Barreto, Darius Diogo; Kumar, Ajeet; Santapuri, Sushma

Extension-torsion-inflation coupling in compressible magnetoelastomeric thin tubes with helical magnetic anisotropy. (English) Zbl 1440.74064

J. Elasticity 140, No. 2, 273-302 (2020).

Summary: An axisymmetric and axially homogenous variational formulation is presented for coupled extension-torsion-inflation deformation in compressible magnetoelastomeric tubes in the presence of azimuthal and axial magnetic fields. The tube's material is assumed to have a preferred magnetization direction which lie in the radial plane but at an angle from the tube's axial direction – this imparts helical magnetic anisotropy to the tube. The governing differential equations necessary to solve the above deformation problem are obtained which are shown to reduce to a set of nonlinear algebraic equations in the thin tube limit. This allows us to obtain analytical expressions in terms of the applied magnetic field, preferred magnetization direction and magnetoelastic constants which tell us how these parameters can be tuned to generate unusual coupled deformations such as negative Poisson's effect. The study can be useful in designing magnetoelastic soft tubular actuators.

MSC:

74B20 Nonlinear elasticity
74A25 Molecular, statistical, and kinetic theories in solid mechanics
74Q15 Effective constitutive equations in solid mechanics
74F15 Electromagnetic effects in solid mechanics

Keywords:

nonlinear magnetoelasticity; extension-torsion coupling; negative Poisson's effect; helical anisotropy; thin tube

Full Text: DOI

References:

[1] Albanese, A. M.; Cunefare, K. A., Properties of a magnetorheological semi-active vibration absorber, Smart Structures and Materials 2003: Damping and Isolation, 36-44 (2003), Bellingham: SPIE, Bellingham

[2] Bustamante, R.; Dorfmann, A.; Ogden, R. W., A nonlinear magnetoelastic tube under extension and inflation in an axial magnetic field: numerical solution, J. Eng. Math., 59, 1, 139-153 (2007) · Zbl 1123.74016

[3] Bustamante, R., Transversely isotropic nonlinear magneto-active elastomers, Acta Mech., 210, 3-4, 183-214 (2010) · Zbl 1397.74063

[4] Brigadnov, I. A.; Dorfmann, A., Mathematical modeling of magneto-sensitive elastomers, Int. J. Solids Struct., 40, 18, 4659-4674 (2003) · Zbl 1054.74677

[5] Brown, W. F., Magnetoelastic Interactions (1966), Berlin: Springer, Berlin

[6] Deng, H.X., Gong, X.L.: Application of magnetorheological elastomer to vibration control. In: Nonlinear Sci. Complex. pp. 462-470 (2007) · Zbl 1282.74059

[7] Dorfmann, A.; Ogden, R. W., Magnetoelastic modelling of elastomers, Eur. J. Mech. A, Solids, 22, 4, 497-507 (2003) · Zbl 1032.74549

[8] Ericksen, J. L., Magnetizable and polarizable elastic materials, Math. Mech. Solids, 13, 1, 38-54 (2008) · Zbl 1175.74034

[9] Ginder, J. M.; Nichols, M. E.; Elie, L. D.; Tardiff, J. L., Magnetorheological elastomers: properties and applications, Smart Structures and Materials 1999: Smart Materials Technologies, 131-139 (1999), Bellingham: SPIE, Bellingham

[10] Gong, X. L.; Zhang, X. Z.; Zhang, P. Q., Fabrication and characterization of isotropic magnetorheological elastomers, Polym. Test., 24, 5, 669-676 (2005)

[11] Hutter, K., On thermodynamics and thermostatics of viscous thermoelastic solids in the electromagnetic fields. A Lagrangian formulation, Arch. Ration. Mech. Anal., 58, 4, 339-368 (1975) · Zbl 0332.73095

[12] Hutter, K., A thermodynamic theory of fluids and solids in electromagnetic fields, Arch. Ration. Mech. Anal., 64, 3, 269-298 (1977) · Zbl 0366.73001

[13] Hu, W.; Lum, G. Z.; Mastrangeli, M.; Sitti, M., Small-scale soft-bodied robot with multimodal locomotion, Nature, 554, 7690,

81 (2018)

[14] Jolly, M. R.; Carlson, J. D.; Munoz, B. C., A model of the behaviour of magnetorheological materials, Smart Mater. Struct., 5, 5, 607 (1996)

[15] Kari, L.; Blom, P., Magneto-sensitive rubber in a noise reduction context-exploring the potential, Plast. Rubber Compos., 34, 8, 365-371 (2005)

[16] Kankanala, S. V.; Triantafyllidis, N., On finitely strained magnetorheological elastomers, J. Mech. Phys. Solids, 52, 12, 2869-2908 (2004) · Zbl 1115.74321

