbed by the penetrating needle and the final crimp due to the inserted fibre. Using a local through-thickness reinforcement approach allows designers to add reinforcement discretely to areas most susceptible to delamination, while minimising the knockdown of in-plane properties (4).

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The objective of this study is to assess the modes by which the stiffened section fails, while attempting to increase the load carrying ability of the joint by supressing or arresting the low work failure modes.

3. Materials and Manufacturing Method

The preforms were manufactured using a bi-axial (±45°) non-crimped fabric (NCF), comprising of IM7 carbon tows, with an areal weight of 400gsm. The plies were cut from the NCF using an automated ply cutter. The plies cut for the web and flange were laid up first over convex foam tooling, which had been machined with the profile of the skin-stringer from Airex R63.80 foam. The plies were draped layer by layer with orientations of [45, 90, 45, -45, 0]s, and were secured in place using spray adhesive. On top of the web and flange plies, the flat NCF skin was laid up with orientations of [45, 90, 45, 0, 90, 45, -45, 0, -45]s, and secured with spray adhesive.

TTR was applied in the form of tufts, using a RS522 tufting head from KSL - shown in Figure 1 - attached to a Kuka industrial robot, inserting a thread of commercial grade, industrially proven 4 × 1K HTA 40 carbon fibre reinforcement thread from Schappe Techniques. The tufts were inserted from the skin side of the preform, with the loops terminating in the foam backing. The presser foot is intended to assist in the retention of the tufts, and in this case a modified presser foot was fitted to allow the angled insertions across the noodle region to be performed.

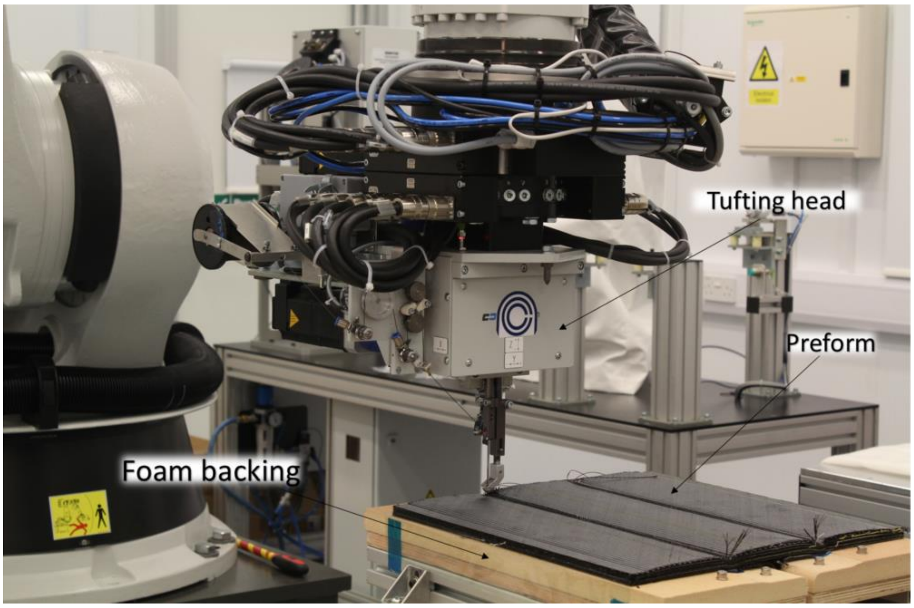

Figure 1 - Tufting carbon skin-stringer panel with carbon thread

Two tufting pattern were chosen to minimise damage onset in the noodle region and flange transition: These are illustrated in figure 2 (b) & (c). Such patterns were selected to investigate the effect of tufting across the noodle region. An unreinforced control specimen was manufactured for reference, as shown in Figure 2 (a).

