El Majaty, Youssri; Brenner, Renald; Leblond, Jean-Baptiste

FFT-based micromechanical simulations of transformation plasticity. Comparison with a limit-analysis-based theory. (English) Zbl 1478.74012

Eur. J. Mech., A, Solids 86, Article ID 104152, 15 p. (2021).

Summary: This work addresses the numerical simulation of transformation plasticity by using a numerical scheme based on the fast Fourier transform (FFT). A two-phase material with isotropic thermo-elastoplastic phases is considered. Together with prescribed transformation kinetics, this permits to describe the plasticity induced by the accommodation of the volume change accompanying the phase transformation (Greenwood-Johnson mechanism). We consider random distributions of α-phase nuclei within a homogeneous γ-phase matrix, with an isotropic growth law of the nuclei. The numerical results are compared to a recently proposed limit-analysis-based theory [*Y. El Majaty* et al., "A novel treatment of Greenwood-Johnson's mechanism of transformation plasticity – case of spherical growth of nuclei of daughter-phase", J. Mech. Phys. Solids 121, 175–197 (2018; doi:10.1016/j.jmps.2018.07.014)], which permits in particular to account for a nonlinear dependence of the "transformation plastic strain" with the stress applied. A very good agreement between the FFT simulations and the theory is obtained, for uniaxial and multiaxial loadings, over a wide range of stresses applied.

MSC:

74C05 Small-strain, rate-independent theories of plasticity (including rigid-plastic and elasto-plastic materials)
74N99 Phase transformations in solids
74S25 Spectral and related methods applied to problems in solid mechanics
74F05 Thermal effects in solid mechanics

Keywords:

fast Fourier transform; transformation plasticity; Greenwood-Johnson phase transformation model; two-phase thermo-elastoplastic material

Software:

Neper

Full Text: DOI

References:

[1] Barbe, F.; Quey, R., A numerical modelling of 3D polycrystal-to-polycrystal diffusive phase transformations involving crystal plasticity, Int. J. Plast., 27, 6, 823-840 (2011) · Zbl 1453.74069

[2] Barbe, F.; Quey, R.; Taleb, L., Numerical modelling of the plasticity induced during diffusive transformation. Case of a cubic array of nuclei, Eur. J. Mech. A, 26, 4, 611-625 (2007) · Zbl 1261.74007

[3] Barbe, F.; Quey, R.; Taleb, L.; de Cursi, E. S., Numerical modelling of the plasticity induced during diffusive transformation. An ensemble averaging approach for the case of random arrays of nuclei, Eur. J. Mech. A, 27, 6, 1121-1139 (2008) · Zbl 1151.74399

[4] Brenner, R.; Lebensohn, R.; Castelnau, O., Elastic anisotropy and yield surface estimates of polycrystals, Int. J. Solids Struct., 46, 16, 3018-3026 (2009) · Zbl 1167.74367

[5] Cherkaoui, M.; Berveiller, M.; Lemoine, X., Couplings between plasticity and martensitic phase transformation: overall behavior of polycrystalline TRIP steels, Int. J. Plast., 16, 10-11, 1215-1241 (2000) · Zbl 1064.74637

[6] Coret, M.; Calloch, S.; Combescure, A., Experimental study of the phase transformation plasticity of 16MND5 low carbon steel under multiaxial loading, Int. J. Plast., 18, 12, 1707-1727 (2002)

[7] Coret, M.; Calloch, S.; Combescure, A., Experimental study of the phase transformation plasticity of 16MND5 low carbon steel induced by proportional and nonproportional biaxial loading paths, Eur. J. Mech. A, 23, 5, 823-842 (2004) · Zbl 1058.74502

[8] Desalos, Y., Comportement Mécanique et Dilatométrique de l'Austénite Métastable de l'Acier A533IRSID Report 95349401 (1981), Rapport

[9] Diani, J.; Sabar, H.; Berveiller, M., Micromechanical modelling of the transformation induced plasticity (TRIP) phenomenon

in steels, Internat. J. Engrg. Sci., 33, 13, 1921-1934 (1995) · Zbl 0899.73462

[10] El Majaty, Y.; Leblond, J.-B.; Kondo, D., A novel treatment of Greenwood-Johnson's mechanism of transformation plasticity - Case of spherical growth of nuclei of daughter-phase, J. Mech. Phys. Solids, 121, 175-197 (2018)

[11] Fischlschweiger, M.; Cailletaud, G.; Antretter, T., A mean-field model for transformation induced plasticity including backstress effects for non-proportional loadings, Int. J. Plast., 37, 53-71 (2012)

[12] Fukumuto, M.; Yoshizaki, M.; Imataka, H.; Okamua, K.; Yamamoto, K., Three-dimensional FEM analysis of helical gear subjected to the carburized quenching process, J. Soc. Mater. Sci. Japan, 50, 6, 598-605 (2001)

[13] Gallican, V.; Brenner, R., Homogenization estimates for the effective response of fractional viscoelastic particulate composites, Contin. Mech. Thermodyn., 31, 3, 823-840 (2019) · Zbl 1442.74014

[14] Ganghoffer, J.; Denis, S.; Gautier, E.; Simon, A.; Sjostrom, S., Finite element calculation of the micromechanics of a diffusional transformation, (Mechanical Behaviour of Materials VI (1992), Elsevier), 165-170

[15] Greenwood, G. W.; Johnson, R., The deformation of metals under small stresses during phase transformations, Proc. R. Soc. Lond. A, 283, 1394, 403-422 (1965)

[16] Gurson, A. L., Continuum theory of ductile rupture by void nucleation and growth: Part I — Yield criteria and flow rules for porous ductile media, J. Eng. Mater. Technol., 99, 1, 2-15 (1977)

