Lallit Anand

Warren and Towneley Rohsenow Professor of Mechanical Engineering, MIT

Anand

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Lallit Anand received his B.Tech. (Hons.) in Mechanical Engineering from the Indian Institute of Technology in Kharagpur in 1970, and earned his PhD degree in 1975 from Brown University. The same year he joined the Mechanical Sciences Division of the Fundamental Research Laboratory of the U.S. Steel Corporation, and served successively as Research Scientist and Senior Research Scientist till 1981. In 1982 he joined the faculty of the Massachusetts Institute of Technology (MIT) as an Assistant Professor, and currently is the Warren and Towneley Rohsenow Professor of Mechanical Engineering. He was elected to the National Academy of Engineering in 2018.

At MIT he has served as the Head of the Area for Mechanics (2008-2013). During the five-year period 1994–1999, he served on the Executive Committee of the Applied Mechanics Division of ASME. In addition, during the period September 1989 through August 1991 he served as the Program Director for the Mechanics of Materials Program, as well as the Manufacturing Processes Program in the Engineering Directorate of the National Science Foundation.

Anand teaches undergraduate and graduate subjects related to Mechanics of Materials, Solid Mechanics, Continuum Mechanics, and Plasticity at MIT.

He has been engaged in a broad-ranging research program in *Mechanics of Materials* which brings systematic theory, experiment, and computation to model the large inelastic deformation of a wide variety of engineering materials, including polycrystalline metals, granular materials, amorphous metals, and polymers. Many of the theories that he has developed have been numerically implemented in finite-element-based computer programs and are widely used for structural and materials-processing design in engineering. His research over the last five years has focused on:

- Formulating a continuum-mechanical theory to describe the various coupled aspects of fluid permeation, large deformations, and fracture of elastomeric gels.
- Developing a unified framework of balance laws and thermodynamically-consistent constitutive equations which couple Cahn-Hilliard-type species diffusion with large elastic-plastic deformations of a body, and account for the swelling and phase segregation caused by the diffusing species. Potential applications of the theory is in the chemo-mechanical analysis of the active electrode particles of lithium-ion batteries during charge-discharge cycles.

He has published over 120 archival journal papers, and advised the research of 27 PhD students at MIT. He has also published three books:

(i) An advanced graduate level book on continuum mechanics with Morton Gurtin and Eliot Fried, titled *The Mechanics and Thermodynamics of Continua*, Cambridge University Press, New York, 2010.

(ii) A book on solid mechanics for first year graduate students with Sanjay Govindjee, titled *Continuum Mechanics of Solids*, Oxford University Press, Oxford, UK, 2020.

(iii) An book on solid mechanics for junior/senior-level undergraduate students with Ken Kamrin and Sanjay Govindjee, titled *Introduction to Mechanics of Solid Materials*, Oxford University Press, Oxford, UK, 2022.

Honors

The honors he has received include:

- Esther and Harold E. Edgerton Professor of Mechanical Engineering, 1983-85.
- Eric Reissner Medal, 1992. *For outstanding contributions to the field of Mechanics of Materials in the past decade.* From the International Society for Computational Engineering & Sciences.
- Southwest Mechanics Series Lecturer, 1992.
- Fellow of Singapore-MIT Alliance, 1999-2013.
- Fellow of American Society of Mechanical Engineers, 2003.
- Clark B. Millikan Visiting Professorship at California Institute of Technology, 2004.
- Khan International Plasticity Medal, 2007. *For outstanding life-long contributions to the field of Plasticity.* From the International Journal of Plasticity.
- Warren and Towneley Rohsenow Professor of Mechanical Engineering, 2009- .
- Special issue of the International Journal of Plasticity in Honor of Lallit Anand, Volume 26, Issue 8, August 2010.
- Distinguished Alumnus Award from Indian Institute of Technology (IIT), Kharagpur, 2011.
- Daniel C. Drucker Medal, 2014. This ASME medal recognizes distinguished contributions to the field of applied mechanics and mechanical engineering through research, teaching, and service to the community over a substantial period of time.
- J. P. Den Hartog Distinguished Educator Award, 2017. This is the highest award conferred for excellence in teaching Mechanical Engineering at Massachusetts Institute of Technology.
- Brown University Engineering Alumni Medal, 2018.
- William Prager Medal, 2018, Society of Engineering Science. “In recognition of outstanding achievements in Solid Mechanics.”
- Member of the National Academy of Engineering, 2018. “For contributions to the development of plasticity for engineering technology: theory, experiment, and computation.”

