Experimental report

11/03/2024

Proposal: **9-10-1752** **Council:** 10/2022

Title: Probing shear-banding in suspensions of soft sphere using RheoSANS own the flow direction

Research area: Soft condensed matter

This proposal is a new proposal

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Samples: PNIPAM:PEG microgels

Instrument	Requested days	Allocated days	From	To
D22	3	2	14/04/2023	16/04/2023

Abstract:

Shear-banding is an ubiquitous phenomenon for soft materials under flow in which it is observed a transient or steady-state non-homogeneous flow with formation of bands sliding with different velocity. It has been reported for a variety of colloidal suspensions, from hard sphere colloids to ultrasoft star polymers. Our data shows indication of shear banding also in suspensions of microgels.
Despite shear banding is a well known phenomenon, the link between shear banding and the evolution of the microstructure and dynamics of colloidal suspensions under flow has been scarcely explored in experiments. Here we propose to study the shear banding observed in microgel suspension in the flow-direction using the 1,2, shear cell available on D22. The possibility of performing spatial resolved measurements in the direction of the flow will provide unique new insight on this phenomenon which can clarify its microscopic origin.

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The beamtime was dedicated to the investigation of the link between structural variations and shear banding in a dense suspension of microgels. In particular, the goal of the SANS experiments was that of measuring structural variations across the gap of a Couette cell in the presence of shear banding, and to link them to velocity profiles previously measured using a heterodyne dynamic light scattering setup. The obtained results allowed to experimentally test the mechanism of flow-concentration coupling previously proposed to explain shear banding in dense suspensions of colloidal hard spheres [1,2].

The sample was a suspension of PNIPAM-PEG microgels with an effective volume fraction $\phi_{eff} \approx 1.3$. The experiments were performed using the 1,2-shear cell on the D22 SANS beamline of ILL, that allows to measure scattering along the flow-gradient plane, at different positions across the gap. Experiments at different shear rates were performed at T = 20 °C for a cell gap equal to 1mm, while the neutron path length through the sample was equal to 5mm. The flow-SANS experiments were performed at a detector distance of 17.6m with an 8.0m rectangular collimation (40x55mm), λ = 6 Å neutron wavelength, and a wavelength spread of $\Delta\lambda/\lambda$ = 10%.

To spatially resolve different positions along the gap, a stepper motor was used to translate the cell perpendicular to the neutron beam path defined with a 0.1 mm wide curved slit x 3mm height across the 1.0 mm gap. Five gap positions (r/H=0.15, 0.35, 0.5, 0.65, 0.85) were measured. Measurements at each position were run for a minimum of 45 minutes (60 minutes in some cases). All experiments covered a Q-range of 0.0022 to 0.028 $Å^{-1}$. Sample transmission measurements were taken at each gap position.

The sample was allowed to equilibrate after loading. Measurements at the slowest shear rate were repeated to ensure reproducibility. Data were analyzed and reduced using lamp and the ILL GRASP software.

At first, the intensity scattered by the sample at rest was measured. At the large packing fraction investigated, $\phi_{eff} \approx 1.3$, the I(Q) of the sample at rest shows the presence of a structure factor (S(Q)) peak around Q ≈ 8×10^{-3} $Å^{-1}$ $^{-1}$, although the peak is not very pronounced (data not shown). Indeed, the combination of a soft, hertzian-like inter-particle potential and polydispersity leads to a decrease of the structural peak in the S(Q) for $\phi_{eff} \gg 1$. Changes in the intensity are observed under shear depending on the position of the beam along the gap. As illustrated in Fig.1, while the overall intensity is slightly shifted vertically, the shape of the curves only changes in the region around the structure factor peak, $4 \cdot 10^{-3}$ $Å^{-1}$$^{-1}$ < Q < $1.4 \cdot 10^{-2}$ $Å^{-1}$$^{-1}$. For smaller and larger Q values the curves present the same Q dependence, suggesting that shear does not significantly affect the single particle shape, since the decay for Q > $1.4 \cdot 10^{-2}$ $Å^{-1}$$^{-1}$ the curves for all rates overlap. On the contrary, shear flow does affect the overall intensity and S(Q) and, therefore, the local packing fraction and eventually the ordering of the system.

As it can be seen in Fig.1, differences between different positions across the gap are particularly pronounced at small shear rate, while they become almost negligible at the largest shear rate. Furthermore, the maximal deviation from the intensity profile in quiescent conditions is registered for the central position within the gap.

