Modeling of laminated composites with finite deformations by asymptotic homogenization method

© Yu.I. Dimitrienko, E.A. Gubareva, D.Yu. Kolzhanova

Bauman Moscow State Technical University, Moscow, 105005, Russia

The article covers a problem of elastic characteristic modeling for laminated composites with finite deformations. The problem is impotent for design of rubber-like and elastomer structures. A variant of asymptotic homogenization method is suggested for laminated elastic composites with finite deformations and periodical structures. Proposed by Yu. Dimitrienko, a universal representation of nonlinear constitutive relation for materials under finite deformations, is applied for composite model developed. Computational method for solution of nonlinear elasticity problem over periodicity cell of composite with finite deformation is suggested. The method is implemented in C++ program codes. The method allows to calculate an effective stress-strain diagrams in terms of averaged Piola—Kirchhoff deformation gradient for laminated composites with finite deformations. Examples of calculations demonstrate feasibility and efficiency of the method developed for prediction of elastic characteristic of laminated composites with finite deformations.

Keywords: *laminated composites, finite deformation, asymptotic homogenization method, Piola—Kirchhoff stress tensor, deformation gradient, universal representation of nonlinear constitutive relation.*

REFERENCES:

[1] Aboudi J. Micromechanics-based thermoviscoelastic constitutive equations for rubber-like matrix composites at finite strains. *Int. J. Solids and Struct.*, 41 (2004), 5611–5629.

[2] Yang Q., Xu F. Numerical modeling of nonlinear deformation of polymer composites based on hyperelastic constitutive law. *Frontiers of Mechanical Engineering in China*. September 2009, vol. 4, issue 3, pp. 284–288.

[3] Aboudi J. Finite strain micromechanical modeling of multiphase composites. *Int. J. Multiscale Comput. Eng*., 6 (2008), 411–434.

[4] Zhang B., Yu X., Gu B. Micromechanical modeling of large deformation in sepiolite reinforced rubber sealing composites under transverse tension. *Polym. Compos*., 2015. doi: 10.1002/pc.23596

[5] Ge Qi, Luo X., Iversen C.B., Nejad H.B., Mather P.T., Dunn M.L., Qi H.J. A finite deformation thermomechanical constitutive model for triple shape polymeric composites based on dual thermal transitions. *Int. J. Solids and Struct.*, 2014, vol. 51, pp. 2777–2790.

[6] Dimitrienko Yu.I., Dashtiyev I.Z. *Vestnik MGTU im. N.E. Baumana. Seriya Estestvennye nauki — Herald of the Bauman MSTU. Series: Natural sciences*, 2001, no. 1, pp. 21–41.

[7] Dimitrienko Yu.I., Sborschikov S.V., Sokolov A.P., Sadovnichiy D.N., Gafarov B.R. *Kompozity i nanostruktury — Composites and Nanostructures*, 2013, no. 3, pp. 35–51.

[8] Ma C.C.M., Taib N.H., Wua S.H., Lina S.H., Wua J.F., Lina J.M. Creep behavior of carbon-fiber-reinforced polyetheretherketone (PEEK) [±45]4s laminated composites. *Composites Part B: Engineering*, 1997, vol. 28, issue 4, pp. 407–417.

[9] Takanoa N., Ohnishia Y., Zakoa M., Nishiyabub K. The Formulation of Homogenization Method Applied to Large Deformation Problem for Composite Materials. *Int. J. of Solids and Structures*, 2000, vol. 37, is. 44 (1), pp. 6517–6535.

[10] Dimitrienko Yu.I., Sokolov A.P. *Matematicheskoe Modelirovanie — Mathematical Models and Computer Simulations*, 2012, vol. 24, no. 5, pp. 3–20.

[11] Dimitrienko Yu.I., Sokolov A.P. *Izvestiya Rossiyskoi akademii nauk. Seriya fizicheskaya — Izvestiya: Physics*, 2011, vol. 75, no. 11, pp. 1549–1554.

