EFFECT OF STITCHING PARAMETER ON MODE II DELAMINATION PROPERTIES OF VECTRAN STITCHED COMPOSITES

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Abstract

Effects of stitching parameter, which are stitch density and stitched thread thickness, were investigated. Tabbed end notch flexure (TENF) test were applied to keep off composite laminates failure before crack propagated. Testing results revealed that moderately stitched laminates has negligible influence on energy release rate (G_{II}), meanwhile densely stitched laminates improved G_{II} significantly. Furthermore, stitched thread thickness did not play notable role on moderately stitched specimens, however it exhibit significant effect in densely stitched specimen.

1. Introduction

Stitching has proven to be an effective interlaminar reinforcement technique to resolve delamination susceptibility in composite materials [1]. Stitching process increased mode I and mode II delamination toughness by 9 times [2] and twice [3], respectively. Furthermore stitching also suppressed delamination growth in low velocity impact [4].

Among many stitch fibers, Vectran possessed the best chemical and mechanical properties, with high moisture and abrasion resistance in addition to the excellent strength, rigidity and stable performance over wide ranges temperature and chemical environments [5].

This worked is addressed to investigate in detail the effect of stitch density and stitch thread thickness on mode II delamination properties of stitched composites where multidirectional laminates are stitched using Vectran thread.

2. Experimental procedures

2.1 Material preparation

Test specimens are cut from quasi isotropic $[+45/0/-45/90]3_S$ CFRP laminates with total 24 plies, manufactured by Toyota Industries Co. Ltd. The laminates consist of T800SC-24K carbon fiber from Toray Industries and Resin XNR/H6813 from Nagase Chemtex to consolidate the composite using vacuum assisted resin transfer molding (VaRTM). Kapton film was inserted to facilitate crack initiation as shown in Fig.1. Vectran thread (Nagai Nenshi Co. Ltd) was used as stitch thread with diameter 200 and 500denier. In order to study effect of stitch density, two different combination of stitch space and stitch pitch were fabricated, which were 6x6 mm and 3x3 mm. This two different stitch density are namely moderately and densely stitched specimen.

In order to avoid laminates failure prior to crack propagation, Aluminum 7075-T6 plate were used as tab material. Al-7075 T6 plates of 1mm thickness were embedded on the top and bottom surface of specimen using high strength epoxy adhesive Hysol EA 9309.3NA from Henkel Co. Ltd. This adhesive has glass beads (diameter 0.13mm) for bond-line thickness control.

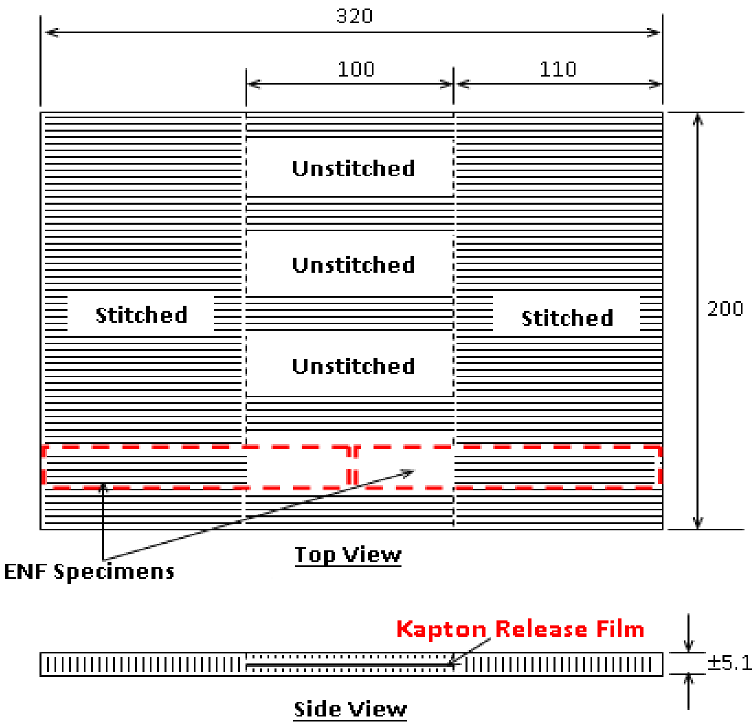

Figure 1. Stitched laminate

2.2 Testing Procedure

Initial crack was created by sharp razor blade at the Kapton film position, continued to propagate the crack using three point bending test until the crack tip passed the first stitched row, but not the second stitched row. This process was feasible to obtain since the crack initiation was propagated at unstitched region where the crack propagate suddenly to center of loading bar during three point bending test.

Tabbed end notch flexure (TENF) test were conducted using Instron Machine 4505-series with 10kN load cell. The total span was 100 mm as shown in Fig.2. The specimens were loaded with constant cross head speed of 0.5mm/min until 1kN then 0.1mm/min till crack propagated, then unloading. New crack lengths positions were measured using travelling microscope with 0.01mm accuracy. Four specimens are tested for each stitched and unstitched laminates. Each specimen was tested with the crack length of 25mm and 45mm. It is important to be noted that at the crack length of 25mm, only one stitch row in the crack region. Meanwhile at the crack length of 45 mm, there were full stitch thread at the crack region with 8 and 15 stitch rows for the case of stitched specimen 6x6 mm and 3x3 mm, respectively.