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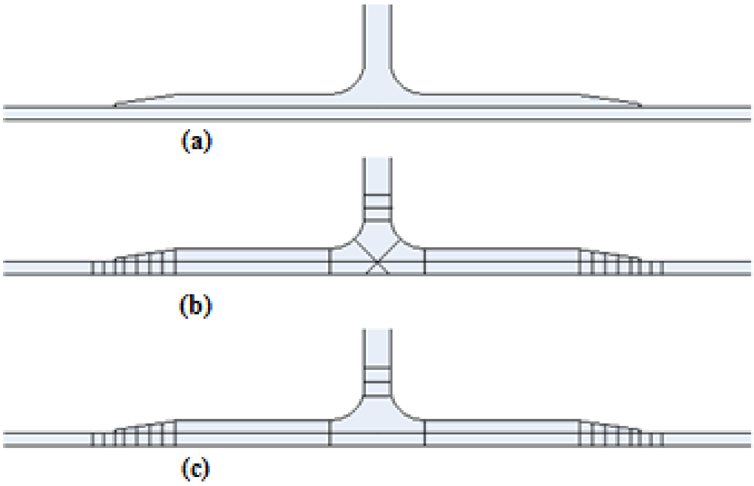

Figure 2 - Specimen tufting configurations (a) untufted control (b) flange transition, web, noodle & radius termination, (c) flange transition, web & radius termination

The preforms were loaded into a rigid tool and infused using atmospheric pressure injection, with RIMR 935/936 Epoxy resin from Momentive. During the infusion, the tooling and preform were heated in an oven to 40°C; this temperature was maintained until the infusion completed. The composite was then cured at 80°C for one hour. The composite panel was cut into coupons 30mm wide, 300mm long for mechanical testing using an automated slitting saw, equipped with a diamond blade.

4. Results

Mechanical tests were performed on each of the specimen configurations shown in Figure 2. Four-point bending tests were used to characterise the expected improvement when selective through-thickness reinforcement was applied, and skin tensile tests were performed to investigate the knockdown to the in-plane properties. The results of these tests are presented below.

4.1 Four-Point Bending Test Results

The cross head displacement rate was 2mm/min, and the load / extension results are plotted in Figure 3. It can be seen that the tufts improve the damage tolerance of the T-joint, but have little influence on the first load drop.

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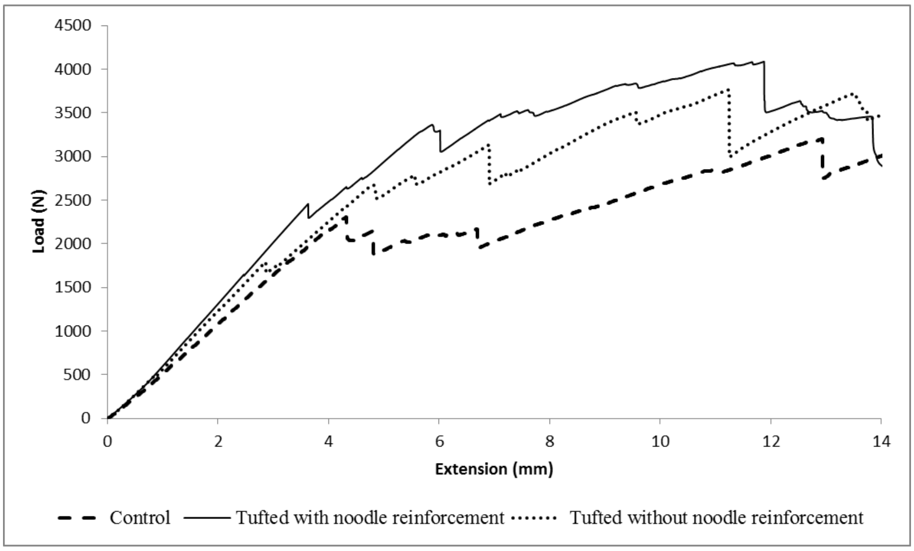

Figure 3 - Typical load-displacement plots for the skin-stringer bending tests

Images of the control specimen captured during testing are shown in Figure 4, the failure intiated in the noodle region, and subsequently propagated towards the stiffener transitions. The failures propagated until full separation of the stiffener/skin occurred.