Leadership and service

In addition to his teaching and research, he has also made significant service contributions in leadership positions:

- **To the Mechanical Engineering Department at MIT**: (i) He served as the Departmental Graduate Admissions Officer during the period 1997–2001. (ii) He served as the Departmental Graduate Officer during the period 2005–2008. (iii) He served as the Head of the Area for Mechanics: Modeling, Experimentation, and Computation (MMEC), 2008–2013.
- **To his field**: (i) He served as the Program Director for the Mechanics and Materials Program, as well as the Manufacturing Processes Program at NSF during the two-year period 1989–1991. For this service to the nation he received a Outstanding Service Citation from NSF in 1991. (ii) During the five-year period 1994–1999, he served the Applied Mechanics community through his service on the Executive Committee of the Applied Mechanics Division of ASME; he was the Chair of this Committee in 1999.

Publication highlights

Polycrystalline plasticity and crystallographic texture evolution

His research highlights are best illustrated by the following two papers with his former students Kalidindi and Bronkhorst on polycrystalline plasticity and crystallographic texture evolution in fcc metals:

- Kalidindi, S.R., Bronkhorst, C.A., Anand, L., 1992. Crystallographic texture evolution in bulk deformation processing of fcc metals. *Journal of the Mechanics and Physics of Solids* 40, 537-569.

- Bronkhorst, C.A., Kalidindi, S.R., Anand, L., 1992. Polycrystalline plasticity and the evolution of crystallographic texture in fcc metals. *Philosophical Transactions of The Royal Society London A* 341, 443-477.

Prior to the publication of these two papers, the topic of constitutive modeling, numerical implementation, and experimental validation of polycrystalline plasticity — based on single crystal deformation — had appeared in various differing, incomplete, and widely-disparate formats in the technical literature. In contrast, Anand and his students provided a comprehensive set of pedigreed experimental stress-strain curves on polycrystalline copper undergoing large deformation in tension, compression, and simple-shear, together with x-ray pole-figure measurements which documented the corresponding evolution of crystallographic texture. They showed that a modern version of a polycrystal theory, first developed by G.I. Taylor, when numerically implemented within a finite element program was able to successfully predict the stress-strain response and the evolution of crystallographic texture. Moreover, using their theory and its numerical implementation they successfully predicted the overall force-displacement curve and the spatially non-homogeneous evolution of crystallographic texture in a plane strain forging experiment. This pair of papers represent a significant milestone in the successful integration of modern continuum mechanics, physical-mechanism-based constitutive modeling, experimentation, and computation.

The crystal plasticity theory and the numerical algorithms developed by Anand and his students have been successfully incorporated into commercial finite element codes and are currently widely-used by researchers across the world.

High-temperature viscoplasticity of metals

An important example of Anand's work in developing modern large-deformation constitutive equations are his papers on high-temperature viscoplasticity of metals:

- Anand, L., 1982. Constitutive equations for the rate-dependent deformation of metals at elevated temperatures. *ASME Journal of Engineering Materials and Technology* 104, 12–17.

- Anand, L., 1985. Constitutive equations for hot-working of metals. *International Journal of Plasticity* 1, 213-231.

