20th European Mechanics of Materials Conference - EMMC20
Florence, Italy | May 27th-29th, 2026
www.emmc20.unifi.it

Model-free Inverse stress identification method for the characterization of grain-scale plasticity in metallic polycrystals

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Paper ID: 193
Symposium S3: Mechanics of metals and crystalline materials: Experiment-modelling synergy

Abstract

The deformation of metallic polycrystals can be investigated across a wide range of length scales, from the atomic scale to the macroscopic level. At each scale, dedicated theoretical frameworks have been developed to describe deformation mechanisms starting from an initially undeformed material. Among these frameworks, Crystal Plasticity (CP) offers an effective means of linking the single-crystal scale to the mesoscopic polycrystalline scale. In its simplest form, CP describes deformation in terms of plastic slip activity and resolved shear stresses defined over a discrete set of crystallographic slip systems within each crystal. The resulting local elastoplastic response depends on the crystallographic lattice orientation, as well as on empirical or physically based hardening laws and long or short range interactions. Although this class of models generally provides satisfactory predictions of global material behavior, validating local responses remains challenging due to the experimental inaccessibility of stress fields and the difficulty of estimating internal state variables. Furthermore, the incorporation of additional physical effects—such as grain size dependence (Hall–Petch effect), grain boundary sliding, and other intergranular mechanisms—remains an open challenge in crystal plasticity modeling. Recently, a Data-Driven Identification

(DDI) approach has been proposed, offering a novel model-free framework for experimentally probing local material responses in continuum media subjected to heterogeneous stress distributions. This approach enables the computation of stress fields without relying on constitutive modeling assumptions, instead exploiting full-field kinematic measurements, conservation laws, and the hypothesis that the ensemble of experimental mechanical states clusters around a single underlying manifold. The present work extends this framework to the experimental analysis of intragranular responses in polycrystalline aggregates. Two inverse approaches are proposed. The first aims to quantify mesoscopic plasticity by exploiting local conservation laws and parsimony principles, with the objective of isolating dominant deformation mechanisms from full-field digital image correlation data while minimizing the number of active variables required to describe the material response. The second approach focuses on identifying plastic slip activity and resolved shear stresses at the crystal scale, seeking a unique hardening response in the resolved shear strain–stress space of the aggregate. Both methods rely on sparse optimization strategies to reduce the dimensionality of the solution space and promote physically meaningful representations of the deformation process. The proposed approaches are validated using synthetic datasets generated for single-phase materials with a face-centered cubic (FCC) crystal structure, and preliminary experimental results are also discussed. Overall, the results demonstrate that these inverse methods can accurately recover key plasticity descriptors from kinematic measurements and initial lattice orientation map, offering promising perspectives for model-free or weakly model-dependent experimental characterization of polycrystalline plasticity.

Keywords:

Crystal plasticity EBSD Digital Image Correlation Sparse Identification Data-Driven Identification