INSTITUT DE FRANCE
Académie des sciences

Comptes Rendus

Physique

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Foreword: Plasticity and Solid State Physics

Volume 22, issue S3 (2021), p. 3-5

<https://doi.org/10.5802/crphys.92>

Part of the Special Issue: Plasticity and Solid State Physics
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Foreword / *Avant-propos*

Foreword: Plasticity and Solid State Physics

Avant-propos : Plasticité et Physique des Solides

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The conference-debate session of the Académie des Sciences on 25 February 2020[1] highlighted the importance of the interactions between physics and mechanics of solids for a better understanding of the plasticity of materials. The idea then arose to prepare a special issue of the *Comptes Rendus Physique* de l'Académie des Sciences to deepen these fruitful relationships between a physical understanding of the mechanisms of plasticity and the continuum modelling of these phenomena in view of the use of constitutive laws adapted to the calculation of engineering structures.

We thank the authors of the articles in this volume for agreeing to explore this question in greater depth by reporting original recent scientific advances or by proposing a review of important results obtained in recent years. All classes of materials are addressed from the point of view of plasticity: metals and alloys of course, but also ceramics and polymers, crystalline as well as amorphous materials. The most recent multiscale experimental approaches (particularly in four dimensions) are used, while the modelling of these phenomena resorts to both discrete and continuum approaches.

A physical approach to the plasticity of solids, be they crystals or glasses, starts at the atomic scale where the elementary mechanisms of deformation take place. In crystals, these processes involve the motion of defects, that are of different nature depending on the material and the deformation conditions. Plastic deformation may be due to the motion of dislocations, which involves their core region that can only be modeled using atomistic methods, as illustrated in olivine by Mahendran et al [1]. Plasticity may also result from the motion of grain boundaries, that offer complex deformation routes, as discussed by Gautier et al based on in situ microscopy and atomistic calculations [2]. In small-scale samples, such as nanoparticules, surfaces become dominant and lead to specific deformation processes, as reviewed by Amodeo and Pizzagalli [3]. Also, imaging crystalline defects in three dimensions and monitoring their evolution over time requires the development of new methods, such as 4d tomography, presented by Mussi et al [4].

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[1] cf. https://www.academie-sciences.fr/fr/Colloques-conferences-et-debats

ISSN (electronic) : 1878-1535

In a multiscale approach, elementary processes are incorporated in higher scale models to predict plasticity at the micro- and possibly macroscales. Such an approach is illustrated by Clouet et al [5] who used ab initio calculations of dislocation core properties to predict the yield stress of single crystals of tungsten. A similar multiscale approach may also be used in amorphous solids where elementary processes of deformation take place in rather elusive shear transformation zones that organize along microscopic shear bands as discussed by Tanguy [6]. A successful example of how to parametrize a mesoscopic model based on atomistic simulations of a glass is also given by Castellanos et al [7].

The modern approach to the mechanical modelling of plasticity reconciles and surpasses the results obtained during the two golden ages of continuum plasticity theory: the introduction of the concept of dislocation density tensor by Nye and Kröner [8, 9] leading to the continuum theory of dislocations, followed by the development of constitutive laws for crystal plasticity based on the internal variable concept, starting in particular from the pioneering work of Mandel, Teodosiu, Sidoroff, Kocks and Mecking [10–12]. The statistical mechanics of crystalline defects turns out to be extremely difficult and its closure has not yet been fully established. Several contributions in this volume report decisive advances in this field. A long-neglected aspect of the analysis of plasticity phenomena is the intermittency of plastic deformation, which results in fluctuations associated with dislocation avalanches and indicates critical dynamics, as discussed by Weiss et al [13]. This essential feature can be captured using the Landau-type mesoscopic continuum plasticity theory proposed by Salman et al [14]. The closure of the statistical theory of dislocations requires new constitutive variables like dislocation alignment and curvature tensors put forward by Weger et al [15] and identified from discrete dislocation dynamics simulations. The identification of macroscopic crystal plasticity constitutive equations from in situ HR-EBSD experimental analysis and from dislocation density simulations is also the subject of the work of Zoller et al [16], which insists on the interactions between various slip systems activated in micropillars under compression. Mesoscale field dislocation mechanics is then used by Berbenni and Lebensohn [17] to study size effects emerging from the cyclic deformation of single crystals. Finally, the simulations presented by Gelebart [18] perform the transition from single crystal to polycrystal behaviour. A statistical distribution of dislocation sources is introduced in order to predict grain size effects in polycrystals. The two latter contributions make use of Fast Fourier Transform-based numerical methods that efficiently address large scale simulations.

Plasticity and its challenges are not limited to metals. The case of polymer-based composites is addressed by Pardoen et al [19]. The authors show how nanomechanical testing methods combined with coarse graining modelling tools provide a new picture of nonlinear fiber–matrix interactions which finally lead to damage initiation.

Physical and mechanical interactions are also illustrated in this volume by the coupling of elastic-plastic deformation and diffusive phase transformations. Ammar et al [20] present phase field finite element simulations coupled with mechanics. The results indicate that the growth of precipitates is strongly affected by the plastic deformation of the matrix which can lead to the splitting of precipitates.

This volume shows strikingly that, despite the long history of this discipline, material plasticity is an extremely active research topic using and enhancing the most recent experimental, theoretical and numerical concepts and techniques. We believe that further progress will be obtained by continued and enriched interactions between different fields, physics and mechanics as discussed here, but also mathematics, chemistry and computer science to cite but a few.

Acknowledgments

Samuel Forest and David Rodney thank Denis Gratias for initiating this special issue. They also acknowledge the great help of the editorial team of the *Comptes Rendus Physique*, in particular Julien Desmarets.

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