[17] Kashima, S.; Miyasaka, F.; Hirata, K., Novel soft actuator using magnetorheological elastomer, IEEE Trans. Magn., 48, 4, 1649-1652 (2012)

[18] Kim, Y.; Parada, G. A.; Liu, S.; Zhao, X., Ferromagnetic soft continuum robots, Sci. Robot., 4, 33 (2019)

[19] Kovetz, A., Electromagnetic Theory, vol. 975 (2000), Oxford: Oxford University Press, Oxford · Zbl 1038.78001

[20] Maugin, G. A., Continuum Mechanics of Electrodynamics Solids (1988) · Zbl 0652.73002

[21] Eringen, A. C.; Maugin, G. A., Electrodynamics of Continua I. Foundations and Solid Media (1990), Berlin: Springer, Berlin

[22] Mehnert, M.; Hossain, M.; Steinmann, P., Towards a thermo-magneto-mechanical coupling framework for magneto-rheological elastomers, Int. J. Solids Struct., 128, 117-132 (2017)

[23] Ogden, R. W.; Steigman, D., Mechanics and Electrodynamics of Magneto-and Electro-Elastic Materials (2011), Wien: Springer, Wien

[24] Pan, E.; Heyliger, P. R., Free vibrations of simply supported and multilayered magneto-electro-elastic plates, J. Sound Vib., 252, 3, 429-442 (2002)

[25] Pao, Y. H., Electromagnetic forces in deformable continua, Mechanics Today (A78-35706 14-70), 209-305 (1978), New York: Pergamon Press, Inc., New York

[26] Pelteret, J. P.; Walter, B.; Steinmann, P., Application of metaheuristic algorithms to the identification of nonlinear magneto-viscoelastic constitutive parameters, J. Magn. Magn. Mater., 464, 116-131 (2018)

[27] Ren, Z.; Hu, W.; Dong, X.; Sitti, M., Multi-functional soft-bodied jellyfish-like swimming, Nat. Commun., 10, 1, 1-12 (2019)

[28] Saxena, P., Finite deformations and incremental axisymmetric motions of a magnetoelastic tube, Math. Mech. Solids, 23, 6, 950-983 (2018) · Zbl 1395.74033

[29] Saxena, S.; Barreto, D. D.; Kumar, A., Extension-torsion-inflation coupling in compressible electroelastomeric thin tubes, Math. Mech. Solids, 25, 3, 644-663 (2020)

[30] Santapuri, S.; Lowe, R. L.; Bechtel, S. E.; Dapino, M. J., Thermodynamic modeling of fully coupled finite-deformation thermo-electro-magneto-mechanical behavior for multifunctional applications, Int. J. Eng. Sci., 72, 117-139 (2013) · Zbl 1423.74245

[31] Santapuri, S.; Steigmann, D. J., Toward a nonlinear asymptotic model for thin magnetoelastic plates, Generalized Models and Non-classical Approaches in Complex Materials 1, 705-716 (2018), Cham: Springer, Cham

[32] Shariff, M. H.B. M.; Bustamante, R.; Hossain, M.; Steinmann, P., A novel spectral formulation for transversely isotropic magneto-elasticity, Math. Mech. Solids, 22, 5, 1158-1176 (2017) · Zbl 1371.74101

[33] Soria-Hernández, C. G.; Palacios-Pineda, L. M.; Elías-Zúñiga, A.; Perales-Martínez, I. A.; Martínez-Romero, O., Investigation of the effect of carbonyl iron micro-particles on the mechanical and rheological properties of isotropic and anisotropic MREs: constitutive magneto-mechanical material model, Polymers, 11, 10, 1705 (2019)

[34] Steigmann, D. J., On the formulation of balance laws for electromagnetic continua, Math. Mech. Solids, 14, 4, 390-402 (2009) · Zbl 1257.74052

[35] Singh, R.; Kumar, S.; Kumar, A., Effect of intrinsic twist and orthotropy on extension-twist-inflation coupling in compressible circular tubes, J. Elast., 128, 2, 175-201 (2017) · Zbl 1374.74017

[36] Singh, R., Singh, P., Kumar, A.: Unusual extension-torsion-inflation couplings in pressurized thin circular tubes with helical anisotropy

[37] Walter, B. L.; Pelteret, J. P.; Kaschta, J.; Schubert, D. W.; Steinmann, P., On the wall slip phenomenon of elastomers in oscillatory shear measurements using parallel-plate rotational rheometry: II. Influence of experimental conditions, Polym. Test., 61, 455-463 (2017)

[38] Zhu, J. T.; Xu, Z. D.; Guo, Y. Q., Magnetoviscoelasticity parametric model of an MR elastomer vibration mitigation device, Smart Mater. Struct., 21, 7 (2012)

[39] https://www.cse-distributors.co.uk/cable/technical-tables-useful-info/table-4e1a