Metal-CFRP T-Joint with 3D printed auxetic metal stiffener

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Motivation and objectives

Modern lightweight thin-walled structures are currently built by deploying a network of stiffeners with different geometry and materials (metal, metal composites, polymer composites,…) to support the lightweight skin, which is typically made of polymer composite. A typical example is represented by T-joints, which is used in several applications, such as wind turbine blades, automotive, and airframes [1-3].

This work presents a new design of hybrid steel/CFRP adhesive bonded joints by creating auxetic structures in the stiffener that allow the redistribution of the stresses inside the adhesive layer and at the stiffener and hence delay the damage initiation and propagation.

Experimental set up and numerical model

- The skin material is T700/M21 CFRP.
- The stiffener material is stainlessteel.
- Skin and stiffener was bonded using Araldite 420 adhesive with 0.4 mm thickness.
- Pull-off test was performed using Instron 5885 by pulling the stiffener and fixing the skin using simply supported boundary conditions ad shown in Figure 1.
- High fidelity FE model was developed as shown in Figure 2 to simulate the different damage modes and extract the strengthening and toughening mechanisms.
- Re-entrant auxetic structure stiffeners with different size was evaluated in this study

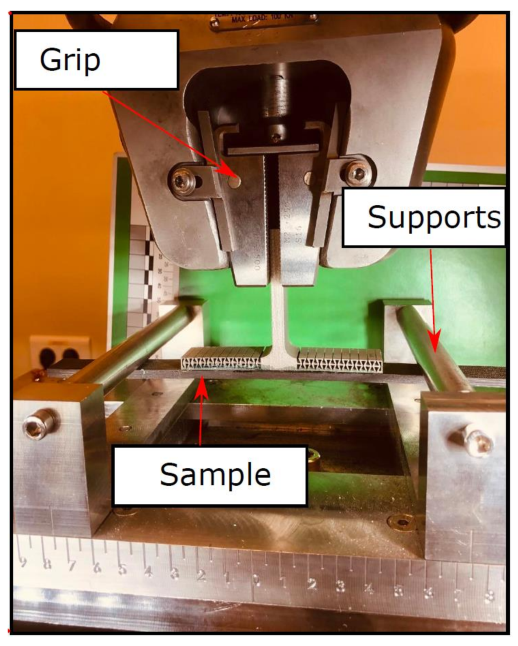

Figure 1. Experimental set up of pull-off test.

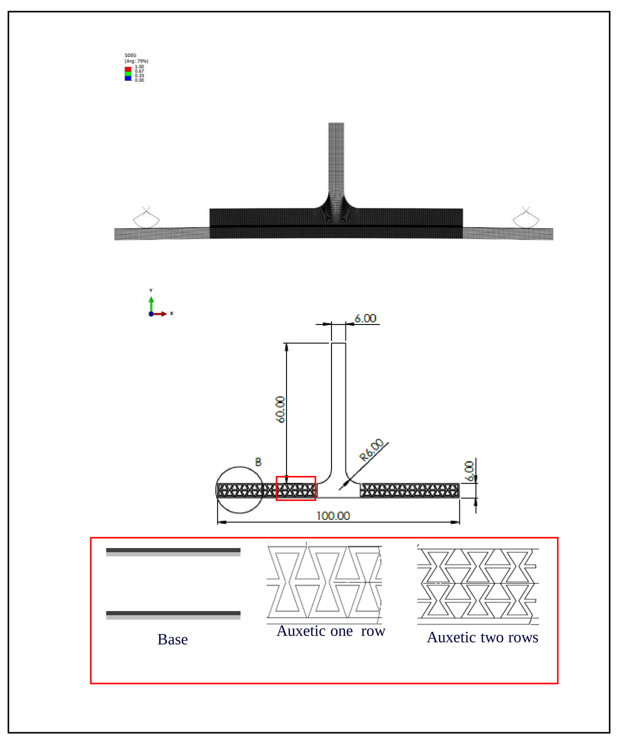

Figure 2. FE model and auxetic structure design.

Results and discussion

Figure 3 shows load-displacement curves obtained experimentally and numerically for T-joint with the one row auxetic stiffener, which shows good comparison between the FE model predictions and the experimental results. The figure also reflect the good repeatability of the experimental test campaign.

Figure 4 shows a comparison of the load-displacement responses for the T-joint with two auxetic stiffeners, one and two rows, and the baseline joint. Significant improvement of the maximum pull-off load/strength was achieved reaching more 200% for the one raw auxetic stiffener. Moreover, high toughness improvement was observed for the T-joint with auxetic stiffeners compared to the baseline joint.