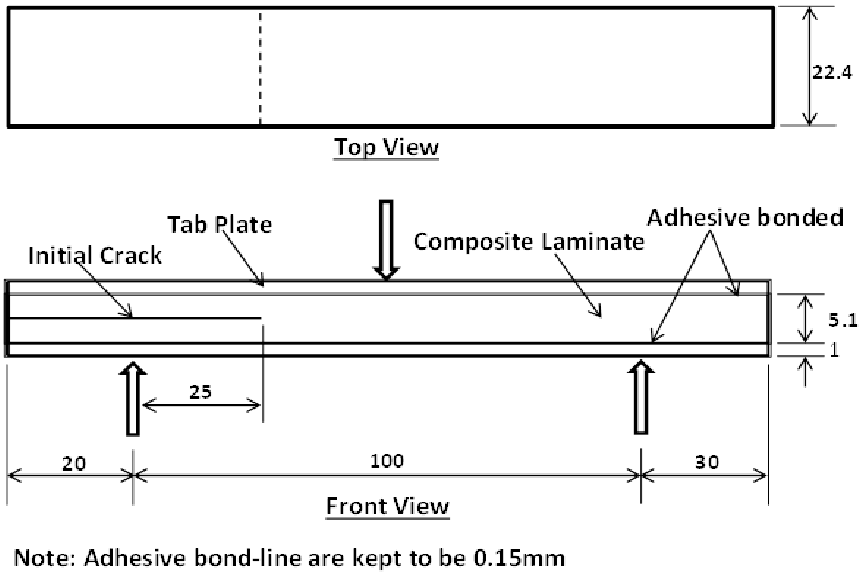

Figure 2. TENF specimen set-up

2.3 Data Reduction

Energy release rates (G_{II}) were calculated using compliance calibration method [6, 7]. Prior to TENF test, the specimen compliance was measured at crack length 0, 10, 20, 30, and 40 mm by applying small load (600N to 700N) with 0.1mm/min of cross head speed. Then compliance data were plotted in term of $(a/L)^3$ vs. C/Co, and slope (m) of the curve was calculated. In order to obtain G_{II} value, the slope (m) introduced to the following equation:

$$G_{II} = \frac{3mP^2a^2C_0}{2wL^3} \quad (1)$$

Where: Co is specimen compliance without crack, P is peak load while the crack start to propagate, a as the crack length, w is width of the specimen, and L is half of the span.

3. Results and discussion

The result of G_{IIC} values of each specimen types are shown in table 1. It is revealed that in case of only one stitch row in the crack region (at crack length of 25mm), all of stitched specimens have lower G_{IIC} compare to unstitched one by the average of 12.7%. A plausible reason for this evident is that compaction effect of stitching process which increase local fiber volume fraction. These higher local fiber volume fractions create higher maximum shear stress at the crack tip. The phenomena of increasing local fiber volume fraction due stitching process had been investigated by Arief Y, et.al [8].

Table.1 also exhibited that in case of moderately stitched laminates, G_{IIC} values at crack length of 45mm have negligible improvement even though there was crack bridging effort by stitch threads at the crack region, but it covered by the reducing of G_{IIC} value due to fiber compaction as reported above. Stitch thread thickness also shown insignificant effect at moderately stitched laminates.

Furthermore, in case of densely stitched laminates, G_{IIC} values at crack length of 45 mm showed valuable increment by the order of 64.3% and 139.9% for stitched thread thickness 200denier and 500denier, respectively.

Finally, all specimens were visually checked whether there is aluminum tabs debonding or plastic deformation during the test. The inspection results found no evident for both of debonding or deformation. So that, it could be guaranteed that the energy loosed during the test was due to the crack extension.

Specimen Type	G_{IIC} at a = 25mm (kJ/m^2)	Increment (%)	GIIC at a = 45mm (kJ/m^2)	Increment (%)
Unstitched	1.03 ±0.06		1.42 ±0.05	
Stitched 6x6mm 200denier	0.90 ±0.09	-12.6	1.42 ±0.06	-0.18
Stitched 6x6mm 500denier	0.92 ±0.10	-11.5	1.46 ±0.07	2.4
Stitched 3x3mm 200denier	0.89 ±0.04	-13.9	2.34 ±0.13	64.3
Stitched 3x3mm 500denier	0.90 ±0.11	-12.8	3.42 ±0.07	139.9

Table 1. Critical energy released rate (G_{IIC}) of each specimen types.

4. Conclusions

Based on the experimental results, several conclusions could be pointed as follows:

- Tab end notch flexure (TENF) test with 1mm thickness of aluminum 7075-T6 are quite applicable for mode II delamination testing of multidirectional stitched laminates.
- In case of only one stitched thread row at the crack region, G_{IIC} of all stitched specimen are lower than unstitched one, due to fiber compaction effect of stitching process.
- Moderately stitched laminates have negligible improvement of G_{IIC}, meanwhile densely stitched laminates exhibited significant improvement.
- Stitch thread thickness did not play important role on moderately stitched specimens, but show significant influence on densely stitched laminates

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