RECENT ADVANCES IN SMALL-ANGLE SCATTERING AND THE APPLICATIONS THEY SERVE FOR HARD MATERIALS

ALLEN, Andrew J
National Institute of Standards and Technology (NIST), United States of America
E-mail: andrew.allen@nist.gov

Major innovations in small-angle X-ray and neutron scattering (SAXS and SANS) at major X-ray and neutron facilities offer a wide range of new characterization tools for researching materials phenomena and processes relevant to advanced applications.

The new generation of diffraction-limited storage rings, incorporating multi-bend achromat (MBA) concepts, dramatically decrease electron beam emittance in the ring, and significantly increase X-ray brilliance over previous 3rd generation sources. For most synchrotron based SAXS, the main result is intense X-ray incident beams that are more compact in the horizontal plane, allowing significantly improved sample spatial resolution, faster run times, and better time resolution. For sufficiently small incident beams, a few tens of micrometers in diameter, such sources offer a new era for coherent-beam SAXS methods such as X-ray photon correlation spectroscopy (XPCS) studies of particle or other material dynamics [1]. Meanwhile, X-ray free-electron laser (XFEL) sources, providing extremely bright, fully coherent, X-ray pulses of 100 femtoseconds or less, now support SAXS studies of material processes where entire SAXS datasets can be collected in a single pulse [2].

SANS facilities continue to evolve at both reactor-based steady-state and pulsed spallation neutron sources. Developments in neutron optics and multiple detector carriages now enable data collection in a few minutes for materials characterization over nanometer-to-micrometer scale ranges [3]. This significantly opens up real-time studies of material processes acting over extended length scales, e.g., reactions in hierarchical systems or rheological SANS (rheoSANS) investigations of particle slurries and suspensions [4] (Fig. 1). At pulsed neutron sources SANS can be increasingly integrated with total scattering (TS) studies of local ordering in complex materials, or with neutron diffraction (ND) for engineering materials and alloys [5]. Meanwhile, polarized SANS and spin echo SANS (SESANS) are becoming established in investigating exotic magnetic ordering phenomena in materials, e.g., skyrmions.

At both X-ray and neutron facilities, increasingly advanced coherent imaging modes have been developed, some exploited in parallel with SAXS and SANS to establish a more quantitative visualization of complex material microstructures. Many of the above innovations have also led to corresponding developments for grazing incidence studies of 2D surface morphologies, thin films and coatings.

Some of these developments will be reviewed and discussed with regard to state-of-art studies directed at hard matter applications, and future prospects highlighted.

Keywords
materials characterization, operando, instrumentation, processing

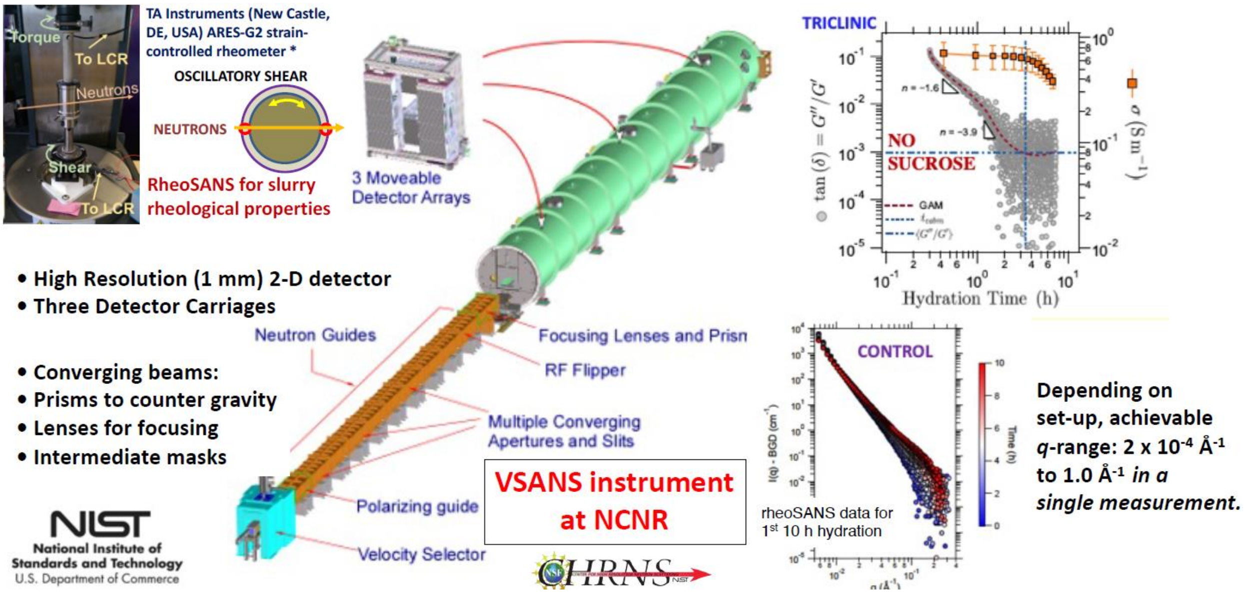

Fig. 1. NIST VSANS at NIST Center for Neutron Research (NCNR) with small-amplitude oscillatory shear (SAOS) cell, example real-time data for hydrating cement, rheology data for shear moduli: G’, G’’ and electrical conductivity, σ.

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