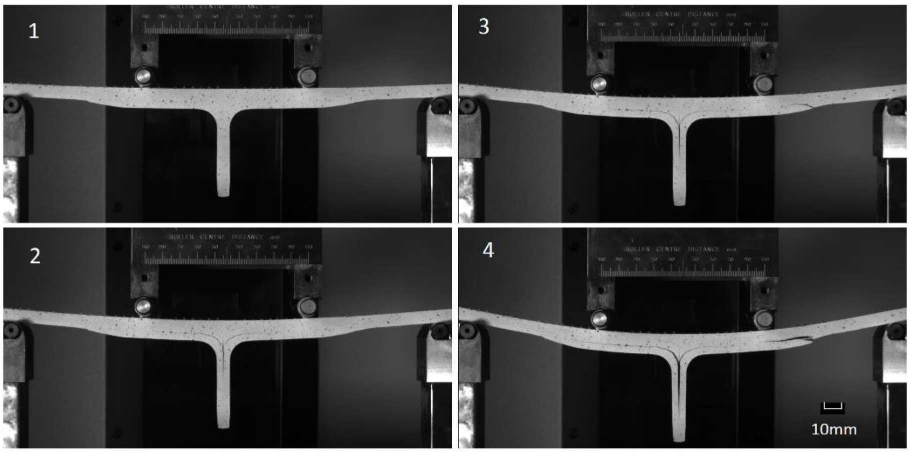

Figure 4 - Initiation & progression of failure in the control specimen under four-point bending configuration

In the through-thickness reinforced specimen shown in Figure 5, tufted with noodle reinforcement, configuration (b), the failure still initiated in the noodle region. However, the progression of the failure mechanism did not involve stiffener / skin separation, but rupture of the tufts at the radius termination in the noodle with crack propagation in the web.

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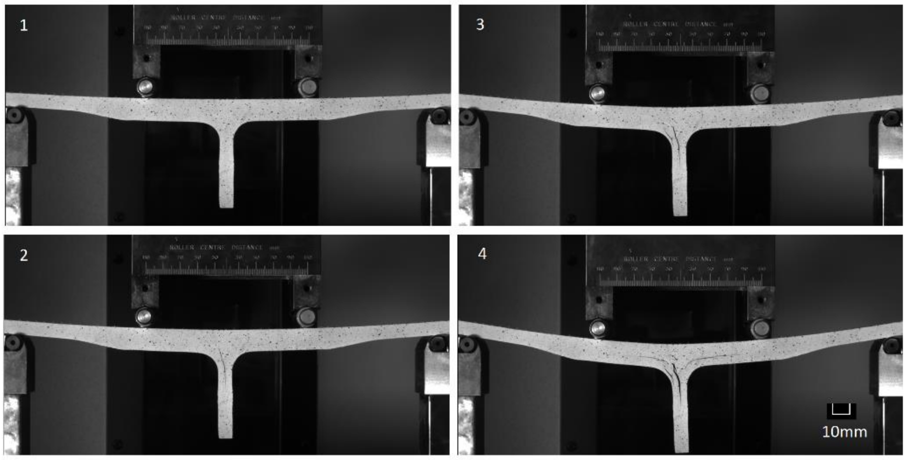

Figure 5 - Initiation and progression of failure in the tufted variant with noodle reinforcement (b) in 4-point bend test

4.2 Skin Tension Test Results

Specimens from each of the configurations shown in Figure 2 were tested in tension, gripped onto the skin outside of the stiffener transitions. The load / extension plots from the tensile tests are shown in Figure 6. The results show that the untufted control specimen withstands higher loads by 19% compared with tufted variant b and up to 24% over the tufted specimens compared with tufted variant c.

