The Effect of Preform Structure on the Tensile Behavior of Carbon/Epoxy Comosites

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ABSTRACT

Three different materials: ends, preforms, and composites were studied to determine the effect of preform structure on the fracture behavior of the composite materials. The ends are different in their tensile characteristics while the preforms are different in their structures. The preform structures are unidirectional laid ends (UD), a non-woven (NW), and a warp-knitted (WK) fabrics. The tensile performance and characteristics were measured at different stages; single ends, preforms, and composite materials. Different fracture behaviors were noticed for each structure. Sudden fibre fracture and epoxy cracking occurred in UD composites, whereas a gradual fracture was noticed for the NW and WK composites. For the UD composite, the fracture occurred parallel and perpendicularly to the loading direction at different positions with fibre/matrix interfacial fracture. The NW fractured in the same mode but in the middle of the specimen. The WK material showed a fracture that is perpendicular to the loading direction and the process showed a brittle fracture.

Key words: Carbon fibres; Textile structures; Preforms; Composites; Tensile test; Fracture stress.

INTRODUCTION

Textile composites offer adequate structural integrity as well as shape ability for near net-shape manufacturing [S.Raman Krishan, 1997]. Their mechanical properties can be tailored to meet a specific end-use require-ment by selecting the fibre and its orientation and arrangement in the textile preform [Michael Bannister, 2001]. The fracture of composite materials depends on the tensile strength of the fibres. For example, different failure modes can be observed when two composite specimens are manufactured with fibres and matrix in different properties and fibre volume fractions.

The strength and Young's modulus of the matrix, when dealing with polymer matrix composites, are lower than those of fibre by two orders of magnitude [M.Khatibzadeh *et al*, 1998]. The failure of the polymer matrix composites reinforced with filament tow involves fibres fracture, interface deboning, and matrix-crack [Leif E.Asp *et al*, 1995]. In general, the strength of

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the composites will increase with the decrease of alignment angle relative to the tensile direction [Shao Yun Fu *et al* 1996].

The strength of carbon fibre composites is directly related to the fibre volume fraction and lay-up direction. The maximum modulus and strength will be reached when the fibres are aligned with the direction of applied stress [M.R.Etemad *et al*, 1992].

Many studies were carried out on the carbon fibre reinforced polymer composites. In this paper, tensile tests have been performed for carbon filament tows, preforms, and especially for composites. The tensile properties and fractographs of composites reinforced with different preforms have been obtained to discuss the effect of preform structure on the fracture behavior of carbon fibre reinforced epoxy composites.

MATERIALS AND METHODS

The fibre type used here is T300, from Torary of Japan, with filament denier of 0.73, and their characteristics are mentioned in Table1. The structures of the preforms manufactured with carbon fibres are as follows:

1- Unidirectional aligned (UD) ends, which are held together by simple thread weaving.
2- Non-woven fabric (NW) made by longitudinal alignment of ends held together by zigzag stitching.
3- Warp-knitted fabric (WK), having its warp ends stitched together with the weft picks by diagonal stitching.

The carbon/epoxy composite materials were fabricated by the hand-lay-up method, with epoxy resin. The single ends, the preforms and their composites were tested for their uniaxial tensile strengths using the Tonometer, at a strain rate of 2mm/min; a gauge length of 10 cm was used for the single ends, and 20 cm gauge length for both the preforms and the composite materials. To ensure good gripping and to avoid slippage at the Tonometer clamps, the clamping parts of the preform and composite specimens were roughened with epoxy resin. The sketch of preform and composite samples configuration is shown in Figure 1.

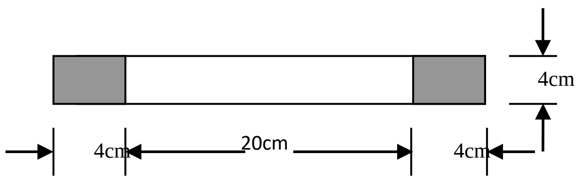


Figure 1: Specimen configuration for the preforms and the composites

The thickness values of the preforms and the composites were measured using the thickness meter and the consequent cross-sectional areas were calculated. These values were used to calculate the tensile stress of the samples from the tensile load. The failing composite specimens were examined under the microscope to take their fractographs in a magnification of 300.

