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A classical lamination model of bi-stable woven composite tape-springs

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Summary. This extended abstract presents the work done so far on modeling woven composite materials, specifically two carbon fiber reinforced plastics materials: twill and plain weave. The material model has been initially verified against data available in a database.

1. Introduction

For decades tape-springs has been used as deployable structures in space due to its compact stowed volume and good structural characteristics when deployed. Metallic tape springs are only stable in the deployed state so a robust containing solution needs to be used to keep them coiled. Moreover, during deployment an active control scheme must be used to prevent blooming [1]. These aspects pose issues on the overall mass budget, reliability and complexity for such mechanisms. However, bi-stable tape springs made of, for instance, woven carbon fiber reinforced plastics (CFRP), show two well-defined stable configurations: the completely stowed and completely uncoiled configurations. Bi-stability in such deployable structures allows a dramatic reduction in mass as well as in control complexity thus, increasing the reliability of the system.

1.1 CFRP modeling

The main modeling difficulties come from the orthotropy of the material and its characteristic woven structure (Fig. 1), embedded in a cured resin matrix. In a plain weave (Fig. 2) odd bundles pass over one and under one perpendicular bundle, and even bundles reverse this order. In the twill type (Fig. 3) odd bundles pass over two perpendicular bundles and under one, while even bundles reverse this order.

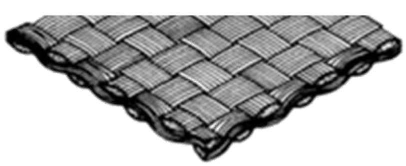

Figure 1: Plain weave woven scheme.

Figure 2: Plain weave CFRP.

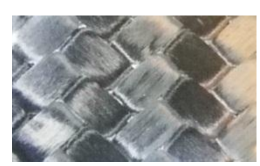

Figure 3: Twill CFRP.

2.1 Bi-stability

In this context, the term bi-stability is used when a structure shows two well-defined stable configurations: coiled and straight (deployed) ones. These two configurations represent local minima of the stored strain energy and, to transit from one to another, external *activation energy* must be provided. Such *activation energy* is in our case a bending moment applied on the edges of the straight configuration in order to flatten it (Fig. 4). Once a certain point (point A in Fig. 4) is reached, the tape-spring section becomes flat and tends to coil in a virtual cylinder with axis perpendicular to the straight configuration axis, storing the generated strain energy. If then we start removing the bending moment applied, the strain energy is slowly released and two phenomena may occur: either the tape spring snaps back to the straight configuration (point B in Fig. 4) or it remains rolled-up storing strain energy (Fig. 5).