The progressive damage evolution in the baseline and auxetic stiffener T-joints showed different damage initiation and propagation criteria. For the baseline joint, the damage initiates as delamination at the CFRP/adhesive interface at the edge of the stiffener, then the delamination propagates at the same interface as shown in Figure 5(a) and 6(a).
For the T-joint with auxetic stiffener, the damage initiated as delamination at at the stiffener/adhesive interface under the first re-entrant structure in the stiffener, then another delamination propagate at the CFRP/adhesive interface at end of the stiffener as shown in Figure 5(b) and 6(b).

The presence of the auxetic structures in the stiffener redistribute the stresses at the steel/adhesive interface and localizing the stresses under the first re-entrant structure due to plastic deformation and hence initiation of delamination. The plastic deformation of the stiffener at this location absorb high part of the applied energy, which leads to delayed damage initiation at the interface. Increasing the applied displacement, a new delamination initiates at the CFRP/adhesive interface at the edge of the stiffener. At this stage, the energy dissipation due to the delamination growth at the stiffener end and under the first re-entrant structure is larger than growth of single edge delamination in the baseline joint. This caused the large toughness improvement for the joints with auxetic stiffeners compared to the baseline joint as shown in Figure 7.

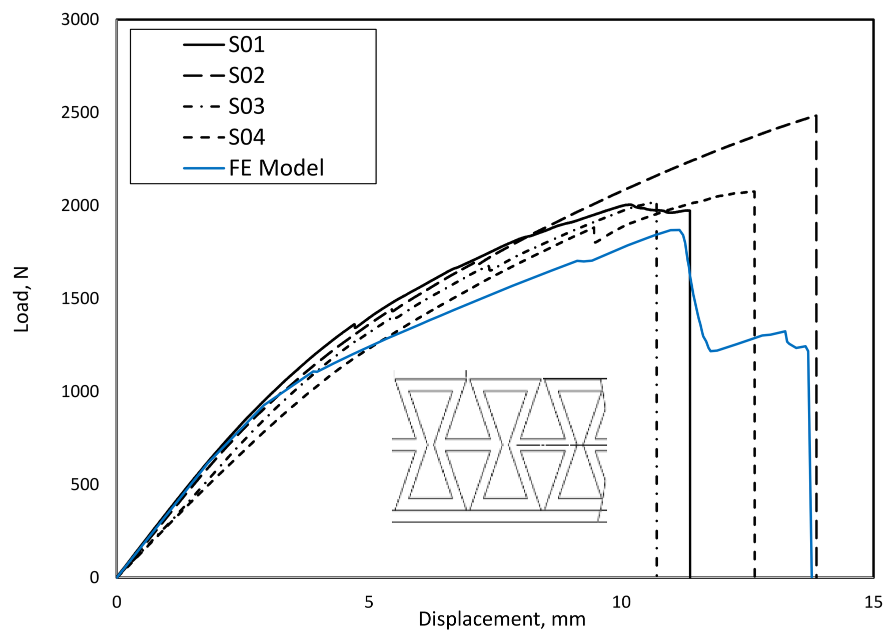

Figure 3. Validation of FE model for one row auxetic stiffener T-joint.