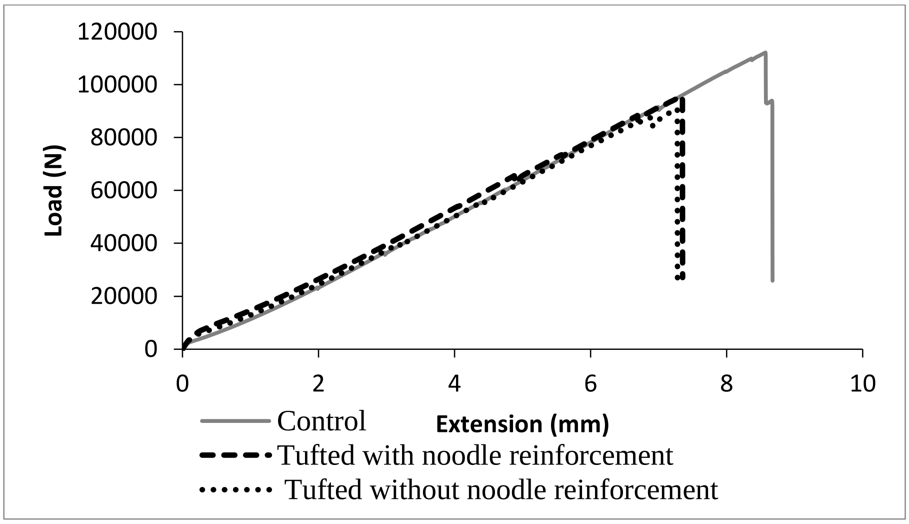

Figure 6 - Skin tension test results with control, and tufted variants

The first load drops for the control specimen shown in Figure 6 relates to failure initiation in the transition regions. The cracks propagated until the stiffener delaminated fully from the skin, and the ultimate failure of the specimen occurred in the skin. The initiation of failure in the through-thickness reinforced variants occurs in the noodle region, propagating to the web tufts, and latterly outward towards the skin/stiffener tranisiton. The ultimate failure of the specimen occurred in the skin, by rupture between the tufts around the noodle region.

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5. Discussion

Inserting the tufts improved the damage tolerance of the stiffener / skin assembly as shown by the higher load levels required to propagate damage in the tufted specimens when tested in four-point bend configuration. Tests perfomed on control specimens, suggest that the failure propagates once delamination initiation occurs, and proceeds unarrested, as the load required to propagate the existing delamination is lower than that of the initiation. In the tufted specimens an increasing load is required to propagate the initiated delamination, as fibres in the through-thickness direction are carrying load.

The area under the load / extension curve shown in Figure 3, gives a measure of the work done during failure. A trapezoidal approximation calculated that the work done during failure was increased by 39% and 24% by inserting tufts, with and without noodle reinforcement respectively.

Failure propagation into the web was arrested by the tufts in the through-thickness reinforced specimens, instead propagating towards the transitions before arresting at the transition tufts, suggesting that additional through-thickness reinforcement may be required in the near noodle region to arrest the failure at this location.

In both of the through-thickness reinforced configurations, an in-plane knockdown of the skin tensile properties was observed. The peak load in tensile skin tests was reduced by 24% for configuration (b), and by 19% in configuration (c). Such reduction has been linked to the increased in in-plane fibre waviness around the tufts. More investigation is required to confirm and quantify such effects.

6. Conclusions

The out-of-plane properties of composite components can be improved using tufting as a method of through-thickness reinforcement. The delaminations in the skin/stiffener transition region can be suppressed by the addition of tufts. This can improve damage tolerance, and the work required to propagate an existing delamination can be increased. The failure path changes as the low work mechanisms are suppressed using through-thickness reinforcement, and effects of this change on the design, efficiency and load-bearing capabilities of the component must be considered properly.

7. References

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