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Simulation of fibers in woven composites: a comparison between solid and beam models

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Micro Abstract
Woven composites find numerous applications in engineering products. Their micromechanical behavior involves complex contact behavior between fibers/matrix, debonding etc and thus warrant micromechanical investigations. Such materials can be geometrically described using computationally intensive solids or reduced structural models like beams/shells etc. This work provides an objective comparison between the two approaches in order to compare pros/cons of each modeling hierarchy.

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Introduction

Composite materials exhibit a variety of advantages in comparison to traditional materials such as metals. By combining several constituent materials with varying physical, mechanical, and/or thermal properties, composites can be engineered to have ideal characteristics for specific applications. Among other properties, composites have high stiffness to weight and strength to weight ratios. These properties lead to many potential applications across a variety of industries, including automotive and aerospace industries, where the use of composites promises improvements in size, speed, and efficiency as discussed in Quinn et. al. [11], Ansar et. al. [1] and Fillep et. al. [3]

Woven composites are especially beneficial in these applications as the intermeshed fiber structure of these materials means they do not suffer from the problem of delamination inherent in traditional laminated composites. Additionally, these materials can be formed into complex shapes and manufactured more easily due to recent innovations in textile production techniques, according to Ansar et. al. [1], and additive manufacturing. Despite these advantages, woven composites are yet to be widely adopted. This lag in implementation can be attributed to the complex behaviors of these materials as well as the current lack of predictive high-fidelity tools for simulation and modeling of composite behavior. Thus, any usage of these materials therefore requires expensive and time consuming physical testing according to Green et. al. [4].

Several methods involving the use of the Finite Element Method, FEM, with different levels of idealization have previously been used to model woven composites. These approaches range from modeling a weave at the scale of the individual fibers making up each warp and weft, as in Durville [2], to approximating the structure of a weave as a single homogeneous shell and neglecting the behavior of individual fibers, as in Fillep et. al. [3]. While each of these approaches has some advantages, each model is affected by its respective assumptions and simplifications as discussed in the work of Saito and Neto [12].

The goal of this work is to gain a better understanding of how weave characteristics, like friction between fibers, fiber radius and spacing, impact the homogenized behavior of a woven composite. The approach taken to modeling the weave was adopted from the technique described by Saito and Neto [12] where a four step Finite Element Analysis (FEA) simulation is used to create a woven structure that is already pre-stressed prior to application of loads.

In the current work, 3D FEM calculations are done using Abaqus CAE and compared with beam models developed using Giraffe. Only isotropic scenarios are considered here and the results are fitted with a hyperelastic Neo-Hookean material.

1 Theoretical Formulation

In this work, we closely follow the work of Gay Neto and co-workers for modeling the microstructure using fiber-to-fiber contact. The woven warp and laminated fibers are modeling using the geometrically-exact formulation of Timoshenko beams. The beam elements are capable of modeling tension, compression, shear, bending and torsional loads. However, the cross-sectional kinematics of these beam elements are treated as a rigid body and the effects of warping are neglected. An equivalent torsional stiffness constant may be evaluated by Saint Venant's theory, thus indirectly considering warping and its effect on decreasing stiffness. The interaction of fibers or woven warp is evaluated through a beam-to-beam frictional contact formulation. The fundamental aspects of contact between circular cross-section beams were originally developed by Wriggers and Zavarise [10], in which beam axes are parametrized as three-dimensional curves and a gap function is defined.

The surface-to-surface contact strategy used in this work makes no distinction of master and slave surfaces and may be regarded as an enhancement of [10], since it considers the actual external beam surfaces parameterizations as boundaries for contact, instead of the beam axis description. Thus, this formulation is directly extensible for non-circular cross-section beams, such as super-eliptical ones, as presented in [8] and [9]. The surfaces are parameterized by convective coordinates. The gap function is defined and a minimum distance problem is solved to address a pair of point-wise contact actions, associated to material points at both bodies, as depicted in Fig. 1. Such an approach can be said to be master-to-master formulation, since no slave-points are elected, from beginning.