- Brown, S.B., Kim, K.H., Anand, L., 1989. An internal variable constitutive model for hot working of metals. *International Journal of Plasticity* 5, 95-130,

These papers, and a companion paper (Weber and Anand, Computer Methods in Applied Mechanics and Engineering 79, 173-202, 1990, see below), form the basis of the finite-element implementation of high-temperature plasticity in the widely-used commercial code ANSYS, where it is called the *Anand Viscoplastic Model.* Anand's viscoplasticity model has also been implemented as a *standard option* in three other widely-used commercial finite element programs ABAQUS, ADINA, and COMSOL. Since Anand's viscoplastic model is a built-in material modeling option in the widely-used finite element programs, it is now routinely used in industry for applications ranging from reliability prediction of solder-joints and thermal design of electronic packaging and surface mount technology, to the computational design of three-dimensional hot-deformation processing operations. Of all of Anand's publications, his papers on high-temperature viscoplasticity of metals have had **the most impact in engineering practice**.

Large deformation constitutive equations and time-integration procedure for isotropic, hyperelastic-viscoplastic solids

Another example of Anand's work in developing modern constitutive equations and robust numerical time-integration algorithms for large deformation plasticity is the following paper with his student Weber:

- Weber, G., Anand, L., 1990. Finite deformation constitutive equations, and a time integration procedure for isotropic, hyperelastic viscoplastic solids. *Computer Methods in Applied Mechanics and Engineering* 79, 173-202.

This computational-mechanics paper — whose focus is large deformation isotropic, hyperelastic-viscoplasticity — has several novel features. Weber and Anand (i) Used the Kroner-Lee $\mathbf{F} = \mathbf{F}^e\mathbf{F}^p$-based decomposition of the deformation gradient $\mathbf{F}$. (ii) Used a strain energy function based on the logarithmic elastic strain as the most appropriate hyperelastic generalization of the infinitesimal isotropic linear elasticity for moderately large elastic deformations (ASME Journal of Applied Mechanics 46, 78-82, 1979). (iii) Resolved the intrinsic indeterminacy of the $\mathbf{F} = \mathbf{F}^e\mathbf{F}^p$-based decomposition, by using rigorous continuum mechanics symmetry arguments to motivate the assumption of $\mathbf{W}^p = \mathbf{0}$ for an isotropic material. (iv) Used a rate-dependent plasticity theory using a single scalar internal hardening variable (ASME Journal of Engineering Materials and Technology 104, 12-17, 1982; International Journal of Plasticity 5, 95-130, 1989). (v) Developed a novel numerical time-integration procedure which is simple and automatically numerically-objective. In contrast to the then widely-used hypoelastic-rate-independent-plasticity framework for large deformation plasticity, the hyperelastic-viscoplastic framework of Anand and Weber is not only thermodynamically-consistent and therefore more satisfying on fundamental physical grounds, it is also of increasing current practical importance in accounting for the large elastic volumetric deformation accompanying shock and ballistic applications. The theory and numerical time-integration algorithm presented in this paper have been widely adopted by several researchers, and have also been implemented in several commercial non-linear finite-element programs.

Shear band localization instabilities

An early example of Anand's research contributions is a paper on Òshear bandsÓ with a former colleague Bill Spitzig, while both were at US Steel Research in the late 1970s:

- Anand, L., Spitzig, W.A., 1980. Initiation of localized shear bands in plane strain. *Journal of the Mechanics and Physics of Solids* 28, 113-128.

A common observation during large plastic deformations of ductile solids is that a general non-homogeneous but smoothly varying deformation pattern often gives way rather abruptly to a pattern exhibiting a loss of smoothness in the form of jump discontinuities in the displacement gradients across certain curved surfaces, while the displacements themselves remain continuous across these surfaces. Experiments show that these surfaces often bound narrow bands, the deformation within each band being predominantly one of shear parallel to the interface between the band and the adjacent material. When this occurs, the deformation is said to have been localized within Òshear bands.Ó If such a jump discontinuity in the displacement gradients across the interface between a band and the adjacent material is formed, and if it persists, then it is usually an important precursor to an occurrence of a jump in the displacements themselves (fracture) across the bounding surfaces of these shear bands. In this paper, Anand and Spitzig studied the initiation of localized shear bands in plane-strain tension and compression. By conducting carefully-crafted experiments on a high-strength maraging steel, they showed that their experiments supported the physical relevance of a theoretical framework by Rudnicki & Rice and Hill & Hutchinson, which viewed the initiation of shear bands as a bifurcation phenomenon from a homogeneous equilibrium field in an elastic-plastic solid. Anand and Spitzig showed that the predictions of the theory were in good qualitative agreement with their experimental observations. This paper has been widely cited in the literature on plastic instabilities and shear band localizations.