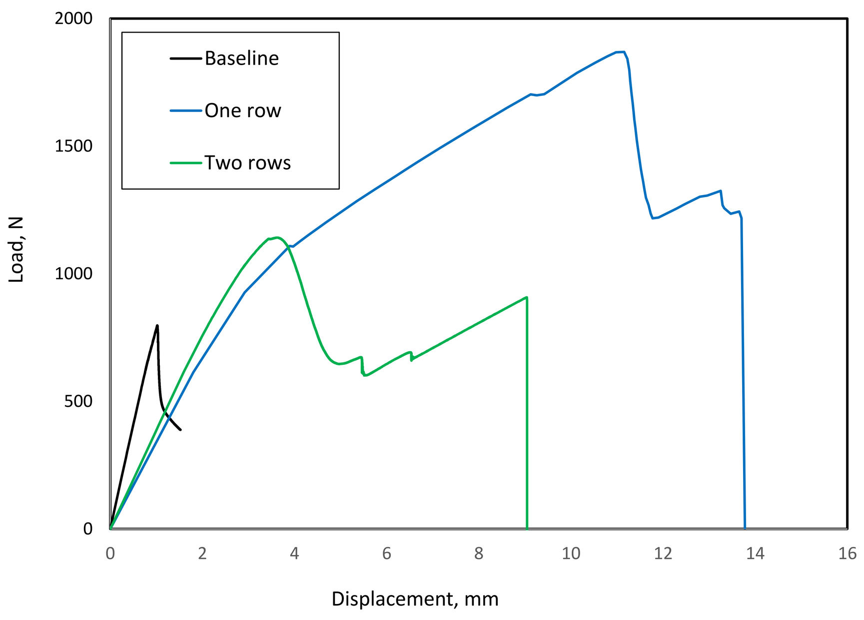

Figure 4. FE model prediction for the pull-off load of T-joint with auxetic stiffener.

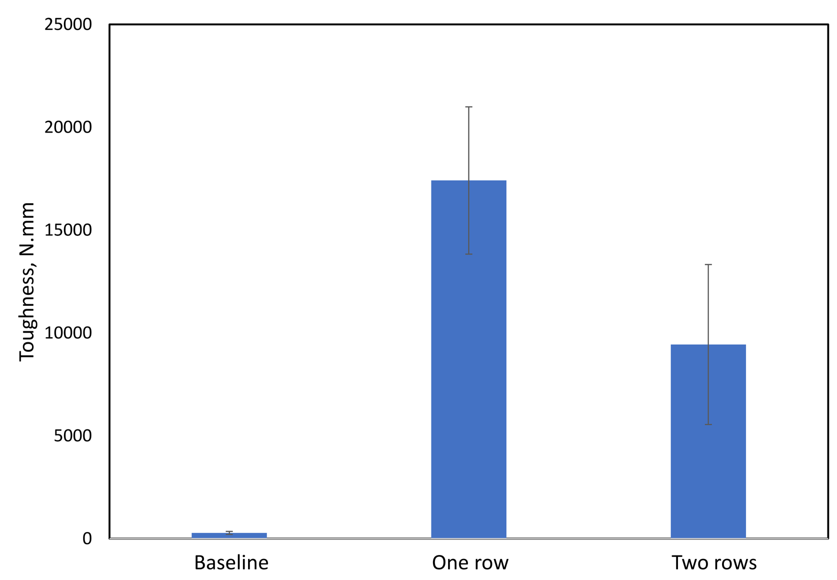

Figure 7. Toughness of the auxetic stiffener T-joints.

