PERGAMON

International Journal of Solids and Structures 38 (2001) 8585–8588

INTERNATIONAL JOURNAL OF SOLIDS and STRUCTURES

www.elsevier.com/locate/ijsolstr

Discussion of "Woven fabric composite material model with material non-linearity for non-linear finite element simulation" by Tabiei and Jiang [Int. J. Solids Struct. 36 (1999) 2757–2771]

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Received 21 June 2000; in revised form 9 March 2001

Tabiei and Jiang (1999) present an approach in which, through homogenization, a model for a woven composite material is developed. The model is suitable for implementation in commercial finite element (FE) packages (to represent a material point). This then enables analysis of structures composed of the woven composite while providing the local stresses and strains in the woven composite yarns at the FE material points. Hence, the objective of the paper, in my opinion, is extremely worthwhile. This type of multi-scale approach to structural analysis shows potential for improving designs, as well as streamlining the design procedure, for structures composed of advanced materials (such as woven composites).

In developing the model for the woven composite, Tabiei and Jiang (1999) identify a repeating unit cell (in the plane of the weave) and divide the unit cell into subcells. Each subcell is then homogenized through the weave's thickness via iso-stress and iso-strain conditions. The composite is thus represented, at this point, by a repeating unit cell consisting of an array of two-dimensional subcells, each with effective (homogenized) properties (see Fig. 1).

The next step in the model development involves homogenization of the two-dimensional subcells to obtain the effective constitutive equations for the repeating unit cell (Tabiei and Jiang, 1999, Section 2.2, p. 2764). Here, the authors state, "... it is assumed that the average in-plane strains and stresses among subcells have the following relationships ..." (Tabiei and Jiang, 1999, p. 2764), and 16 equations are presented, which relate the local (subcell) and global (homogenized) stresses and strains in the repeating unit cell. Although no reference is given, it is my opinion that these equations are, in actuality, the generalized method of cells (GMC) equations developed by Paley and Aboudi (1992). Figs. 1 and 2 compare the geometry employed by Tabiei and Jiang with that of GMC, while Table 1 presents the correspondence between the equations presented by Tabiei and Jiang (1999) and the GMC equations presented by Paley and Aboudi (1992).

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PII: S0020-7683(01)00067-1

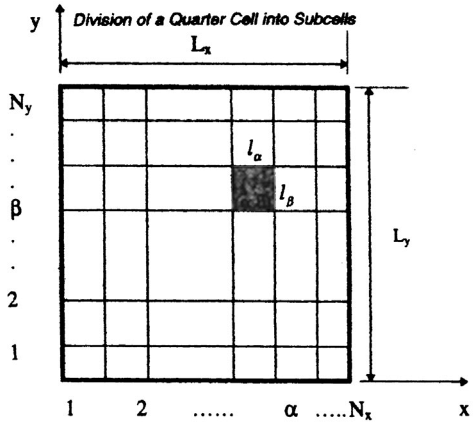

Fig. 1. Geometry employed by Tabiei and Jiang (1999, p. 2760).

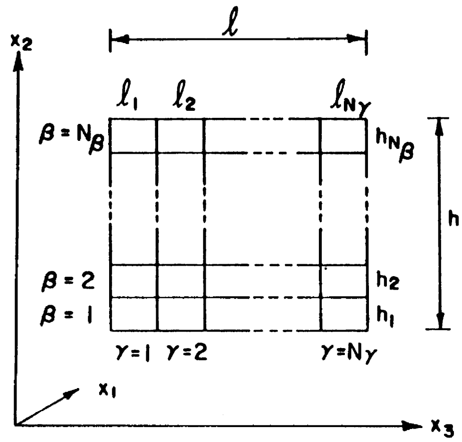

Fig. 2. Geometry of the GMC presented by Paley and Aboudi (1992, p. 129).

For a few of the numerous examples of investigations that have employed the GMC approach, the reader is referred to Aboudi (1985, 1986, 1987a,b, 1988, 1989a,b, 1991, 1995, 1996, 1999, 2000), Arnold et al. (1999), Bednarcyk and Pindera (1996, 1997, 2000a,b), Lissenden and Arnold (1997), Pindera and Bednarcyk (1999), Robertson and Mall (1994), Wilt and Arnold (1994, 1996), and Wilt et al. (1997). Of particular interest to the readers of the presently discussed article are Bednarcyk and Pindera (2000a,b), in which GMC was applied to modeling woven composites. In these papers, analysis begins on the scale of the individual constituents (fiber and matrix) rather than on the scale of the infiltrated yarns (as is the case in the presently discussed approach). This eliminates the need for a priori knowledge of homogenized properties of the infiltrated fiber yarns and provides the fields in the fiber and matrix constituents. These truly microscale fields are useful for incorporation of microscale features such as fiber–matrix interfacial debonding, damage, and microfailure criteria. By beginning analysis on the scale of the infiltrated fiber yarns, features such as these must be incorporated via appropriate transversely isotropic theories, which are clearly more complex and less widely available than their isotropic counterparts. Finally, in Bednarcyk and Pindera (2000a,b), homogenization of the three-dimensional woven composite unit cell was performed in