[12] Dimitrienko Yu.I., Sborschikov S.V., Sokolov A.P. *Mekhanika kompozitsionnykh materialov i konstruktsiy — Composite Mechanics and Design*, 2013, vol. 19, no. 3, pp. 365–383.

[13] Dimitrienko Yu.I., Gubareva E.A., Sborschikov S.V. *Matematicheskoe modelirovanie i chislennye metody — Mathematical Modeling and Computational Methods*, 2014, no. 1, pp. 36–57.

[14] Dimitrienko Yu.I., Yakovlev D.O. *Mekhanika kompozitsionnykh materialov i konstruktsiy — Composite Mechanics and Design*, 2014, vol. 20, no. 2, pp. 260–282.

[15] Dimitrienko Yu.I., Yakovlev N.O., Erasov V.S., Fedonyuk N.N., Sborschikov S.V., Gubareva E.A., Krylov V.D., Grigorev M.M., Prozorovsky A.A. *Kompozity i nanostruktury — Composites and Nanostructures*, 2014, vol. 6, no. 1, pp. 32–48.

[16] Dimitrienko Yu.I., Fedonyuk N.N., Gubareva E.A., Sborschikov S.V., Prozorovsky A.A. *Nauka i obrazovanie. Elektronnoe nauchno-tekhnicheskoe izdanie — Science and Education. Electronic Scientific and Technical Journal*, 2014, no. 7, doi: 10.7463/0714.0717805.

[17] Dimitrienko Yu.I. *Vestnik MGTU im. N.E. Baumana. Seriya Estestvennye nauki — Herald of the Bauman MSTU. Series: Natural sciences*, 2012, no. 3, pp. 86–100.

[18] Dimitrienko Yu.I. *Nonlinear Continuum Mechanics and Large Inelastic Deformations*. Springer, 2010, 722 p.

[19] Dimitrienko Yu.I. *Mekhanika sploshnoy sredy. Tom 2. Universal'niye zakony mekhaniki i elektrodinamiki sploshykh sred.* [Continuum Mechanics. Vol. 2. Universal laws of continuum mechanics and electrodynamics]. Moscow, BMSTU Publ., 2011, 560 p.

[20] Dimitrienko Yu.I. *Mekhanika sploshnoy sredy. Tom 4. Osnovy mekhaniki tverdogo tela* [Continuum Mechanics. Vol. 4. Fundamentals of solid mechanics]. Moscow, BMSTU Publ., 2013, 624 p.

[21] Golub, G.H. Eigenvalue computation in the 20th century. *J. of Computational and Applied Mathematics*, 2000, vol. 23, no. 1–2, pp. 35–65. doi:10.1016/S0377-0427(00)00413-1

Dimitrienko Yu.I. (b. 1962) graduated from Lomonosov Moscow State University in 1984. Dr. Sci. (Phys.-Math.), Professor, Head of the Computational Mathematics and Mathematical Physics Department, Director of Scientific-educational Center of Super-computer Engineering Modeling and Program Software Development of Bauman Moscow State Technical University. Member of the Russian Academy of Engineering Sciences. Author of over 300 publications in the field of computational mechanics, gasdynamics, thermomechanics of composite materials, mathematical simulations in material science. e-mail: dimit.bmtstu@gmail.com.

Gubareva E.A. (b. 1982) graduated from Lomonosov Moscow State University in 2004. Cand. Sci. (Phys.-Math.), Assoc. Professor, deputy head of the Computational Mathematics and Mathematical Physics Department at Bauman Moscow State Technical Universi-

ty. Author 40 scientific publications in the field of composite mechanics, asymptotic analysis, contact mechanics. e-mail: gubareva_ea@pochta.ru

Kolzhanova D.Yu. (b. 1993), student of the Computational Mathematics and Mathematical Physics Department at Bauman Moscow State Technical University.
e-mail: darya.kolzhanova@yandex.ru