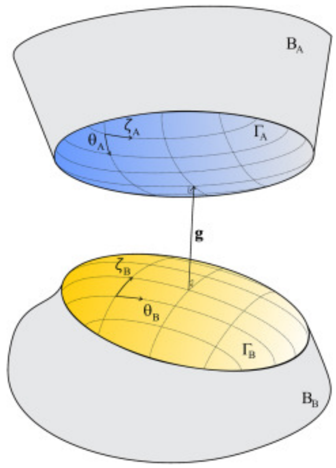


Figure 1. Bodies B_A and B_B candidate to contact interaction. For each body a subset of the boundary is parameterized: the surfaces Γ_A and Γ_B. (Source: Neto et. al. [8])

The master-to-master formulation may present significantly less computational effort, compared to standard master-slave approaches, as only one gap is addressed for each pair of surfaces, even for contact material points changing along the system evolution.

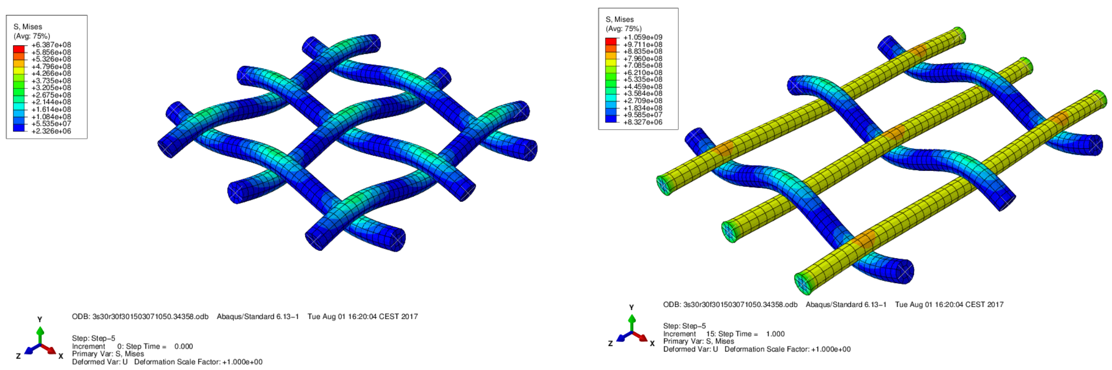
The software suite GIRAFFE (Generic Interface Readily Accessible For Finite Elements) developed at the Polytechnic School in the University of São Paulo is used for modeling the microstructure using beam-to-beam interaction models. A detailed discussion on the numerical aspects of the implementation are provided in the works of Gay Neto et. al. [5–9].

Further on, in addition to, the microstructural behavior developed based on beam-to-beam contact models are also verified and compared with solid-to-solid contact using 3D FEM in Abaqus CAE.

2 Results and Discussions

A four-step approach as described by Saito and Neto [12] is used to generate a pre-stressed weave for the analysis. Several parameters relevant to the geometry and contact interactions between fibers are varied to understand their impact on the overall homogenized mechanical behavior. These parameters include fiber radius, spacing, and friction coefficient. Five different spacings of 0.2, 0.25, 0.275, 0.3, 0.35m; fiber radius of 0.02, 0.025, 0.0275, 0.03, 0.035m; and friction co-efficient of 0.2, 0.25, 0.3, 0.35, 0.4 were considered.

It should be noted that in all tests, the fibers were considered to be hyperelastic and modeled using a Neo-Hookean material model. The warp and weft fibers had identical geometries and the material properties are held constant. The resulting weaves were simulated under uniaxial conditions and imposing up to 100% strains. The resulting weaves are as shown in Fig.2.



(a) Pre-stressed weave **(b)** Weave under uniaxial loading

Figure 2. Configuration of weaves: Prestressed structure before the uniaxial test (left); Weave subjected to 100% loading

The resulting homogenized stress-strain behavior is as shown in Fig. 3.

Conclusions

While previous works have concluded that the effects of friction significantly impact the behavior of weaves, in this work it was found that, in the tested range of friction coefficients, friction had no perceivable impact, atleast in the considered range.

