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Editorial

Applications of Crystal Plasticity in Forming Technologies

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The Special Issue on 'Crystal Plasticity in Forming Technologies' is a collection of 11 original articles dedicated to theoretical and experimental research that provides new insights and practical findings in topics related to crystal plasticity.

Advancements in materials science have led to the development of complex materials for targeted applications and have pushed manufacturing boundaries. As the microstructural attributes of any material are responsible for the bulk deformation behavior and life after failure, it is important to engineer them to obtain the desired material properties necessary for their safe functionality during their service life. Furthermore, the formability limits of such materials play a huge role in dictating bulk deformation process limits during manufacturing and hence can significantly affect the cost of production. In the recent past, crystal plasticity-based numerical simulation models have paved the way for developing microstructurally informed detailed models to analyze the global and local deformation behavior of a wide variety of single- and multi-phase metallic and non-metallic materials. Such models can be used to study the effect of microstructural artifacts on the deformation and damage behavior of materials under multiaxial loading conditions. In conjunction with advanced computer algorithms, these models can be applied to optimize microstructural attributes for the desired material application or a process route.

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With the advent of electromobility and the requirement for lightweight structures, magnesium alloys are becoming an attractive choice for industries. However, the manufacturing process and loading conditions can drastically affect the deformation behavior of these alloys during service. Crystal-plasticity-based phenomenological or physical numerical simulation models can help in this case. Yaghoobi et al. [1] reviewed recent advances in the crystal plasticity modeling of magnesium and its alloys. They highlighted the benefits and limitations of different models that capture detwinning in such simulations and the advances of several experimental techniques that complement the development and validation of such detailed models. Continuing with experimental techniques, Sun et al. [2] investigated the effect of grain-boundary misorientation on slip transfer in Mg–Gd–Y magnesium alloy. They proposed that the ductility of such materials can be significantly improved by the initial yielding of the components to increase the local misorientation index in medium strain regimes. In high-strain regimes of the same material class, Liu et al. [3] investigated the local strain heterogeneity using electron backscattered diffraction (EBSD) measurement and digital image correlation (DIC) analysis of miniature tensile test samples. They showed that damage initiation occurs at triple points of the grains with highly contrasting Schmidt factors. Such experimental trials on the mesoscale are necessary to identify simulation model parameters and validate the results.

Multiphase steels are extensively used because of their high strength and improved stability at higher temperatures. Qayyum et al. [4] worked on analyzing the influence of non-metallic inclusions on the local deformation and damage behavior of Modified 16MnCrS5 Steel. They carried out full-phase crystal plasticity simulations on plain strain 2D periodic RVEs constructed using EBSD data from differently processed samples. These simulations investigated the effect of different processing routes on the local microstructure and the distribution of inclusions, resulting in local heterogeneity during deformation. Qayyum et al. [4] argued that the local results might be affected by the assumption of 2D RVEs. To fill this gap, Tseng et al. [5] worked on understanding the difference in the local difference between simulations of crystal plasticity of 2D and 3D RVE. They then provided a methodology to transform local stress and strain distributions from 2D to 3D observations in full-phase crystal plasticity simulations of dual-phase steels.

A comparison of structural, microstructural, elastic, and microplastic properties of all-aluminum alloy conductor (A50) and aluminum conductor steel-reinforced (AC50) cables after various operation periods in power transmission lines was presented in [6]. They used outer clippings of actual transmission wires that were in operation for 0–20 years in the Volgograd region of Russia. Appropriate samples were manufactured and analyzed for microstructural, crystallographic, or density changes. They found that the AC50-reinforced wires performed slightly better than the A50 wires in microstructural integrity over the years. Furthermore, they pointed out that recrystallization in the wire strains exposed to long aging times under external load is a very important consideration for structures with long expected service lives. Continuing with this estimation, Trusov et al. [7] tried to describe dynamic recrystallization by employing an advanced statistical multilevel model. In this article, they propose an original method of statistical modeling to form and reconstruct the grain structure by applying the Laguerre polyhedral. The proposed model has high computational efficiency and can describe the peculiarities of physical mechanisms, where the decisive factor is the interaction between contacting grains.

Zhang et al. [8] developed a multiscale model that connects discrete dislocation dynamics to the finite element method to study the plastic behavior of materials on small scales. This is a user-subroutine-based model with a complicated boundary problem for discrete dislocation dynamics (DDD) simulation. The model was solved using the finite element method (FEM). The plastic strain was calculated in discrete dislocation dynamics (DDD) and transferred to the FEM to participate in the constitutive law computation. Uniaxial compression tests on single-crystal micropillars were carried out to validate the generated model. The yield stress was shown to depend on sample size and underlying deformation mechanisms.

In addition to the works mentioned above, some cross-discipline work has been published in this Special Issue related to scale bridging simulations for other cases and materials. These articles provide a comprehensive understanding of how crystal-plasticity-based models can be used in other branches of materials science to improve understanding of material deformation and damage behavior.

Solder joints in electronic systems comprise only a few crystals and have significantly anisotropic thermo-mechanical behavior. Therefore, it is important to understand their reliability under varying loading conditions to ensure the robust functionality of the electronic systems that now power our lives. The reliability of SAC305 Individual Solder Joints during stress–fatigue conditions at room temperature was investigated by Abueed et al. [9]. They used a specially designed fixture with an Instron 5948 micromechanical tester and analyzed the stress–strain loops from different loading conditions to distinguish damage from fatigue from damage from creep. Their findings show that using higher stress levels or longer dwell times greatly reduces fatigue while significantly improving plastic work and strain.

Skakunova and Rychkov [10], in their article, used Raman spectroscopy and optical microscopy to analyze L-leucinium hydrogen maleate (LLHM). This first molecular crystal retains its unusual plasticity at freezing temperatures. LLHM was cooled to 11 K without undergoing a phase transition, while high-pressure impact caused noticeable changes in crystal structure between 0.0 and 1.35 GPa. Surprisingly, the pressure transmission medium (PTM) significantly impacted how the LLHM system behaved under difficult circumstances. High pressures have been associated with LLHM phase transitions into an amorphous form or solid–solid phase transitions that cause crystal fracture. The researchers showed that the low-temperature stability of LLHM raises the intriguing hypothesis that LLHM maintains flexibility below 77 K.

Lastly, Jiandong and Lianhe [11] investigated the Griffith crack problem and the relationship between a screw dislocation and semi-infinite fracture in cubic quasicrystal piezoelectric materials using a complex variable function approach. They provided an in-depth discussion regarding the linear force and coupling elastic coefficient that affect the stress intensity factor of phonon and phason fields. They pointed out that numerical examples that the linear force and the coupling elastic constant significantly influence the stress intensity factor.

We hope this collection of papers will meet the expectations of readers looking for new advances in applications of crystal plasticity in forming technologies and bring inspiration for further research work.

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