Rheology and Elasticity Studies at Ultra-High Pressures and Temperatures

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PREFACE

One of the major goals of geophysical research is to understand deformation in the deep earth. The COMPRES (Consortium for Materials Properties Research in Earth Sciences) workshop on 'Rheology and Elasticity Studies at Ultra-High Pressures and Temperatures' held on 21–23 October 2005 at the Advanced Photon Source, Argonne National Laboratory, organized by Haozhe Liu, Hans-Rudolf Wenk, and Thomas S Duffy has provided an opportunity to assemble more than 50 scientists from six countries. Experts in diamond anvil cell (DAC) design, large volume high-pressure apparatus, and data analysis defined the current state of ultra-high pressure deformation studies and explored initiatives to push the technological frontier. The DAC, when used in a radial diffraction geometry, emerges as a powerful tool for investigations of plasticity and elasticity of materials at high pressures. More information regarding this workshop can be found at the website: http://www.hpcat.aps.anl.gov/Hliu/Workshop/Index1.htm. In this special issue of *Journal of Physics: Condensed Matter*, 17 manuscripts review the state-of-the-art and hopefully stimulate researchers to participate in this field and advance it to a new level.

A major incentive for high-pressure research has been the need of geophysicists to understand composition, physical properties and deformation in the deep earth in order to interpret the macroscopically observed seismic anisotropy. In the mantle and core, materials deform largely in a ductile manner at low stresses and strain rates. From observational inferences and experiments at lower pressures, it is considered plausible that deformation occurs in the field of dislocation creep or diffusion creep and deformation mechanisms depend in a complex way on stress, strain rate, pressure, temperature, grain size and hydration state. With novel apparatus such as the rotational Drickamer press or deformation DIA (D-DIA) multianvil apparatus, large volumes ($\sim$10 mm^3) of materials can be deformed at pressure and temperature. Unfortunately these experiments do not presently extend to pressures of the lower mantle that comprises most of the volume of the earth. Thus deformation mechanisms of minerals such as perovskite (in the lower mantle), post-perovskite (in the anisotropic D" zone) and ϵ-iron (in the inner core) remain enigmatic. Here developments in the DAC offer new opportunities. At present, this is a novel, and in many ways still very primitive, method to deform minerals at high pressure, confined to room temperature and moderate strains. No doubt this will change in the near future as new technologies become implemented, for example laser heating, remote pressure control, especially fine control of strain rate during compression, decompression and cycling procedures for DAC radial diffraction studies.

The first paper, by Bassett, gives a perspective on the significance of stress in DAC experiments. An issue once considered by many a nuisance has become a gold mine when it comes to unravelling material properties at very high pressures. At high pressures many silicates and oxides become ductile, even at room temperature, and ductile deformation results in development of preferred orientation that can be used to infer deformation mechanisms as illustrated in the reviews by Wenk *et al* and Merkel. Mao *et al* investigate the strength of solidified argon and find it increases greatly and exceeds 2.7 GPa with applied pressure at 55 GPa. Singh *et al* investigate the dependence of strength on grain size by studying nanocrystalline gold, while Yoneda and Kubo use axial diffraction geometry to determine both mean pressure and deviatoric stress of gold. Miyagi *et al* illustrate the Rietveld method for quantitative texture analysis of $CaSiO_3$ perovskite. Speziale *et al* map strain gradients in the

DAC by investigating texture variations in copper to 25 GPa. Naturally, efficient and accurate image processing is a requirement for reduction and analysis of diffraction data (Hinrichsen *et al*). A complementary study by Conil and Kavner explores DAC heterogeneities with numerical methods. Using the D-DIA multianvil apparatus, the differential lattice strains in polycrystalline Fe_2SiO_4 and MgO were measured to investigate the evolution of the weighting factor for Reuss and Voigt bounds during plastic flow by Chen *et al* , while Weidner and Li studied MgO and mixtures of MgO and spinel ($MgAl_2O_4$) for fabric and residual stresses development during a plastic deformation cycle. Mao and Mao describe an ingenious device for remote pressure control and demonstrate it with a sample of platinum to 230 GPa. Large strains can be obtained with a rotational DAC and this influences the pressure at which the α–ϵ transition occurs in iron (Ma *et al*). Chesnut *et al* introduce a new DAC adapted for radial diffraction geometry. While much of the current DAC work in radial geometry is done with monochromatic x-rays and angle dispersive 2D detectors, the radial x-ray diffraction program at X17C of NSLS at energy dispersive XRD geometry is reviewed by Hu *et al* . Meng *et al* introduce the double-sided laser heating technique at ID-B of HPCAT, and propose a rotational design for applying the laser heating technique to radial x-ray diffraction studies at simultaneous high pressure-temperature (PT) conditions. These contributions provide a sound introduction and overview of the current science for anyone interested in elasticity and plasticity of materials at ultrahigh pressure.

We are thankful to Dr Richard Palmer and Professor Marshall Stoneham for the opportunity to publish these carefully selected and reviewed proceedings in *Journal of Physics: Condensed Matter* where they reach a large audience. We acknowledge the authors for contributing exciting papers to this issue, to participants at the workshop for stimulating presentations and discussions, and to many reviewers whose suggestions improved the manuscripts. We are most grateful to COMPRES and its Director Dr Robert Liebermann for generous financial support of this workshop, and the support from local organizing committee Veronica O'Connor, Dave Mao, Guoyin Shen and other HPCAT staff. The goal of the project was not to provide final conclusions in a dynamic field but to stimulate progress.

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