RESULTS AND DISCUSSION

1. Basic data of the materials

The parameters and tensile properties of the materials used in the experiments are shown in Table 1.

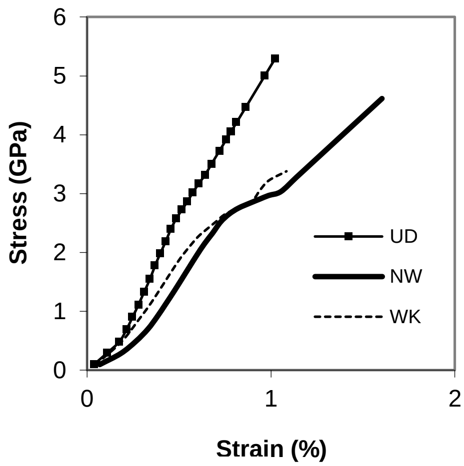
Table 1: The parameters and tensile properties of the materials

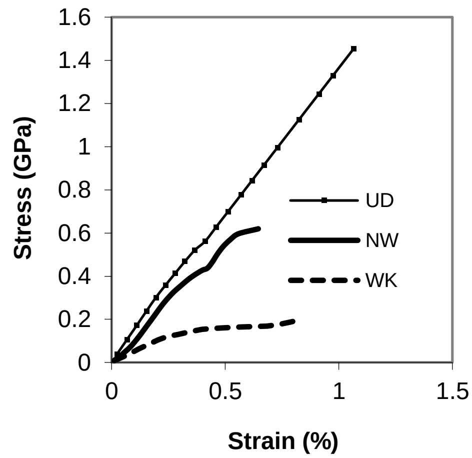
Samples / Properties	Strands			Preforms			Composites		
	UDF	NWF	WKF	UDF	NWF	WKF	UDF	NWF	WKF
N_t or W_m	820	630	220	207.86	323.39	471.52	773.3	971.52	1350.98
d or t	0.719	0.680	0.630	0.015	0.028	0.034	0.035	0.051	0.057
S_s or S_f	0.41	0.36	0.31	4.1	6.12	10.85	4.1	6.12	10.85
Stress σ_b (GPa)	5.3	4.6	3.4	1.5	0.6	0.2	1.1	0.8	0.78
Strain ε_b (%)	1.023	1.6	1.08	1.07	0.65	0.84	1.6	0.7	1.06
Modulus (GPa)	280	152	167	3.01	2.15	0.63	2.73	2.40	0.74
V_f (%)							69	62	67

* N_t, the linear density of strands (Tex), Wm weight per square meter of preform and composite, (g/m^2)
* D is the average diameter (mm), t is the thickness (mm).
* S_s, the cross-sectional area of strands, S_f is for fabrics and composites respectively. (mm^2)
* V_f (%) is the fibre volume fraction in the composite.

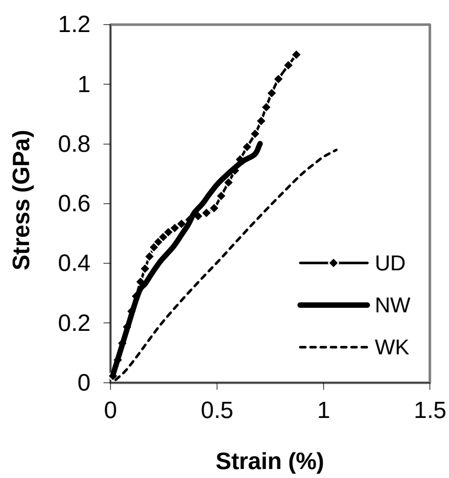
2. The tensile characteristics of the materials

The stress-strain plots of the three different materials are shown in Figure 2. Figure 3 shows the histograms of the materials to explain the maximum stress values. Each plot and histogram contains the three members of one group for making a quick comparison concerning the tensile properties. The UD materials in all cases show a higher breaking stress than the NW and the WK materials. The high tensile strength of ends led to a high tensile strength of preform and composite.