Shape-memory metals

Shape-memory alloys, such as Ni-Ti, are widely used as functional/smart materials for a variety of applications, including arterial stents. The individual grains in these polycrystalline materials can abruptly change their lattice structure in the presence of suitable thermo-mechanical loading. This capability of undergoing a solid-solid, diffusionless, displacive phase transformation leads to the technologically important properties of pseudoelasticity and shape-memory. In the publications,

- Thamburaja, P., Anand, L., 2001. Polycrystalline shape-memory materials: effect of crystallographic texture. *Journal of the Mechanics and Physics of Solids* 49, 709-737, and
- Anand, L., Gurtin, M.E., 2003. Thermal effects in the superelasticity of crystalline shape-memory materials. Journal of the Mechanics and Physics of solids 51, 1015-1058.

Anand, with Thamburaja and Gurtin formulated and numerically implemented a crystal-mechanics-based large-deformation constitutive theory for shape-memory materials accounting for thermal effects, and demonstrated that their theory was able to capture the major features of the experimentally-measured effects of crystallographic texture on pseudoelasticity of a polycrystalline Ti-Ni alloy in a variety of proportional and non-proportional loading experiments under both isothermal and thermo-mechanically coupled situations. The structure of the theory has also been found to be of use for modeling the elastic-plastic response of other systems which undergo austenite-martensite phase transformations.

Mechanics of metallic glasses

Over the past thirty years, certain amorphous metallic alloys which can be solidified in relatively large section sizes under moderate cooling rates have been developed. Such disordered metals, referred to as bulk metallic glasses, represent a new class of materials which possess impressive mechanical and magnetic properties. These materials hold promise for several potential applications in engineering. The micro-mechanisms of inelastic deformation in bulk metallic glasses are not related to dislocation-based mechanisms that characterize the plastic deformation of crystalline metals. Because of the lack of long-range order in the atomic structure of these materials, the plastic deformation of amorphous metallic glasses is fundamentally different from that in crystalline solids. Computer simulations in the literature show that at a micromechanical level, inelastic deformation in metallic glasses occurs by local shearing of clusters of atoms ($\approx$ 30 to 50 atoms); this shearing is accompanied by inelastic dilatation that produces strain-softening, which then leads to the formation of shear bands. In

- Anand, L., Su, C., 2005. A theory for amorphous viscoplastic materials undergoing finite deformations, with application to metallic glasses. *Journal of the Mechanics and Physics of Solids* 53, 1362-1396,

Anand, with his student Su, developed the first physical-mechanism-based continuum-level finite deformation plasticity theory for metallic glasses. The flow-rule in this theory is a rate-dependent generalization of "double-shearing" flow-rule used in soil mechanics (Anand, L., Gu, C. JMPS 48, 1710-1733, 2000).

A particularly important characteristic of metallic glasses is their intrinsic homogeneity to the nanoscale because of the absence of grain boundaries. Also, since metallic glasses are amorphous materials, they exhibit a glass transition, and at temperatures above this glass transition, they soften dramatically and are therefore amenable to net-shape thermoplastic forming processes. This characteristic, coupled with their unique mechanical properties, makes them ideal materials for fabricating nano and microscale components. This was very nicely demonstrated in two recent papers by Anand and his co-workers (Acta Materialia 56, 3290-3305, 2008; Journal of Micromechanics and Microengineering 19, Article Number: 115030, 2009).

