Folding of a bistable composite tape-spring structure

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Introduction

A bistable composite tape-spring is a thin-walled, laminated open slit tube, which is stable in both extended and coiled configurations (see Fig. 1). The governing factors of its bistability depend on the material constitutive behaviour, initial geometrical proportions, and geometrically non-linear structural behaviour [1]. This inherent behaviour is similar to the lock-stay or side-stay assemblies (see Fig. 2) within an aircraft landing gear: these extend and retract with the gear, but remain in a fixed position when the gear is stowed in the bay or locked in the down position [2]. Thus, it is envisaged that by using bistable composite tape-springs, it may reduce further the weight, complexity and maintenance, compared to conventional lock-link assemblies [3].

Fig. 1 Configurations of a bistable composite tape-spring.

The lock-stays are selected as the first potential application of bistable tape-springs. Both stays are mainly subjected to relatively low compressive loads, and are static in two different positions - when the gear is locked in the deployed (Fig. 2-a) or retracted position (Fig. 2-b). We have investigated the folding of bistable composite tape-springs through experiments, finite element analysis (FEA) and theoretical analysis.

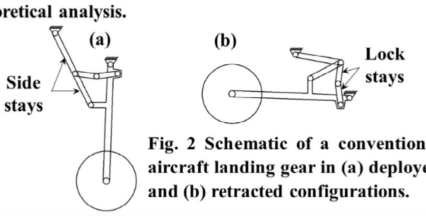
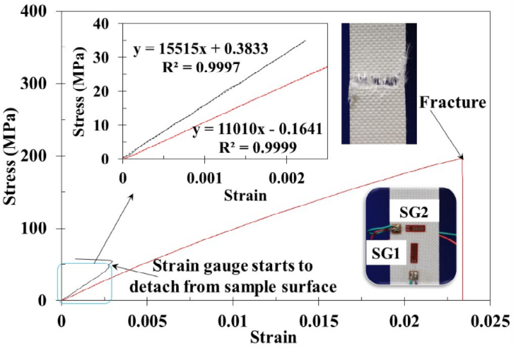


Fig. 2 Schematic of a conventional aircraft landing gear in (a) deployed and (b) retracted configurations.

Materials characterisation

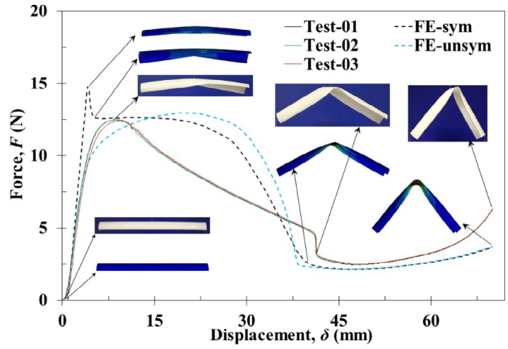
Materials properties of the woven composite have been characterised through embedded strain gauges (SGs) [4]. The differences in fibre tow geometries result in different moduli in warp and weft directions.

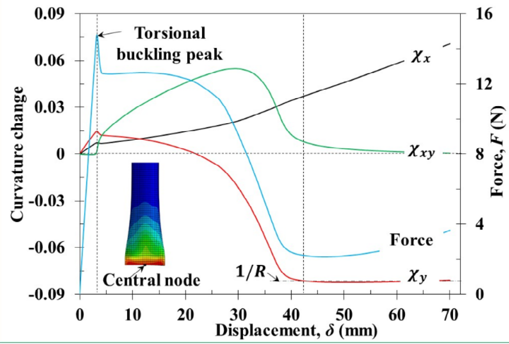


Sample No	Tensile strength (MPa)	Strain at failure (%)	Modulus (GPa) Strain gauge	Modulus (GPa) Crosshead motion	Poisson's ratio
$[0/90]_3$	σ_1^{WC}	ε_{1f}^{WC}	E_1^{WC}		ν_{12}
1	206.68	3.55	12.79	8.39	0.11
2	206.52	3.56	12.27	6.11	0.12
3	233.08	3.26	13.90	10.10	0.11
Mean ± SE	215.4 ± 8.8	3.46 ± 0.10	13.0 ± 0.5	8.2 ± 1.2	0.11 ± 0.01
$[90/0]_3$	σ_2^{WC}	ε_{2f}^{WC}	E_2^{WC}		ν_{21}
1	196.29	2.33	15.52	11.01	0.13
2	203.05	2.34	18.69	8.66	0.16
3	194.87	2.34	13.98	8.46	0.21
Mean ± SE	198.1 ± 2.5	2.34 ± 0.01	16.1 ± 1.4	9.4 ± 0.8	0.17 ± 0.03

Shape in folding

We have devised a simple 'free' bending system with minimal constraints, to study the folding nature of composite tape-springs. A typical folding process consists of linear bending, torsional buckling, localisation and then folding. Finite element analysis provides further insight into the torsional buckling phenomenon [5].



