Shear-induced vortices and macroscopic alignment in graphene oxide lyotropic liquid crystals

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Graphene oxide (GO) is known to form well aligned layered liquid crystal structures in aqueous dispersion, above certain concentrations and particle sizes [1]. Such a system, known as a lyotropic phase, is typically charge- and sterically stabilised. It has also been shown that flow and confinement conditions affect the alignment and stability of these phases [2].

In this work, we report on the alignment of GO flakes under a wide range of shear flow conditions. For the first time, we probe the orientation of GO flakes in real-time using shear induced polarized light imaging (SIPLI) [3], and small angle X-ray and light scattering with in-situ rheometer (Rheo-SAXS and Rheo-SALS).

Under certain high concentration and high shear rate conditions, we observe a unique pattern in SIPLI; a Maltese cross combined with shear banding (Figure 1).

References

[1] Rouhollah Jalili, Sayeed Aboutalebi, et. al. Materials Horizons, 1 (2014) 87
[2] Philippe Poulin, Rouhollah Jalili, et. al. PNAS, 40 (2016) 11088-11093
[3] Oleksandr O. Mykhaylyk, Nicholas J. Warren, Andrew J. Parnell, Gerhard Pfeifer, Joerg Laeuger, J. Poly. Sci., 21 (2016) 2151-2170

The size distribution of GO flakes, the shear rate and the gap size between rotating parallel plates significantly affects the structure and periodicity of the bands. The onset of turbulence results in an anomalous shear thickening of the GO dispersion. At other regimes of flow and concentration, conventional lyotropic or isotropic phases are observed.

The structure is attributed to Taylor vortex type flow; a helical flow pattern with the axis of the helix tangential to the flow direction at any point. The orientations prescribed by this helical flow are consistent with anomalous observations in Rheo-SAXS and Rheo-SALS using different shear geometries.

The range of shear rates and stress overlaps with a number of processes of technological relevance to GO, such as wet spinning and injection moulding, which could lead to undesirable or, alternatively, controllable textures in graphene fibres and composites.

Figures

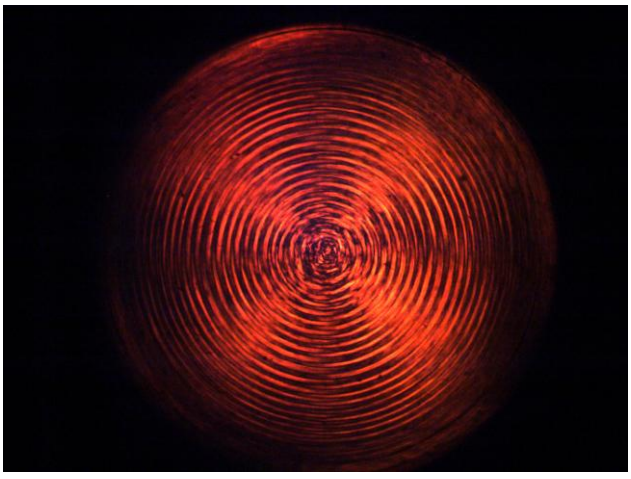

Figure 1: SIPLI image of GO suspension sheared in plate-plate geometry (shear rate at the sample edge is 100 rad/s). The Maltese cross indicates overall alignment along the flow, whilst the banding results from helical vortices.