Strain gradient plasticity

A number of experimental results published over the last twenty years, concerning the strength of micron-dimensioned metallic components undergoing inhomogeneous plastic flow, show that this strength is inherently size-dependent, with smaller being stronger. Because conventional plasticity theories do not contain intrinsic material length-scales, such theories cannot describe size-dependent phenomena, a drawback that has led to the recent development of theories that attempt to capture such phenomena via dependencies on plastic-strain gradients. Working together with Morton Gurtin of Carnegie Mellon University, Anand has published several theoretical papers on strain-gradient plasticity, of which the following paper, Working together with Morton Gurtin of Carnegie Mellon University, Anand has published several **theoretical** papers on strain gradient plasticity, of which the two major ones are:

- Gurtin, M.E., Anand, L., 2005. A theory of strain-gradient plasticity for isotropic, plastically irrotational materials. Part I: small deformations. *Journal of the Mechanics and Physics of Solids* 53, 1624–1649.

- Gurtin, M.E., Anand, L., Lele, S.P., 2007. A gradient single-crystal plasticity with free energy dependent on dislocation densities. *Journal of the Mechanics and Physics of Solids* 55, 1853–1878.

These papers have been very well received in the burgeoning literature on size-dependent plasticity.

Elastomeric gels

There are numerous elastomeric materials which can absorb large quantities of suitable fluids without the essential skeletal network structure of the elastomer being disrupted by the action of the fluid. Such a polymer network, together with the fluid molecules, forms a swollen aggregate called an elastomeric gel. Elastomeric gels are ubiquitous; they are found in foods and medicines, and they find use in several important and diverse applications including valves for microfluidic devices, and tissue engineering. Indeed, many body parts in humans and other animals are gel-like in constitution.

Anand, with his students has formulated a continuum-mechanical theory to describe the various coupled aspects of fluid permeation, heat transfer, and large deformations (e.g., swelling and squeezing) of thermally-responsive elastomeric gels. They have also numerically implemented their theory, and solved several interesting boundary-value problems of engineering interest.

- Chester, S.A., and Anand, L., 2010. A coupled theory of fluid permeation and large deformations for elastomeric materials. Journal of the Mechanics and Physics of Solids 58, 1879–1906.
- Chester, S.A., and Anand, L., 2011. A thermo-mechanically-coupled theory for fluid permeation in elastomeric materials: application to thermally-responsive gels. Journal of the Mechanics and Physics of Solids 59, 1978-2006.
- Chester, S.A., Di Leo, C.V., Anand, L., 2015. A finite element implementation of a coupled diffusion-deformation theory for elastomeric gels. International Journal of Solids and Structures 52, 1-18.
- Mao, Y., Anand, L., 2018. A theory for fracture of polymeric gels. Journal of the Mechanics and Physics of Solids 115, 30-53.

Phase-field theory for species diffusion coupled with large elastic-plastic deformations

In recent research Anand and his students have developed a unified framework of balance laws and thermodynamically-consistent constitutive equations which couple Cahn-Hilliard-type species diffusion with large elastic-plastic deformations of a body, and account for the swelling and phase segregation caused by the diffusing species. A technologically important area of application of the theory is in the chemo-mechanical analysis of the evolution of large stresses which develop because of the volume changes associated with the diffusion of lithium ions in the active electrode particles of lithium-ion batteries during charge-discharge cycles.

- Anand, L., 2012. A Cahn-Hilliard-type theory for species diffusion coupled with large elastic-plastic deformations. Journal of the Mechanics and Physics of Solids 60, 1983–2002.
- Di Leo, C.V., Rejovitzky, E., Anand, L., 2014. A Cahn-Hilliard-type phase-field theory for species diffusion coupled with large elastic deformations: application to phase-separating Li-ion electrode materials. Journal of the Mechanics and Physics of Solids 70, 1-29.
- Di Leo, C.V., Rejovitzky, E., Anand, L., 2015. Diffusion-deformation theory for amorphous silicon anodes: the role of plastic deformation on electrochemical performance. International Journal of Solids and Structures 67-68, 283-296.