Table 1
Correspondence between the original GMC equations (Paley and Aboudi, 1992) and the equations of Tabiei and Jiang (1999)

Tabiei and Jiang (1999) equation #	GMC (1992) equation #
(22a)	(47)
(22b)	(46)
(22c)	(48)
(22d)	(49)
(22e)	(36)
(22f)	(35)
(22g)	(32)
(23)	(61)
(24)	(53)
(25)	(43)
(26)	(56) & (57)
(27)	(59)
(28)	(62)
(29)	(62)
(30)	(63)

one step via use of the triply periodic version of GMC (Aboudi, 1995). The concept of homogenizing through the thickness of the woven reinforcement prior to homogenization in the plane of the weave, as presented by Tabiei and Jiang (1999), is a good idea. I hope that this brief discussion provides the *IJSS* readership with some insight into the appropriate credit for the underlying micromechanics equations used in the paper.

Note added in press

No authors' closure received.

References

Aboudi, J., 1985. The effective thermomechanical behavior of inelastic fiber-reinforced materials. International Journal of Engineering Science 23 (7), 773–787.
Aboudi, J., 1986. Elastoplasticity theory for composite materials. SM Archives 11 (3), 141–183.
Aboudi, J., 1987a. Closed form constitutive equations for metal matrix composites. International Journal of Engineering Science 25 (9), 1229–1240.
Aboudi, J., 1987b. Damage in composite – modeling of imperfect bonding. Composites Science and Technology 28, 103–128.
Aboudi, J., 1988. Constitutive equations for elastoplastic composites with imperfect bonding. International Journal of Plasticity 4, 103–125.
Aboudi, J., 1989a. Micromechanical analysis of fibrous composites with coulomb frictional slippage between the phases. Mechanics of Materials 8, 103–115.
Aboudi, J., 1989b. Micromechanical analysis of composites by the method of cells. Applied Mechanics Reviews 42 (7), 193–221.
Aboudi, J., 1991. Mechanics of Composite Materials: A Unified Micromechanical Approach. Elsevier, New York.
Aboudi, J., 1995. Micromechanical analysis of thermo-inelastic multiphase short-fiber composites. Composites Engineering 5 (7), 839–850.
Aboudi, J., 1996. Micromechanical analysis of composites by the method of cells - update. Applied Mechanics Reviews 49 (10), S83–S91.
Aboudi, J., 1999. Micromechanical prediction of the response of electrostrictive multiphase composites. Smart Materials and Structures 8, 663–671.

Aboudi, J., 2000. Micromechanical modeling of finite viscoelastic multiphase composites. Zeitschrift für angewandte Mathematik und Physik 51, 114–134.

Arnold, S.M., Bednarcyk, B.A., Wilt, T.E., Trowbridge, D., 1999. Micromechanics analysis code with generalized method of cells (MAC/GMC) user guide, version 3.0, NASA/TM-1999-109070.

Bednarcyk, B.A., Pindera, M.-J., 1996. Inelastic thermal response of Gr/Cu with nonuniform fiber distribution. Journal of Aerospace Engineering 4 (9), 93–105.

Bednarcyk, B.A., Pindera, M.J., 1997. Micromechanical modeling of woven metal matrix composites. NASA-CR-204153.

Bednarcyk, B.A., Pindera, M.J., 2000a. Inelastic response of a woven carbon/copper composite – Part II: Micromechanics model. Journal of Composite Materials 34 (4), 299–331.

Bednarcyk, B.A., Pindera, M.J., 2000b. Inelastic response of a woven carbon/copper composite Part – III: Model-Experiment correlation. Journal of Composite Materials 34 (5), 352–378.

Lissenden, C.J., Arnold, S.M., 1997. Theoretical and experimental considerations in representing macroscale flow/damage surfaces for metal matrix composites. International Journal of Plasticity 13 (4), 327–358.

Paley, M., Aboudi, J., 1992. Micromechanical analysis of composites by the generalized cells model. Mechanics of Materials 14, 127–139.

Pindera, M.-J., Bednarcyk, B.A., 1999. An efficient implementation of the generalized method of cells for unidirectional, multi-phased composites with complex microstructures. Composites B 30, 87–105.

Robertson, D.D., Mall, S.M., 1994. Micromechanical analysis of metal matrix composite laminates with fiber/matrix interfacial damage. Composites Engineering 4 (12), 1257–1274.

Tabiei, A., Jiang, Y., 1999. Woven fabric composite material model with material nonlinearity for nonlinear finite element simulation. International Journal of Solids and Structures 36, 2757–2771.

Wilt, T.E., Arnold, S.M., 1994. Micromechanics analysis code (MAC) user guide, version 1.0. NASA-TM-106706.

Wilt, T.E., Arnold, S.M., 1996. Micromechanics analysis code (MAC) user guide, version 2.0. NASA-TM-107290.

Wilt, T.E., Arnold, S.M., Saleeb, A.,1997. A coupled/uncoupled computational scheme for deformation and fatigue damage analysis of unidirectional metal-matrix composites. In: McDowell, D.L. (Ed.), Applications of Continuum Damage Mechanics to Fatigue and Fracture, ASTM STP 1315, pp. 65–82.