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Anisotropic yield criterion for metals exhibiting tension-compression asymmetry. (English)

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Summary: The present study is devoted to developing a yield criterion that can model both the yielding asymmetry and plastic anisotropy of pressure-insensitive metals. First, a new isotropic yield criterion which can model the yielding asymmetry of pressure-insensitive metals is proposed. The main advantage of the proposed criterion is that it leads to a good approximation of yield loci calculated by the Taylor-Bishop-Hill crystal plasticity model. Further, the isotropic criterion is extended to orthotropy to take plastic anisotropy into account. The new anisotropic criterion is general and can be used in three-dimensional stresses. The coefficients of the criterion are determined by an error minimization procedure. Applications of the proposed theory to a hexagonal close packed (HCP) magnesium, a Cu-Al-Be shape memory alloy and a Ni3Al based intermetallic alloy show that the proposed theory can describe well the plastic anisotropy and yielding asymmetry of metals and the transformation onset of the shape memory alloy, showing excellent predictive ability and flexibility.

MSC:

74C05 Small-strain, rate-independent theories of plasticity (including rigid-plastic and elasto-plastic materials)
74D10 Nonlinear constitutive equations for materials with memory
74E10 Anisotropy in solid mechanics

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Keywords:

yield criterion; yielding asymmetry; plastic anisotropy; Magnesium alloy; shape memory alloy; intermetallic alloy

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References:

[1] D. BANABIC, Sheet Metal Forming Processes: Constitutive Modelling and Numerical Sim-ulation, Springer Heidelberg, Dordrecht, London New York, (2010).

[2] H. YANG, X. G. FAN, AND Z. C. SUN ET AL., Recent developments in plastic forming technology of titanium alloys, Sci. China. Tech. Sci., 54 (2011), pp. 490-501.

[3] F. F. ZHANG, J. S. CHEN, AND J. CHEN ET AL., Review on development and experimental vali-dation for anisotropic yield criterions (in Chinese), Adv. Mech., 42 (2012), pp. 68-80.

[4] D. C. DRUCKER, Relation of experiments to mathematical theories of plasticity, J. Appl. Mech., 16 (1949), pp. 349-357. · Zbl 0036.39903

[5] A. V. HERSHEY, The plasticity of an isotropic aggregate of anisotropic face centered cubic crystals, J. Appl. Mech. Trans. ASME, 21 (1954), pp. 241-249. · Zbl 0059.18802

[6] M. H. YU, L. N. HE, AND L. Y. SONG, Twin shear stress strength theory and its generalization (in Chinese), Sci. China. Ser A, 12 (1985), pp. 1113-1120.

[7] R. HILL, A theory of the yielding and plastic flow of anisotropic metals, Proc. Soc. London. A, 193 (1948), pp. 281-297. · Zbl 0032.08805

[8] D. BANABIC, Anisotropy of Sheet Metals, Springer-Verlag, Berlin Heidelberg, New York, (2000).

[9] M. H. YU, Advances in strength theories for materials under complex stress state in the 20th Cen-tury, Appl. Mech. Rev., 55 (2002), pp. 198-218.

[10] R. HILL, Theoretical plasticity of textured aggregates, Math. Proc. Camb. Phil. Soc., 85 (1979), pp. 179-191. · Zbl 0388.73029

[11] R. HILL, Constitutive modelling of orthotropic plasticity in sheet metals, J. Mech. Phys. Solids, 38 (1990), pp. 405-417. · Zbl 0713.73044

[12] R. HILL, A user-friendly theory of orthotropic plasticity in sheet metals, Int. J. Mech. Sci., 35 (1993), pp. 19-25. · Zbl 0825.73174

[13] R. HILL, S. S. HECKER, AND M. S. STOUT, An investigation of plastic flow and differential work hardening in orthotropic

brass tubes under fluid pressure and axial load, Int. J. Solids. Struct., 31 (1994), pp. 2999-3021. · Zbl 0943.74509

[14] W. F. HOSFORD, Texture strengthening, Metals. Eng. Quart., 6 (1966), pp. 13-19.

[15] W. F. HOSFORD, A generalized isotropic yield criterion, J. Appl. Mech., 39 (1972), pp. 607-609.