[17] Hill, R., The essential structure of constitutive laws for metal composites and polycrystals, J. Mech. Phys. Solids, 15, 2, 79-95 (1967)

[18] Kempen, A.; Sommer, F.; Mittemeijer, E., Determination and interpretation of isothermal and non-isothermal transformation kinetics; the effective activation energies in terms of nucleation and growth, J. Mater. Sci., 37, 7, 1321-1332 (2002)

[19] Lebensohn, R. A.; Brenner, R.; Castelnau, O.; Rollett, A. D., Orientation image-based micromechanical modelling of subgrain texture evolution in polycrystalline copper, Acta Mater., 56, 15, 3914-3926 (2008)

[20] Lebensohn, R. A.; Kanjarla, A. K.; Eisenlohr, P., An elasto-viscoplastic formulation based on fast fourier transforms for the prediction of micromechanical fields in polycrystalline materials, Int. J. Plast., 32, 59-69 (2012)

[21] Leblond, J.-B.; Devaux, J.; Devaux, J., Mathematical modelling of transformation plasticity in steels I: case of ideal-plastic phases, Int. J. Plast., 5, 6, 551-572 (1989)

[22] Lee, S.-B.; Lebensohn, R.; Rollett, A. D., Modeling the viscoplastic micromechanical response of two-phase materials using Fast Fourier transforms, Int. J. Plast., 27, 5, 707-727 (2011) · Zbl 1405.74012

[23] Magee, C. L.; Paxton, H. W., Transformation Kinetics, Microplasticity and Aging of Martensite in Fe-31 NiTechnical Report (1966), Carnegie Inst. of Tech.: Carnegie Inst. of Tech. Pittsburgh, PA

[24] Mandel, J., Contribution théorique à l'étude de l'écrouissage et des lois de l'écoulement plastique, (Applied Mechanics (1966), Springer), 502-509

[25] Miyao, K.; Wang, Z.; Inoue, T., Analysis of temperature, stress and metallic structure in carburized-quenched gear considering transformation plasticity, J. Soc. Mater. Sci. Japan, 35, 399, 1352-1357 (1986)

[26] Monchiet, V.; Charkaluk, E.; Kondo, D., A micromechanics-based modification of the gurson criterion by using eshelby-like velocity fields, Eur. J. Mech. A, 30, 6, 940-949 (2011) · Zbl 1278.74024

[27] Moulinec, H.; Suquet, P., A numerical method for computing the overall response of nonlinear composites with complex microstructure, Comput. Methods Appl. Mech. Engrg., 157, 1-2, 69-94 (1998) · Zbl 0954.74079

[28] Offerman, S.; Van Dijk, N.; Sietsma, J.; Lauridsen, E.; Margulies, L.; Grigull, S.; Poulsen, H.; van der Zwaag, S., Phase transformations in steel studied by 3DXRD microscopy, Nucl. Instrum. Methods Phys. Res. B, 246, 1, 194-200 (2006)

[29] Offerman, S.; Van Wilderen, L.; Van Dijk, N.; Sietsma, J.; Rekveldt, M. T.; Van der Zwaag, S., In-situ study of pearlite nucleation and growth during isothermal austenite decomposition in nearly eutectoid steel, Acta Mater., 51, 13, 3927-3938 (2003)

[30] Otsuka, T., Modélisation Micromécanique de la Plasticité de Transformation dans les Aciers par Homogénéisation Numérique Fondée sur la TFR (2014), Université Paris 13, (Ph.D. thesis)

[31] Otsuka, T.; Brenner, R.; Bacroix, B., FFT-based modelling of transformation plasticity in polycrystalline materials during diffusive phase transformation, Internat. J. Engrg. Sci., 127, 92-113 (2018) · Zbl 1423.74717

[32] Quey, R.; Dawson, P.; Barbe, F., Large-scale 3D random polycrystals for the finite element method: Generation, meshing and remeshing, Comput. Methods Appl. Mech. Engrg., 200, 17-20, 1729-1745 (2011) · Zbl 1228.74093

[33] Suquet, P.; Moulinec, H.; Castelnau, O.; Montagnat, M.; Lahellec, N.; Grennerat, F.; Duval, P.; Brenner, R., Multi-scale modeling of the mechanical behavior of polycrystalline ice under transient creep, Procedia IUTAM, 3, 76-90 (2012)

[34] Taleb, L.; Cavallo, N.; Waeckel, F., Experimental analysis of transformation plasticity, Int. J. Plast., 17, 1, 1-20 (2001)

[35] Taleb, L.; Petit, S.; Jullien, J.-F., Prediction of residual stresses in the heat affected zone, (J. Phys. IV (Proceedings), Vol. 120 (2004), EDP sciences), 705-712

[36] Taleb, L.; Sidoroff, F., A micromechanical modeling of the Greenwood-Johnson mechanism in transformation induced plasticity, Int. J. Plast., 19, 1821-1842 (2003) · Zbl 1098.74550

[37] Vincent, Y.; Bergheau, J.-M.; Leblond, J.-B., Viscoplastic behaviour of steels during phase transformations, C.-R. Méc., 331, 9, 587-594 (2003)

[38] Weisz-Patrault, D., Multiphase model for transformation induced plasticity. Extended Leblond's model, J. Mech. Phys. Solids, 106, 152-175 (2017)

[39] Wong, S. L.; Madivala, M.; Prahl, U.; Roters, F.; Raabe, D., A crystal plasticity model for twinning- and transformation-

induced plasticity, Acta Mater., 118, 140-151 (2016)