It was ultimately determined that the most significant factors to weave behavior are the material properties of the constituent fibers. The shape of this plot closely mirrors the shape expected for a neo-Hookean material model. Because of these findings, it is concluded that for weaves with identical warp and weft fibers, uniaxial tensile behavior can be roughly modeled as a homogeneous hyperelastic material.

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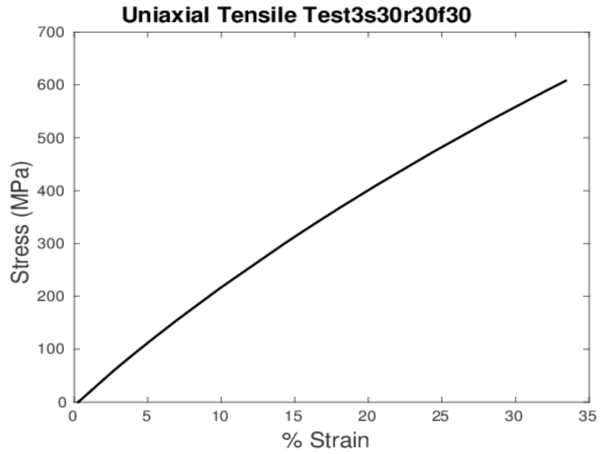

Figure 3. Homogenized stress-strain behavior of woven composite subjected to uniaxial tensile loading.

References

[1] M. Ansar, W. Xinwei, and Z. Chouwei. Modeling strategies of 3d woven composites: A review. *Composite Structures*, 93(8):1947–1983, 2011.

[2] D. Durville. Finite element simulation of textile materials at mesoscopic scale. In *FEMTTC 2007: Proceedings of the Finite Element Modelling of Textiles and Textile Composites, 26-29 Sep 2007, St. Petersberg, Russia*, 2007.

[3] S. Fillep, J. Mergheim, and P. Steinmann. Towards an efficient two-scale approach to model technical textiles. *Computational Mechanics*, 59(3):385–401, 2017.

[4] S. D. Green, M. Y. Matveev, A. C. Long, D. Ivanov, and S. R. Hallett. Mechanical modelling of 3d woven composites considering realistic unit cell geometry. *Composite Structures*, 118:284–293, 2014.

[5] A. G. Neto and C. A. Martins. Structural stability of flexible lines in catenary configuration under torsion. *Marine Structures*, 34:16–40, 2013.

[6] A. G. Neto, P. M. Pimenta, and P. Wriggers. Contact between rolling beam and flat surfaces. *International Journal for numerical Methods in Engineering*, 97:683–706, 2014.

[7] A. G. Neto, P. M. Pimenta, and P. Wriggers. Self-contact modeling on beams experiencing loop formation. *Computational Mechanics*, 55:193–208, 2014.

[8] A. G. Neto, P. M. Pimenta, and P. Wriggers. A master-surface to master-surface formulation for beam to beam contact. part i: frictionless interaction. *Computer Methods in Applied Mechanics and Engineering*, 303:400–429, 2016.

[9] A. G. Neto, P. M. Pimenta, and P. Wriggers. A master-surface to master-surface formulation for beam to beam contact. part ii: frictional interaction. *Computer Methods in Applied Mechanics and Engineering*, 319:146–174, 2017.

[10] G. Z. P. Wriggers. On contact between three-dimensional beams undergoing large deflections. *Communications in Applied Numerical Methods*, 13:429–438, 1997.

[11] J. P. Quinn, A. T. Mcllhagger, and R. Mcllhagger. Examination of the failure of 3d woven composites. *Composites Part A: Applied Science and Manufacturing*, 39(2):273–283, 2008.

[12] M. T. Saito and A. Neto. Woven fabrics computational simulation using beam-to-beam contacts formulation. In *CILAMCE 2016: Proceedings of the XXXVII Iberian Latin American Congress on Computational Methods in Engineering, 6-9 Nov 2016, Brasilia, DF, Brazil*, 2016.