[16] W. F. HOSFORD, AND T. J. ALLEN, Twining and directional slip as a cause for strength differential effect, Met. Trans., 4 (1973), pp. 1424-1425.

[17] W. F. HOSFORD, The Mechanics of Crystals and Textured Polycrystals, Oxford University Press, New York, (1993).

[18] F. BARLAT, AND J. LIAN, Plastic behavior and stretchability of sheet metals. Part I: Yield function for orthotropic sheets under plane stress conditions, Int. J. Plast., 5 (1989), pp. 51-66.

[19] F. BARLAT, D. J. LEGE, AND J. C. BREM, A six-component yield function for anisotropic materi-als, Int. J. Plast., 7 (1991), pp. 693-712.

[20] F. BARLAT, J. C. BREMA, AND J. W. YOON ET AL., Plane stress yield function for aluminum alloy sheets-part 1: theory, Int. J. Plast., 19 (2003), pp. 1297-1319. · Zbl 1114.74370

[21] F. BARLAT, J. N. YOON, AND O. CAZACU, On linear transformations of stress tensors for the description of plastic anisotropy, Int. J. Plast., 23 (2007), pp. 876-896. · Zbl 1359.74014

[22] L. B. XIN, G. S. DUI, AND S. Y. YANG ET AL., Elastic-plastic analysis for functionally graded thick-walled tube subjected to internal pressure, Adv. Appl. Math. Mech., 8 (2016), pp. 331-352.

[23] Z. Y. CAI, M. WAN AND Z. G. LIU ET AL., Approximate method formulating plastic potentials of porous sheet metals with non-quadratic anisotropy, Int. J. Mech. Sci., 123 (2017), pp. 198-213.

[24] H. B. WANG, W. ZHOU AND Y. YAN ET AL., Parameter determination method of Gotoh yield criterion based on non-associated flow rule, China J. Theor. Appl. Mech., 50 (2018), pp. 1051-1062.

[25] W. C. LIU. B. K. CHEN, AND Y. PANG, Numerical investigation of evolution of earing, anisotropic yield and plastic potentials in cold rolled FCC aluminum alloy based on the crystallo-graphic texture measurements, Euro. J. Mech. A/Solids, 75 (2019), pp. 41-55. · Zbl 07067440

[26] Y. S. LOU, AND J. W. YOON, Alternative approach to model ductile fracture by incorporating anisotropic yield function, Int. J. Solids. Struct., 164 (2019), pp. 12-24.

[27] X. S. WANG, W. L. HU, AND S. J. HUANG, ET AL., Experimental investigations on extruded 6063 aluminum alloy tubes under complex tension-compression stress states, Int. J. Solids. Struct., 168 (2019), pp. 123-137.

[28] S. S. EZZ, D. P. POPE, AND V. PAIDAR, The tension/compression flow stress asymmetry in Ni 3 (Al, Nb) single crystals, Acta. Metall., 30 (1982), pp. 921-926.

[29] O. CAZACU, AND F. BARLAT, A criterion for description of anisotropy and yield differential effects in pressure-insensitive metals, Int. J. Plast., 20 (2004), pp. 2027-2045. · Zbl 1107.74006

[30] O. CAZACU, B. PLUNKETT, AND F. BARLAT, Orthotropic yield criterion for hexagonal close packed metals, Int. J. Plasticity, 22 (2006), pp. 1171-1194. · Zbl 1090.74015

[31] O. CAZACU, R. I. IOAN, AND W. Y. JEONG, Orthotropic strain rate potential for the description of anisotropy in tension and compression of metals, Int. J. Plasticity, 26 (2010), pp. 887-904. · Zbl 1426.74056

[32] Y. S LOU, H. HUH, J. W. YOON, Consideration of strength differential effect in sheet metals with symmetric yield functions, Int. J. Mech. Sci., 66 (2013), pp. 214-223.

[33] O. CAZACU, AND J. B. STEWART, Analytical criterion for porous solids containing cylindri-cal voids in an incompressible matrix exhibiting tension-compression asymmetry, Philos. Mag., 93 (2013), pp. 1520-1548.

[34] R. K. VERMA, T. KUWABARA, AND K. CHUNG ET AL., Experimental evaluation and constitu-tive modeling of non-proportional deformation for asymmetric steels, Int. J. Plast., 27 (2011), pp. 82-101.

