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

Crystal Plasticity Modeling of Rough Zinc Coatings for Wear Prediction

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Paper ID: 321
Symposium S3: Mechanics of metals and crystalline materials: Experiment-modelling synergy

Abstract

Zinc coatings are widely used to provide cathodic protection for steel, effectively preventing corrosion in automotive and other industrial applications. However, during metal forming processes, where high contact pressures are applied, zinc coatings are prone to wear, often manifesting as flakes or powders. These detached zinc particles can adhere to tool surfaces and subsequently cause scratches on the zinc surface, a phenomenon known as galling and representing a severe form of adhesive wear. Experimental observations of zinc-coated steel sheets reveal that the mechanical vulnerability of zinc is strongly linked to its hexagonal close-packed (HCP) crystal structure and pronounced plastic anisotropy. Deformation is dominated by basal slip, while twinning is activated only at higher critical resolved shear stresses, resulting in limited deformation compatibility at the polycrystalline level and promoting surface damage under contact loading. To investigate the deformation and wear behavior of zinc coatings under metal forming conditions, we employ a crystal plasticity finite element method (CPFEM) with contact boundary conditions implemented using a primal–dual active set strategy. The influence of crystallographic anisotropy on contact area evolution is quantified by comparing predictions obtained using anisotropic crystal plasticity and isotropic plasticity models. Wear is assessed using an experimentally motivated framework based

on recent findings by Aghababaei et al. [1], which identify a critical contact area separating smoothening from debris-dominated wear mechanisms. By comparing the simulated real contact area of individual asperities with this critical threshold, we estimate wear volume and identify conditions leading to galling. The results highlight the importance of crystallographic effects in controlling contact mechanics and wear initiation, providing a mechanistic link between experimentally observed wear phenomena and microstructure-sensitive modeling.

Keywords:

Crystal plasticity Contact mechanics Zinc coating Adhesive wear

References:

[1] R. Aghababaei, et al., “Critical length scale controlsadhesive wear mechanisms”, Nature Communications 7, 11816(2016).