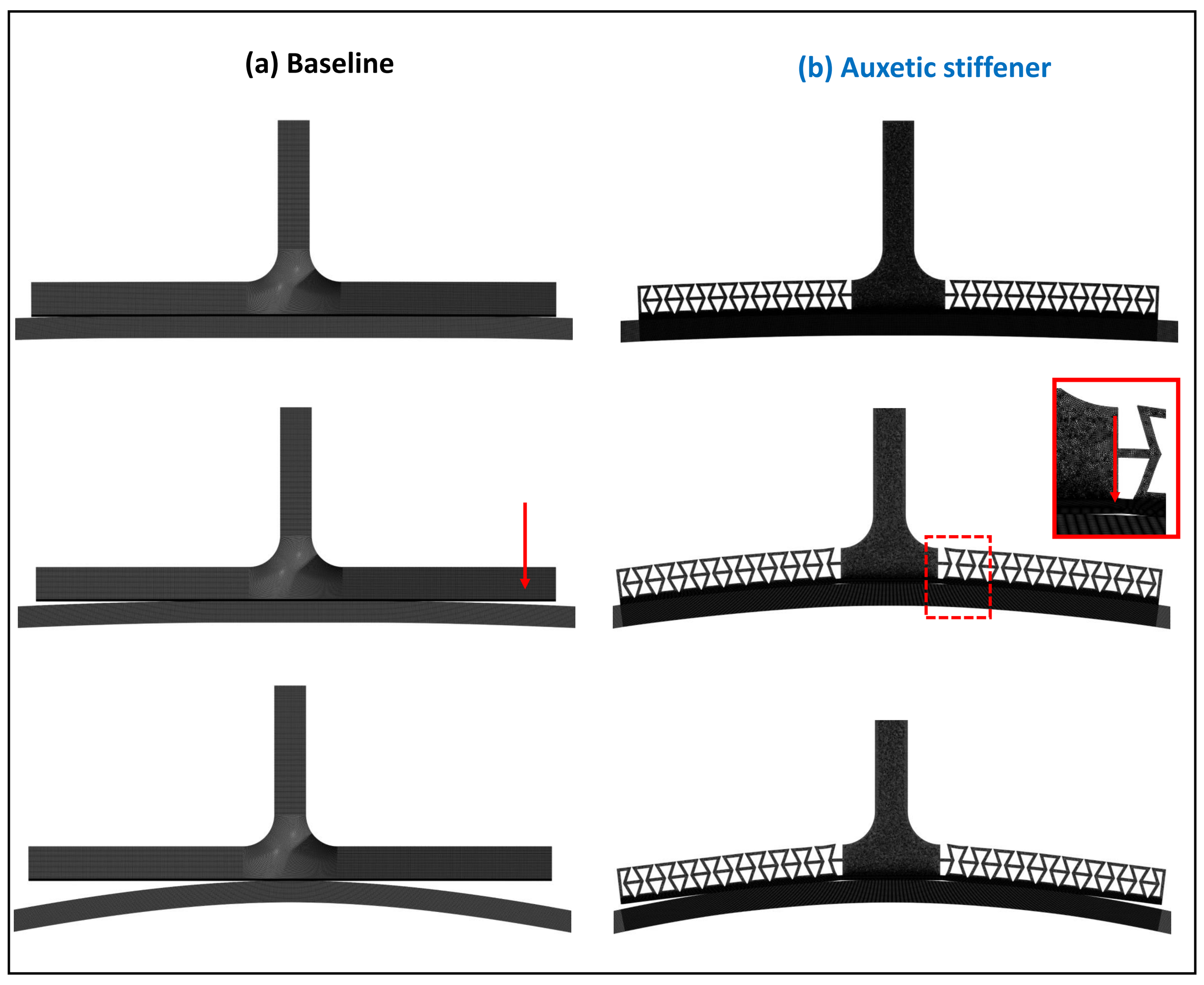

Figure 5. Progressive damage in a baseline metal-CFRP T-joint and T-joint with auxetic stiffener.

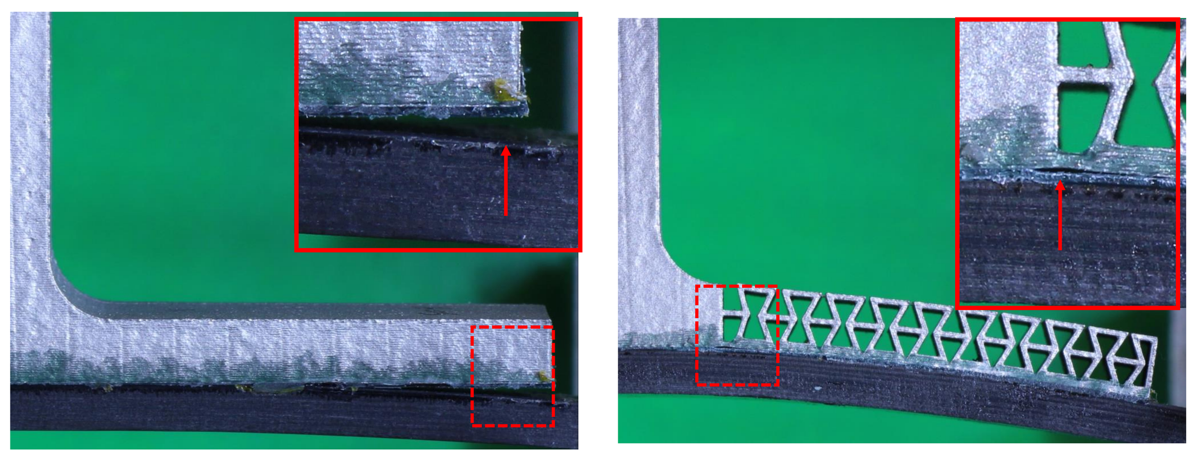

Figure 6. Experimental damage initiation in (a) baseline T-joint, and (b) T-joint with auxetic stiffener.

Conclusions

- We developed a new auxetic stiffener metal-CFRP T-joint with enhanced strength and toughness and reduced weight.
- The strength and toughness improvement reached 2 and 80 times larger than the conventional joints, respectively.
- The developed joint showed a progressive damage mode, which is different from the conventional joint, where delamination initiates at the adhesive/CFRP interface at the stiffener edge in the conventional joint. However, for the auxetic stiffener joint, the delamination initiates under the first auxetic structure in at the steel/adhesive interface due to the large plastic deformation at the stiffener.

References

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