Anisotropic Inelasticity – Modelling, Simulation, Validation

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Abstract

The main purpose of this work is threefold. First, to consider a phenomenological model for anisotropic elastoplasticity at finite plastic strains within the framework of continuum mechanics with internal variables. The model aims to describe metallic solids, where the source of anisotropy may be either a kind of texture in polycrystals, which allows for an orthotropic modelling in an averaged sense, or the anisotropy of fcc single crystals. The second thrust is to derive and implement within the finite-element framework stable and efficient time integration algorithms for the evolution equations of elastoplasticity, for both, finite plastic strains and for the infinitesimal strain case. The algorithmic formulation of unilateral contact in this work opens the door to the simulation of metal forming processes such as deep-drawing and extrusion. The third aim is to validate the material model along with its corresponding numerical treatment. Significant anisotropic phenomena of crystalline materials at large, inelastic deformations should be captured within the simulations. It is shown that the earing effect of a deep drawn cup is predicted. Furthermore, the present work is devoted to elucidate a curious phenomenon of a spherical indentation test into a fcc single crystal; upon release of the ball, the indent looks rather like a square than like a circle. The topography of the indentation crater is reconstructed applying scanning electron microscopy along with digital image processing. The anisotropic topography of the sample is predicted by the material model in the simulations. Corroborated on the experimental findings a kinematical explanation of the observed deformation pattern is proposed that operates on the micromechanical scale of plastic deformation in a fcc single crystal.

Kurzfassung

Das wesentliche Ziel dieser Arbeit ist dreifältig. Zunächst wird ein phänomenologisches Materialmodell für anisotrope Elastoplastizität bei grossen plastischen Deformationen im Rahmen der Kontinuumsmechanik mit internen Variablen vorgestellt. Das Modell zielt darauf ab, metallische Festkörper zu beschreiben, deren anisotropes Verhalten ent-weder von einer näherungsweise orthotropen Textur in Polykristallen verursacht ist, oder durch die Struktur eines kubisch-flächenzentrierten (kfz) Einkristalls. Das zweite Ziel ist, stabile und effiziente Zeitintegrationsverfahren für die plastischen Evolutionsgleichungen zu entwickeln, sowohl für grosse plastische Deformationen wie auch für den Fall kleiner Deformationen. Die vorgestellte Methode des unilateralen Kontakts im Rahmen der Finite-Element-Methode ermöglicht die Simulation typischer Umformprozesse wie Tiefziehen oder Extrusion. Das dritte Ziel ist, das Materialmodell samt der zugehörigen numerischen Verfahren zu validieren. Es gilt, signifikante anisotrope Materialphänomene, die bei grossen inelastischen Deformationen auftreten, in numerischen Berechnungen zu erfassen. Es wird gezeigt, dass die sog. Zipfelbildung am Rand eines tiefgezogenen Bechers vorhergesagt wird. Darüberhinaus widmet sich diese Arbeit einem verblüffenden Materialphänomen, das bei einem Eindrückversuch mit einer Kugel in einen kfz-Einkristall aufgetreten ist; der verbleibende Einddrückkrater gleicht eher einem Quadrat denn einem Kreis. Es gelingt in dieser Arbeit, die Topographie des Kraters mit Rasterelektronenmikroskopie und digitaler Bildverarbeitung zu rekonstruieren. Die anisotrope Topographie des Eindrucks wird durch das Materialmodell in Simulationen richtig vorhergesagt. Gestützt auf den experimentellen Befund wird eine physikalisch plausible Erklärung des Deformationsmusters vorgeschlagen, die auf diskreten Gleitvorgängen in der kfz-Elementarzelle gründet.

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