These are but a few highlights of Anand's publications. He has published several other important and widely-cited papers on various topics in mechanics and physics of solids:

- **Granular materials** (JMPS 31, 105-1322, 1984; JMPS 48, 1710-1733, 2000; IJP 17, 147-209, 2001).
- **Crystal plasticity with combined slip and twinning in fcc and hcp materials** (JMPS 46, 671-696, 1198; IJP 19, 1843-1864, 2003).
- **Nanocrystalline metals** (JMPS 52, 2587-2616, 2004; Acta Materialia 54, 3177-3190, 2006);
- **Amorphous polymers** (IJSS 40, 1465-1487, 2003; IJP 25, 1474-1494, 2009; IJP 25, 1495-1459, 2009; IJP 26, 1138-1182, 2010).
- **Shape-memory polymers** (JMPS 58, 1100-1124, 2010).
- **Oxidation of metals with application to thermal barrier coatings** (IJP 27, 1409-1431, 2011; Acta Materialia 61, 399-424; Surface and Coatings Technology 222, 68-78, 2013).

Publications of Lallit Anand

Books

1. Gurtin, M.E., Fried, E., Anand, L., 2010. **The Mechanics and Thermodynamics of Continua**. Cambridge University Press, New York, ISBN 978-0-521-40598-0.

   This fundamental book on continuum mechanics includes an extensive discussion of both small-deformation and large- deformation theories of isotropic and crystal plasticity theories, as well as a treatment of modern theories of gradient-plasticity.

2. Anand, L., Govindjee, S., 2020. **Continuum Mechanics of Solids**. Oxford University Press, Oxford, UK, ISBN 978-0-19-886472-1

   This book on continuum mechanics of solid presents a unified treatment of the major concepts in Solid Mechanics for beginning graduate students in the many branches of engineering. The major topics covered in this book include: *Elasticity*, *Viscoelasticity*, *Plasticity*, *Fracture*, and *Fatigue*. In addition to these standard topics in Solid Mechanics, because of the growing need for engineering students to have a knowledge of the coupled multi-physics response of materials in modern technologies related to the environment and energy, the book also includes chapters on *Thermoelasticity*, *Chemoelasticity*, *Poroelasticity*, and *Piezoelectricity.*

3. Anand, L., Kamrin, K., Govindjee, S., 2022. **Introduction to Mechanics of Solid Materials**. Oxford University Press, Oxford, UK, ISBN: 9780192866080.

   Introduction to Mechanics of Solid Materials is concerned with the deformation, flow, and fracture of solid materials. This textbook offers a unified presentation of the major concepts in Solid Mechanics for junior/senior-level undergraduate students in the many branches of engineering — mechanical, materials, civil, and aeronautical engineering among others.

   The book begins by covering the basics of kinematics and strain, and stress and equilibrium, followed by a coverage of the small deformation theories for different types of material response: (i) Elasticity; (ii) Plasticity and Creep; (iii) Fracture and Fatigue; and (iv) Viscoelasticity. The book has additional chapters covering the important material classes of: (v) Rubber Elasticity, and (vi) Continuous-fiber laminated composites. The text includes numerous examples to aid the student. A substantial companion volume with example problems is also available on the book's companion website.

Journal papers

1. Anand, L., Gurland, J., 1975. The relationship between the size of cementite particles and the subgrain size in quenched-and-tempered steels. Metallurgical Transactions 6A, 928–931.

2. Anand, L., Gurland, J., 1976. Effect of internal boundaries on the yield strengths of spheroidized steels. Metallurgical Transactions 7A, 191–197.

3. Anand, L., Gurland, J., 1976. Strain-hardening of spheroidized high carbon steels. Acta Metallurgica 24, 901–909.

4. Anand, L., 1979. On H. Hencky's approximate strain-energy function for moderate deformations. ASME Journal of Applied Mechanics 46, 78–82.