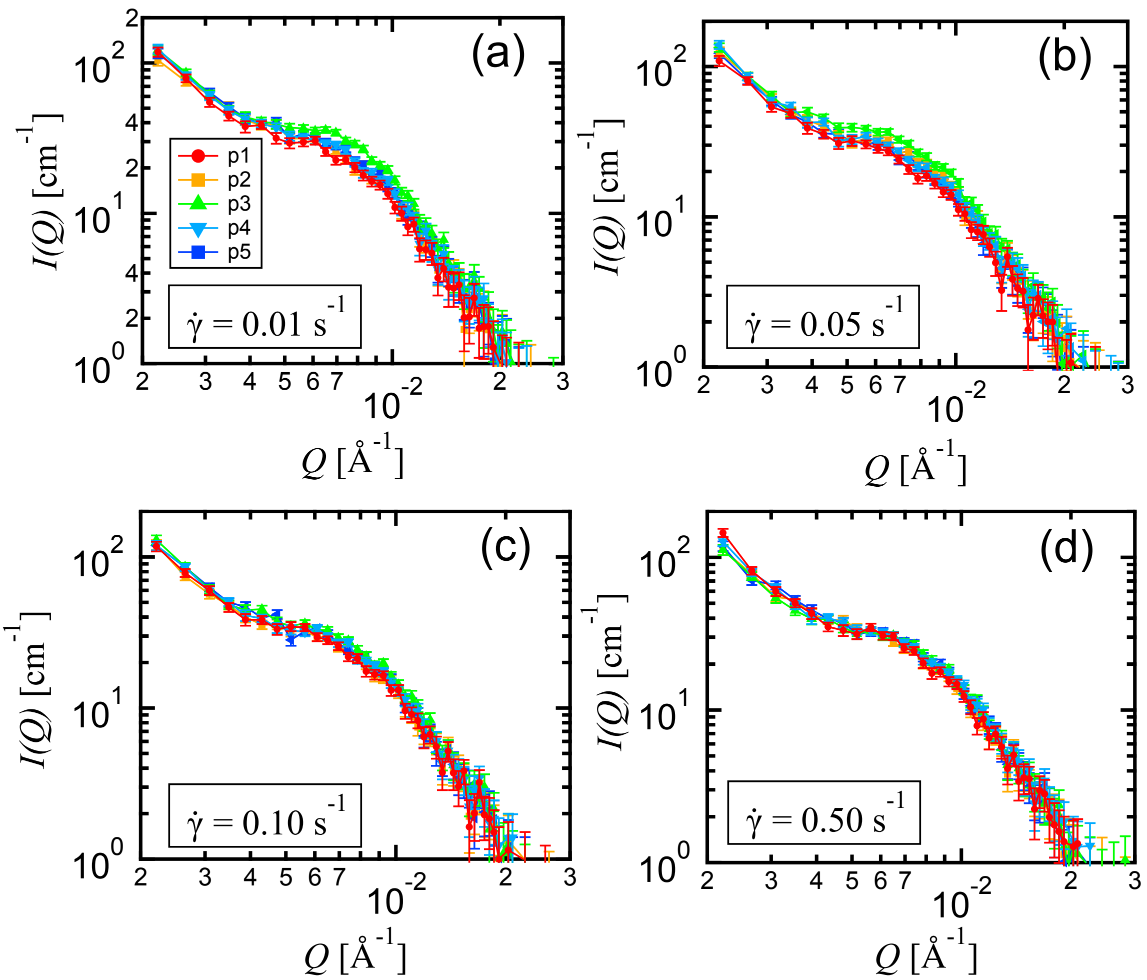

Figure 1: SANS scattering intensities I(Q) measured for different shear rates $\dot{\gamma}$ (as indicated) at 5 different positions p1-p5 along the gap, with 1 being close to the external cylinder surface and 5 to the internal cylinder surface. Position 3 corresponds to the middle of the gap.

This finding can be directly connected to the velocity profiles measured at the same rates (not shown): In the central region of the gap, velocity profiles show the presence of plug-flow at small shear rates, while the unsheared band disappears at larger rates. The larger scattering intensity measured in the same position of the gap at small shear rates therefore can be associated with an increase in the local packing fraction, inducing local jamming and the plug-flow. The increase in the local packing fraction was confirmed by the values of the transmission, that show a minimum in the middle of the gap.

[1] R. Besseling, L. Isa, P. Ballesta, G. Petekidis, M. E. Cates, and W. C. K. Poon, Phys. Rev. Lett. 105, 268301.
[2] H. Jin, K. Kang, K. H. Ahn, and J. K. G. Dhont, Soft Matter 10, 9470 (2014).