[35] D. STEGLICH, W. BROCKS, AND J. BOHLEN ET AL., Modeling direction-dependent hardening in magnesium sheet forming simulations, Int. J. Mater Form., 4 (2011), pp. 243-253.

[36] M. N. MEKONEN, D. STEGLICH, AND J. BOHLEN ET AL., Mechanical characterization and constitutive modeling of Mg alloy sheets, Mater. Sci. Eng. A, 540 (2012), pp. 174-186.

[37] M. O. ANDAR, T. KUWABARA, AND D. STEGLICH, Material modeling of AZ31 Mg sheet con-sidering variation of r-values and asymmetry of the yield locus, Mater. Sci. Eng. A, 549 (2012), pp. 82-92.

[38] O. CAZACU, New yield criteria for isotropic and textured metallic materials, Int. J. Solids. Struct., 139-140 (2018), pp. 200-210.

[39] A. R. RAJAB, AND S. E. BAYAOUMI, Fundamentals and Applications, CRC Press LLC, (1999).

[40] G. I. TAYLOR, AND H. QUINNEY, The plastic distortion of metals, Philos. Trans. R. Soc. A, 230 (1931), pp. 323-362. · Zbl 0003.08003

[41] J. W. F. BISHOP, AND R. HILL, A theoretical deviation of the plastic properties of a polycrystalline face-centered metal, Philos. Mag. Ser., 42 (1951), pp. 1298-1307. · Zbl 0044.45002

[42] Z. SOBOTKA, The fundamental relations of theory of plasticity and a new concept of the plastic potential for the anisotropic materials, Stavebnicky, Casopsis XIV, pp. 373-380.

[43] J. P. BOEHLER, AND A. SAWCZUK, Equilibre limite des sols anisotropes, J. Mecanique., 9 (1970), pp. 5-33. · Zbl 0194.28402

[44] A. P. KARAFILLIS, AND M. C. BOYCE, A general anisotropic yield criterion using bounds and a transformation weighting tensor, J. Mech. Phys. Solids, 41 (1993), pp. 1859-1886. · Zbl 0792.73029

[45] O. CAZACU, AND F. BARLAT, Generalization of Drucker's yield criterion to orthotropy, Math. Mech. Solids. 6 (2001), pp. 613-630. · Zbl 1128.74303

[46] Q. HU, X. F. LI AND X. H. HAN ET AL., A normalized stress invariant-based yield criterion: Modeling and validation, Int. J. Plast., 99 (2017), pp. 248-273.

[47] W. ALT, Nichtlineare Optimierung, Vieweg Verlag, (2002).

[48] H. ARETZ, A nonquadratic plane stress yield function for ortho-tropic sheet metals, J. Mater. Pro-ces. Tech., 168 (2005), pp. 1-9.

[49] M. O. ANDAR, T. KUWABARA, AND D. STEGLICHC, Material modeling of AZ31 Mg sheet considering variation of r-values and asymmetry of the yield locus, Mater. Sci. Eng. A, 549 (2012), pp. 82-92.

[50] M. O. ANDAR, T. KUWABARA, AND D. STEGLICHC, Description of Anisotropy and yield dif-ferential effects for AZ31 Mg sheet using Cazacu 2004 yield criterion, J. JSEM, Special Issue, 12 (2012), pp. 151-156.

[51] C. BOUVET, S. CALLOCH, AND C. LEXCELLENT, Mechanical behavior of a Cu-Al-Be shape memory alloy under multiaxial proportional and non-proportional loadings, J. Eng. Mater. Tech., 124 (2002), pp. 112-124.

[52] X. H. ZHAO, Z. H. HUANG, AND Y. N. TAN ET AL., New Ni3Al-based direction-ally-solidified superalloy IC10, J. Aeronaut. Mate., 26 (2006), pp. 20-24.

[53] L. CHEN, W. D. WEN, AND H. T. CUI, Measurement and analysis of yield locus of superalloy IC10 under biaxial tension, Acta. Aeronaut. Astronaut. Sin., 33 (2012), pp. 77-84.

[54] A. S. KHAN, S. J. YU, AND H. W. LIU, Deformation induced anisotropic responses of Ti-6Al-4V alloy Part II: A strain rate and temperature dependent anisotropic yield criterion, Int. J. Plast., 7 (2012), pp. 14-26.