5. Anand, L., 1980. Constitutive equations for rate-independent, isotropic elastic-plastic solids exhibiting pressure-sensitive yielding and plastic dilatancy. ASME Journal of Applied Mechanics 47, 439-441.
6. Anand, L., Spitzig, W.A., 1980. Initiation of localized shear bands in plane strain. Journal of the Mechanics and Physics of Solids 28, 113–128.
7. Anand, L., Spitzig, W.A., 1982. Shear band orientations in plane strain. Acta Metallurgica 30, 553–561.
8. Anand, L., 1982. Constitutive equations for the rate-dependent deformation of metals at elevated temperatures. ASME Journal of Engineering Materials and Technology 104, 12–17.
9. Anand, L., 1982. Elastic moduli of gray and ductile cast irons. Scripta Metallurgica 16, 173–177.
10. Anand, L., 1983. Plane deformations of ideal granular materials. Journal of the Mechanics and Physics of Solids 31, 105–122.
11. Anand, L., 1984. Some experimental observations on localized shear bands in plane strain. Scripta Metallurgica 18, 423–427.
12. Anand, L., 1984. A rate constitutive equation for moderate strain isotropic elasticity. Mechanics Research Communications 11, 345–352.
13. Anand, L., 1985. Constitutive equations for hot-working of metals. International Journal of Plasticity 1, 213-231.
14. Anand, L., 1986. Moderate deformations in extension-torsion of incompressible isotropic elastic materials. Journal of the Mechanics and Physics of Solids 34, 293–304.
15. Anand, L., Kim, K.H., Shawki, T.G., 1987. Onset of shear localization in viscoplastic solids. Journal of the Mechanics and Physics of Solids 35, 407–429.
16. Brown, S.B., Kim, K.H., Anand, L., 1989. An internal variable constitutive model for hot working of metals. International Journal of Plasticity 5, 95–130.
17. Lush, A.M., Weber, G., Anand, L., 1989. An implicit time-integration procedure for a set of internal variable constitutive equations for isotropic elasto-viscoplasticity. International Journal of Plasticity 5, 521–549.
18. Haghi, M., Anand, L., 1990. High temperature deformation mechanisms and constitutive equations for the ODS superalloy MA 956. Metallurgical Transactions 21A, 353-364.
19. Weber, G., Anand, L., 1990. Finite deformation constitutive equations, and a time integration procedure for isotropic, hyperelastic viscoplastic solids. Computer Methods in Applied Mechanics and Engineering 79, 173–202.
20. White, C.S., Bronkhorst, C., Anand, L., 1990. An improved isotropic-kinematic hardening model for moderate deformation metal plasticity. Mechanics of Materials 10, 127–147.
21. Weber, G.G., Lush, A.M., Zavaliangos, A., Anand, L., 1990. An objective time-integration procedure for isotropic rate-independent and rate-dependent elastic-plastic constitutive equations. International Journal of Plasticity 6, 701–744.

22. Anand, L., Zavaliangos, A., 1990. Hot working: constitutive equations and computational procedures. Annals of CIRP 39, 235–238.

23. Haghi, M., Anand, L., 1991. Analysis of strain-hardening viscoplastic thick-walled sphere and cylinder under external pressure. International Journal of Plasticity 7, 123–140.

24. Bronkhorst, C.A., Kalidindi, S. R., Anand, L., 1991. An experimental and analytical study of the evolution of crystallographic texturing in fcc materials. Textures and Microstructures 14–18, 1031–1036.

25. Zavaliangos, A., Anand, L., 1991. Towards a capability for predicting the formation of defects during bulk deformation processing. Annals of CIRP 40, 267–271.

26. Zavaliangos, A., Anand, L., 1991. Thermal aspects of shear localization in microporous viscoplastic solids. International Journal of Numerical Methods in Engineering 33, 595–634.

27. Kalidindi, S.R., Bronkhorst, C.A., Anand, L., 1992. Crystallographic texture evolution in bulk deformation processing of fcc metals. Journal of the Mechanics and Physics of Solids 40, 537–569.

28. Haghi, M., Anand, L., 1992. A constitutive model for isotropic, porous, elasto-viscoplastic metals. Mechanics of Materials 13, 37–53.

29. Kalidindi, S.R., Anand, L., 1992. An approximate procedure for predicting the evolution of crystallographic texture in bulk deformation processing of fcc metals. International Journal of Mechanical Sciences 34, 309–329.