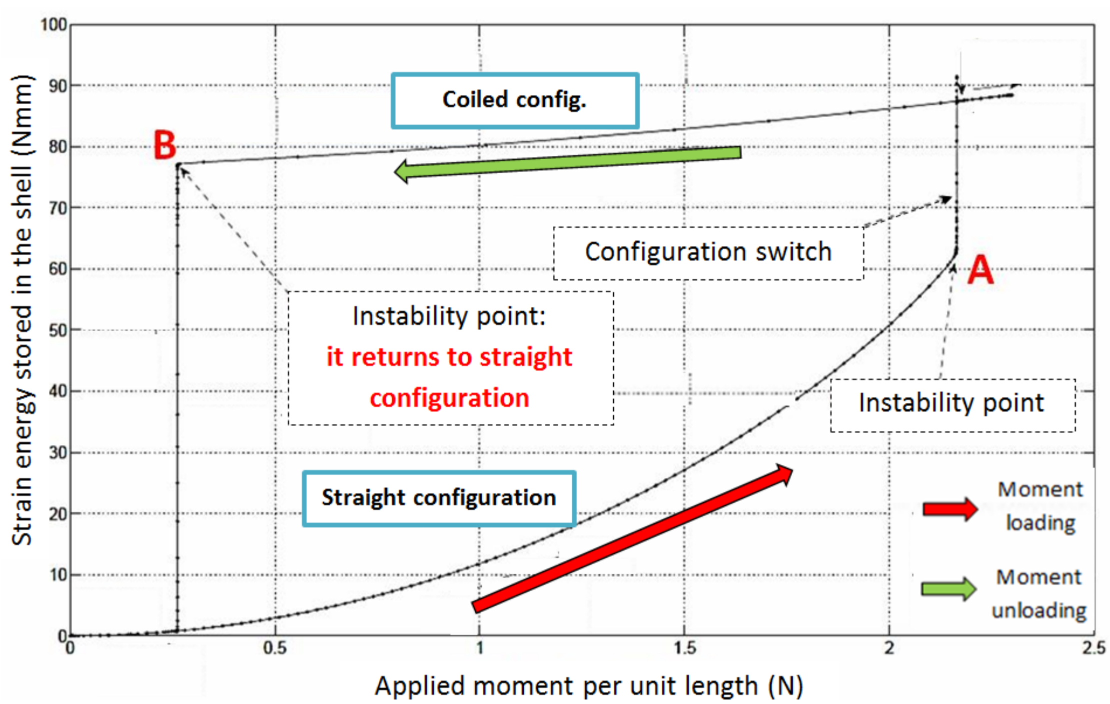

Figure 4: Strain energy curves for a non-bi-stable tape-spring.

2. Models

The material model developed here is based on Naik's model [2], which simplifies the unit cell of the material of Fig. 1 into a four layer cell made of two resin layers on the outer layers and the interlacing carbon fiber bundles as separated unidirectional (UD) plies as in Fig. 6. Naik's model predicts well the in-plane behavior of the material but not the out-of-plane behavior and the bending stiffness is a crucial parameter here since it is the origin of the strain energy generated. Thus, the strain energy is directly related to the bi-stability characteristics of the boom. Consequently, Naik's model was modified by dividing the basic cell into a series of plies, until a model that permits to vary the thickness and position of each layer (Fig. 7) to tune the bending characteristics without affecting the in-plane properties of the material.

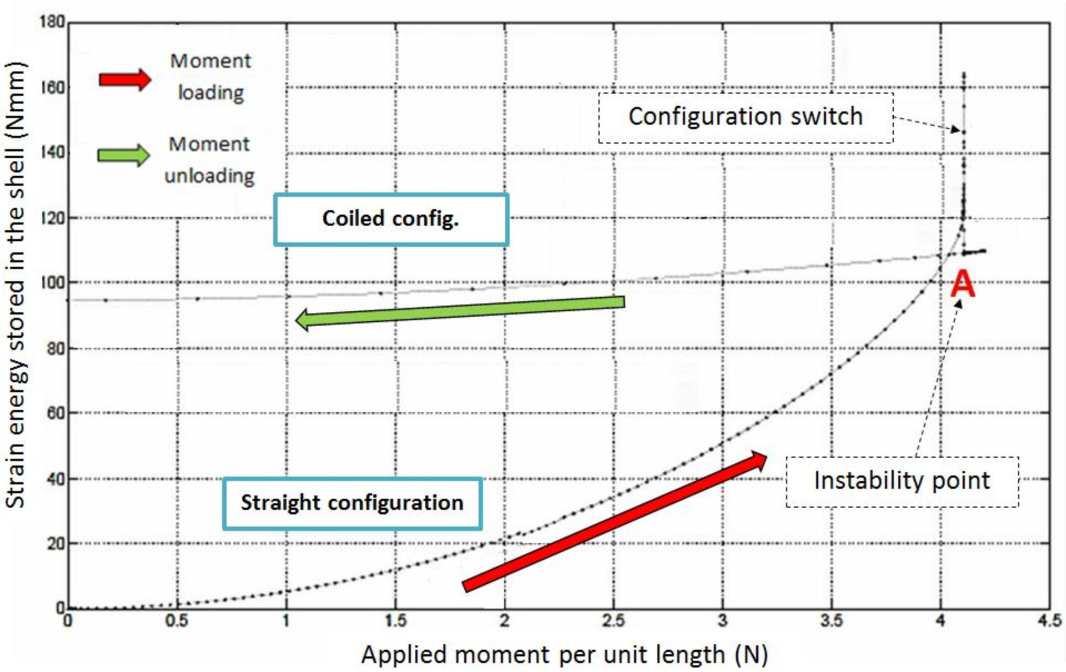

Figure 5: Strain energy curves for a bi-stable tape-spring.