(a) Tows

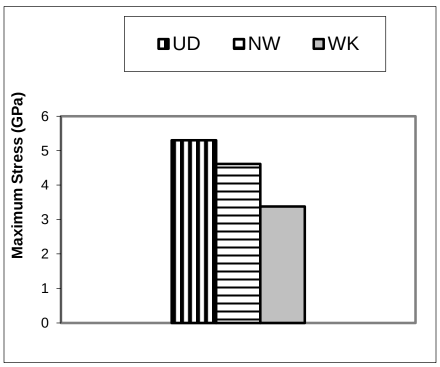


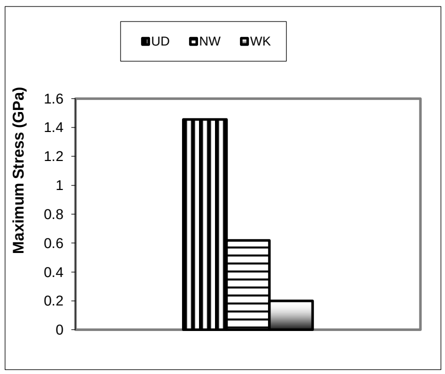
(b) Preforms

(c) Composites

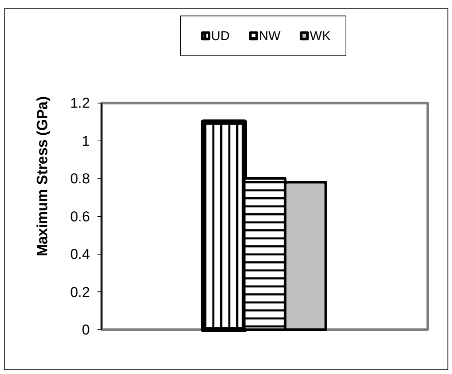
Figure 2: Stress-strain plots of the materials

In figure 3 (c), the WK composite has a fracture stress that is very close to that of the NW composite. This is mainly due to the presence of the weft threads. The existence of weft yarns contributes to the increase of the tensile strength of the composite while the weft yarns have no effects on the preform axial tensile strength when the test is carried axially in the warp direction only. This is because of the presence of the embedded matrix material in-between the weft strands which when axially tensioned, bears part of the load put on the warp strands. Another reason is the presence of the stitching thread that holds together the warp and the weft strands.





(a) Tows (b) Preforms



(c) Composites

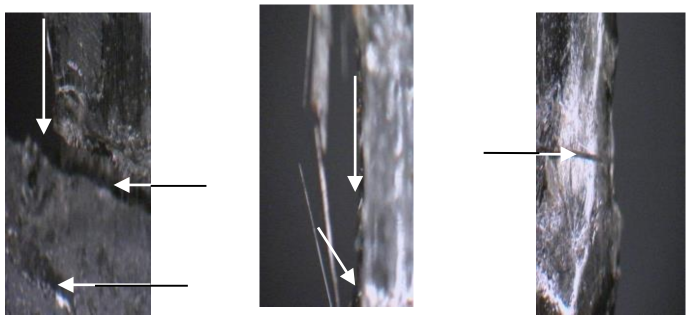
Figure 3: Maximum stress values of the materials

3. The fractographs of the composites

The mechanical parameters give an indication of the first failure, which happens to the samples every time. The fractographs of the composites are of major concern rather than the preforms and the strands when dealing with composites as structural materials. The uniaxial loading of the composites leads to different kinds of failure, as illustrated in Figure 4, which shows microscopical images of the fractured samples. The arrows indicate the points of fracture.

The composite made of the UD fractures suddenly and in a brittle mode as a result of fibres breakage followed by a brittle matrix extension, at different positions. This is mainly due to the sheet-like structure of the UD preform, which enables an easy fracture process that consists of fibre deboning from the matrix.