30. Bronkhorst, C.A., Kalidindi, S.R., Anand, L., 1992. Polycrystalline plasticity and the evolution of crystallographic texture in fcc metals. Philosophical Transactions of The Royal Society London A 341, 443–477.

31. Kalidindi, S.R., Anand, L., 1993. Large deformation simple compression of a copper single crystal. Metallurgical Transactions 24A, 989–992.

32. Zavaliangos, A., Anand, L., 1993. Thermo-elastoviscoplasticity of isotropic porous materials. Journal of the Mechanics and Physics of Solids 41, 1087–1118.

33. Anand, L., Tong, W., 1993. A constitutive model for friction in forming. Annals of CIRP 42, 361–366.

34. Anand, L., 1993. A constitutive model for interface friction. Computational Mechanics 12, 197–213.

35. Anand, L., Kalidindi, S.R., 1994. The process of shear band formation in plane strain compression of fcc metals: effects of crystallographic texture. Mechanics of Materials 17, 223–243.

36. Kalidindi, S.R., Anand, L., 1994. Macroscopic shape change and evolution of crystallographic texture in pre-textured fcc metals. Journal of the Mechanics and Physics of Solids 42, 459–490.

37. Balasubramanian, S., Anand, L., 1996. Single crystal and polycrystal elasto-viscoplasticity: application to earing in cup drawing of fcc materials. Computational Mechanics 17, 209–225.

38. Anand, L., Kothari, M., 1996. A computational procedure for rate-independent crystal plasticity. Journal of the Mechanics and Physics of Solids 44, 525–558.

39. Anand, L., Balasubramanian, S., 1996. Polycrystal plasticity: application to earing in cup drawing. Annals of CIRP 45, 263–268.

40. Anand, L., 1996. A constitutive model for compressible elastomeric solids. Computational Mechanics 18, 339–355.

41. Kothari, M., Anand, L., 1998. Elasto-viscoplastic constitutive equations for polycrystalline metals: application to tantalum. Journal of the Mechanics and Physics of Solids 46, 51–83.

42. Balasubramanian, S., Anand, L., 1998. Polycrystalline plasticity: application to earing in cup drawing of Al2008-T4 sheet. ASME Journal of Applied Mechanics 65, 268–271.

43. Staroselsky, A., Anand, L., 1998. Inelastic deformation of fcc materials by slip and twinning. Journal of the Mechanics and Physics of Solids 46, 671–696.

44. Anand, L., Gu, C., 2000. Granular materials: constitutive equations and shear localization. Journal of the Mechanics and Physics of Solids 48, 1710–1733.

45. Gu, C., Kim, M., Anand, L., 2001. Constitutive equations for powder metals: application to powder forming processes. International Journal of Plasticity 17, 147–209.

46. Gearing, B.P., Moon, H.S., Anand, L., 2001. A plasticity model for interface friction: application to sheet metal forming. International Journal of Plasticity 17, 237–271.

47. Thamburaja, P., Anand, L., 2001. Polycrystalline shape-memory materials: effect of crystallographic texture. Journal of the Mechanics and Physics of Solids 49, 709–737.

48. Balasubramanian, S., Anand, L., 2002. Elasto-viscoplastic constitutive equations for polycrystalline fcc materials at low homologous temperatures. Journal of the Mechanics and Physics of Solids 50, 101–126.

49. Balasubramanian, S., Anand, L., 2002. Plasticity of initially-textured hexagonal polycrystals at high homologous temperatures: application to titanium. Acta Materialia 50, 133–148.

50. Thamburaja, P., Anand, L., 2002. Superelastic behavior in tension-torsion of an initially-textured Ti-Ni shape-memory alloy. International Journal of Plasticity 18, 1607–1617.

51. Staroselsky, A., Anand, L., 2003. A constitutive model for hcp materials deforming by slip and twinning: application to magnesium alloy AZ31B. International Journal of Plasticity 19, 1843–1864.

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