After tuning the material model parameters against data from a database, it is implemented in the coiling simulation developed in the software Abaqus. With the proper boundary conditions on the booms, the tips are flattened over the spool, Fig. 8(a), making coincident the edge nodes with a set of nodes in the spool. Rotation is then applied to the spool, pulling the boom and coiling it, Fig. 8(b), which generates strain energy that is stored on the coiled configuration. When only the transition zone (a few centimeters) is left, the coiling stops, Fig. 8(c). Note that it is vital to keep this transition zone since it is the mechanism that drives the deployment towards the second stable configuration.

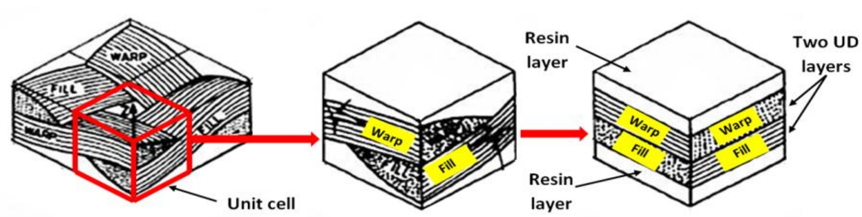

Figure 6: Unit cell simplification in Naik’s model (from [2]).

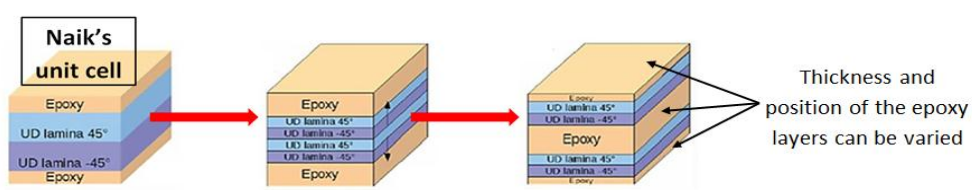

Figure 7: Naik’s cell model modification to obtain the proposed model.

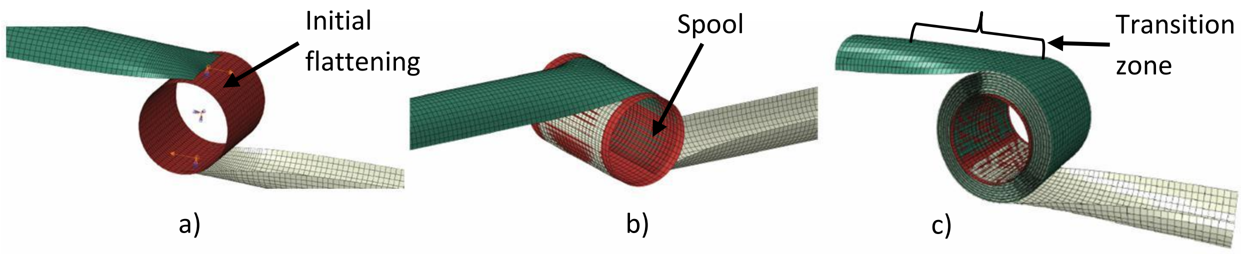

Figure 8: Coiling simulation steps.

3. Results

A case example is shown in Table 1. It corresponds to a plain weave specimen with fiber volume content (V_f) of 0.85, gap ratio (g/a) of 0.21 and fiber direction at 45° bias, which is a well-approximated example of the plain weave CFRP we have for the project and to be used in our simulations. V_f is a common parameter that comes along other properties and defines the volume of fibers with respect to the resin; g/a is a parameter created here in order to take into account the gaps observed in the plain weave case; the bias is measured with respect to the longitudinal direction of the boom and must be 45° here to ensure a symmetrical mechanical properties longitudinally (0°) and transversely (90°) to the tape-spring.

Table 1: Plain weave with V_f = 0.85, g/a = 0.21 and at 45° bias.

Property	Model prediction	Error with respect to database values
Tensile modulus (GPa)	11.75	–1.48
Shear modulus (GPa)	27.0	+2.98
Poisson's ratio (-)	0.794	–0.92

4. Discussion and conclusions

Bi-stability strongly relies on the out-of-plane properties (bending) thus a model that is accurate in bending is crucial. Previous modeling techniques were not successful (or computationally too expensive [3]). To address this aspect a modified Naik's model was developed. The modifications made on Naik's model has provided a significantly improvement on the results agreement with real material properties. However, several aspects need to be improved and others further investigated to include them in our analyses, i.e. observed creep, low temperature sensitivity and friction during deployment.

References

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