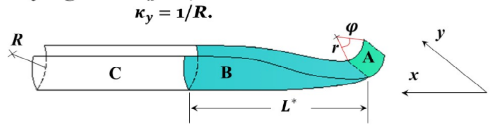


Folded tape shape – theoretical

Geometrical boundary conditions:

Ploy region A: $\kappa_x = 1/r$; $\kappa_y = 0$. **Ploy region B:** $\kappa_x = 0$; $\kappa_y \to 0 \sim 1/R$.

Ploy region C: $\kappa_x = 0$; $\kappa_y = 1/R$.



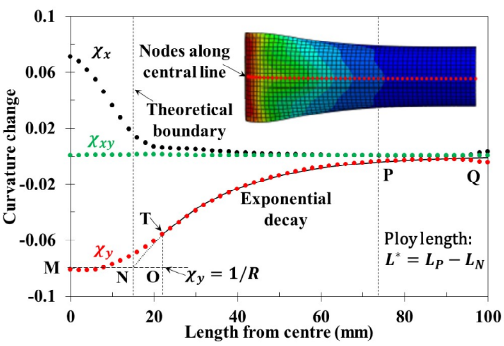
Define k as the exponential decay parameter, the change in transverse curvature in ploy region B [2]:

$$\chi_y = -\frac{1}{R}\cdot\exp\left(-\frac{k\pi x}{b}\right)\cos(\pi y/b)$$

$$k^4 = \frac{B}{36S}\cdot\frac{\beta}{1-\nu^2/\beta}\cdot\frac{t^2R^2}{b^4}$$

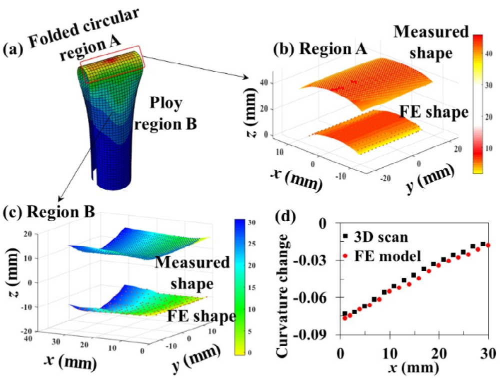
Characteristic length of decay, i.e. ploy length [2]:

$$L^* = \frac{b^2}{\pi}\left[\frac{1-\nu^2/\beta}{120\beta}\right]^{1/4}\sqrt{c/t}$$

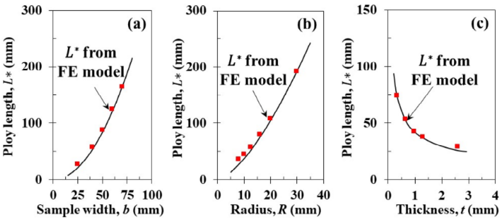


Folded tape shape – experimental and FEA

The folded tape shape from FEA has been compared to the real composite tape. Owing to the differences in boundary conditions, the central fold region A is not comparable, while the ploy region B from both methods are effectively the same [5].

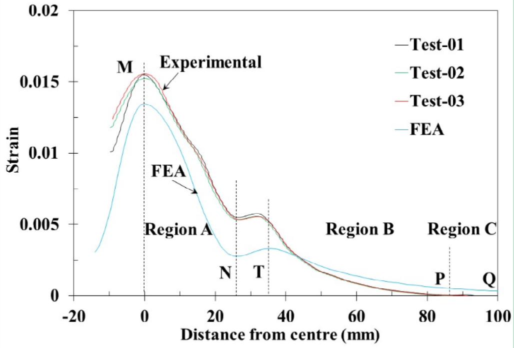


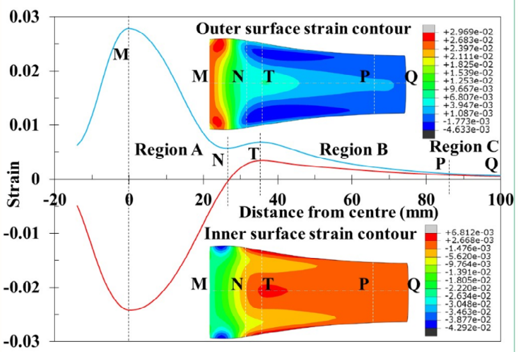
A parameter study on the governing factors of the ploy region has been performed using the FE model: good agreement with the theoretical analysis has been observed [6].



Folded tape strain

The strain distribution in a folded composite tape has been investigated [6,7]. Experimental data have been compared to FEA, and show good agreement. A 'shoulder-like' feature is observed, which corresponds to the transition region around point T.





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