Asociación Argentina
de Mecánica Computacional

Resúmenes de Mecánica Computacional Vol I, pp. 33-33
C.I. Pairetti, M.A. Pucheta, M.A. Storti, C.M. Venier (Eds.)
C. Pairetti, C. Venier (Issue eds.)
Rosario, November 5-8, 2024

SIMULATION OF METAL FORMING USING ELASTO-VISCO-PLASTIC CRYSTAL PLASTICITY MODELING

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Keywords: Crystal plasticity, EVPSC model, Anisotropy, Finite Elements Analysis, Spring-back, Irradiation creep

Abstract. As computational capabilities increase, simulations play an increasingly relevant role in the design of forming operations and the prediction of mechanical response of metallic alloys under diverse conditions. Such approach is sound – and reduces the extent of experimental characterization - provided that the constitutive laws being used reliably describe the mechanical response of the material. Crystal plasticity models - as opposed to empirical continuum laws - are arguably the most advanced tool for such a task because they are based on the elastic, thermal and plastic mechanisms at the level of the grains that constitute the aggregate. In addition, by representing the materials as an ensemble of grains with different crystal orientations, crystal plasticity models allow one to explicitly account for the effect of texture, and so anisotropy, on the mechanical response of the aggregate. This presentation describes an elasto-visco-plastic polycrystal (EVPSC) model (Y. Jeong and C. N. Tomé, International Journal of Plasticity 135 (2020), 102812) based on the concept above and discusses its implementation as a user material subroutine (UMAT) in the FE solver Abaqus/standard. The model treats grains as fully anisotropic inclusions embedded in an anisotropic Homogeneous Effective Medium (HEM) with the average properties of the polycrystal. The hardening behavior is described using a model based on dislocation-evolution. Within such model an empirical back-stress contributes to Bauschinger effects, and creep contributes to stress relaxation. The model parameters were calibrated using a set of uniform mechanical tests. Such approach allows one to link the crystallographic length scale of the grains to the continuum scale of the polycrystal, and the latter to the macroscopic scale of the technologic components. We present several applications that demonstrate such paradigm and discuss specific aspects of material response that it can address. Specifically, we investigate spring-back following plastic bending in several rolled alloys: a martensitic EDDQ (extra-deep-drawing-quality) mild steel, a dual phase martensitic-austenitic steel DP980, and hcp Magnesium. We also describe an application involving irradiation creep and growth in nuclear reactor fuel elements. Specifically, the prediction of loss of contact during irradiation (gap opening) between Zircaloy cladding tubes and the Zircaloy gris holding them in place. Differences on texture between tube and grid lead to different deformation trends, which in turn leads to loss of contact between grid and tube and so to fretting wear and eventual fuel rod leakage. In all cases the predictions are compared with experimentally available information.

ISSN: 2591-3522