Both of the composites made of the NW and the WK preforms suffer from a gradually occurring fracture process. Though the one of the NW preform fractures in the middle edge and both fibre and epoxy cracking occur, in a fibre pull-out manner, while that made of the WK suffers from the fracture at a position almost near the tabs and at its edge as a result of resin cracking only. A separation effect occurs in the space between the transversely aligned weft threads, which is filled with the matrix giving an opportunity of a high strain values without a significant fracture stress. Therefore, micro-cracks are initiated by the fracture of the resin.



(a) UD (b) NW (c) WK

Figure 4: Fractographs of the three different composite materials

The tensile fracture stresses are strongly affected by the type of the preform structure used because the same resin has been used. It is clear from the above-mentioned data that the difference in fracture stresses has decreased from preform to composite. When the preform changed to have more fibres and different orientation, the fracture profiles showed more gradual matrix deboning and/or fibre pull-out and less brittle manner of fracture with different fibre/ criteria.

CONCLUSION

The fracture process of the composite made of the unidirectional aligned fibres consisted of fibre deboning from the matrix, leading to a brittle fibre and matrix fracture at different points of the specimen. As the structure turned to be a non-woven composite, a fibre pull-out occurred with a fracture of both the fibre and the matrix. The warp knitted composite had shown initiation of micro-cracks in the resin region leading to less fracture of the fibres.

As the structure of the preform changed, the fracture of the composites showed different profiles. The fracture was noticed to be parallel and perpendicular to the loading direction for the composite made of the unidirectional aligned fibres. While the non-woven compo-site had shown a fracture parallel to the loading direction, the warp knitted composite fracture was perpendicular to the loading direction.

REFERENCES

Leif E.Asp, Lars A.Beglund (1995). Composites Sc. and Tech. 53: 27-37.

Michael Bannister (2001).Composites, part a, 32: 901-910.

M.Khatibzadeh, M.R.Piggott (1998).Composites Sc. and Tech. 58: 497-504.

M.R.Etemad, E.Pask, and C.B.Besant (July 1992). Composites, 23 (4): 253- 259

Shao Yun Fu, Bernd Lauke (1996). Composites Sc. and Tech., 56: 1179-1190.

S.Raman Krishan (1997). Composites Sc. and Tech. 57: 1-21.

أثر التركيب النسجي على خواص الشد لعناصر شعيرات الكاربون المزدوجة

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الخلاصة

تمت دراسة ثلاثة أشكال نسجية مختلفة تضمنت خيوط ، منسوجات ، وعناصر مزدوجة تم تصنيعها من شعيرات الكاربون وذلك لمعرفة خصائص الشد والتمزق . احتوت التراكيب النسجية على ثلاثة أنواع مختلفة تمثلت في أقمشة مصنوعة من خيوط ذات اتجاه أحادى ، وأقمشة غير منسوجة وأقمشة تريكو السدا. قيست خصائص الشد للخيوط المكونة لهذه الأقمشة وكذلك الأقمشة نفسها ومن ثم تم تصنيع العناصر المزدوجة ليتم قياس خصائصها أيضا .خلصت الدراسة الى ان العناصر المزدوجة من الأقمشة ذات الاتجاه الاحادى للخيوط قد تعرضت لتمزق مفاجئ مع حدوث تصدع في البوليمر في حين ان العناصر المزدوجة للأقمشة غير المنسوجة وأقمشة تريكو السدا قد تمزقت تدريجياً . حدث التمزق للنوع الأول من الاقمشة في اتجاهين احدهما مواز والآخر عمودي على اتجاه تحميل قوة الشد وذلك في عدة مواضع مختلفة وقد احتوى التمزق على تصدع بين سطحي الشعيرات والبوليمر .بالنسبة للعناصر المزدوجة من الأقمشة غير المنسوجة فقد تمزقت بنفس الصورة أعلاه ولكنها اقتصرت على المنطقة الوسطى من العينة . أظهر النوع الثالث من هذه العناصر تمزقاً متعامداً على اتجاه التحميل مع حدوث تمزق بينى هش .