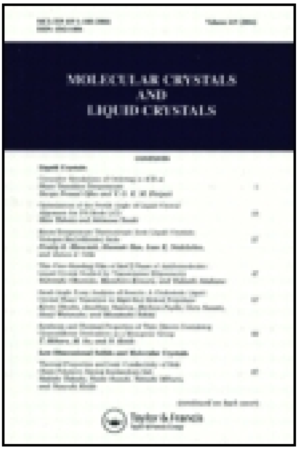

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Band Formation in Sheared HPC Solutions. Effects of Sample Thickness

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BAND FORMATION IN SHEARED HPC SOLUTIONS. EFFECTS OF SAMPLE THICKNESS.

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Abstract A parallel plate apparatus was used to observe the formation of the banded texture in HPC solutions after shear. A curve on the shear rate-total deformation plane is determined, giving the threshold for band formation. The position of such a curve is found to depend strongly on sample thickness.

INTRODUCTION

It is well known that in all nematic and cholesteric polymeric liquid crystals a characteristic banded texture can be observed after shear, which is not found in low molecular weight materials. Bands run perpendicular to the direction of shear, corresponding to a periodic pattern of the molecular orientation around the shear direction[1,2]. In spite of its generality, however, the phenomenon has not yet received a convincing explanation. Also, quantitative information is still scarce, although there is a general consensus that bands appear only if the shear rate is sufficiently high.

The aim of the present work was that of exploring the possible influence of additional variables, namely, the total shear deformation and the sample thickness. An ad hoc apparatus was built where both those variables, as well as the shear rate, could be varied in a controlled fashion.

EXPERIMENTAL

A scheme of the apparatus used is shown in Figure 1. The sample is confined between two optical glass plates. The upper plate is driven by a DC, electronically controlled motor. Both the speed and the overall displacement can be set. Adjustment of a micrometric tilting stage guarantees that the lower surface of the upper plate moves in its own plane. The parallelism of the upper face of the lower plate, as well as the gap thickness, are provided by another set of micrometric movements. Parallelism of the plates is monitored by the multiple reflections of a laser beam. The gap thickness is measured micrometrically, and is further controlled by focussing the microscope on suitable marks printed on the glass surfaces. Polarized light is used to observe the sample texture.

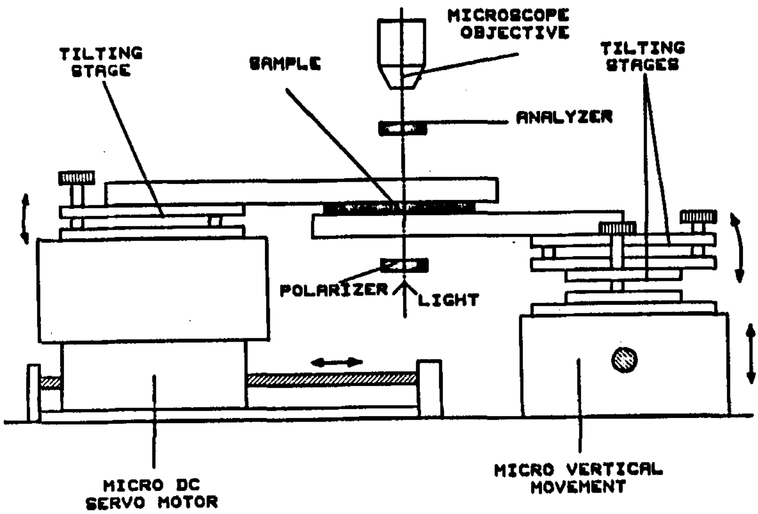

FIGURE 1. Schematic view of the parallel plate apparatus.

The limits of the apparatus are as follows. The parallelism accuracy is of order 20 μm over the whole plate length of 10 cm. Thus we have kept the minimum gap thickness to a value of 150 μm. While in principle there is no upper bound to the gap thickness, a good transparency of the sample is obtained for values less than 1 mm. As the minimum and maximum plate speeds are 0.35 mm/s and 16 mm/s, respectively, workable values of shear rate and shear deformation fall within 0.5÷100 1/s and 1÷500, respectively.

The liquid crystal polymer used in these experiments is Hydroxypropylcellulose (HPC) supplied by Aldrich with a molecular weight of ca. 300.000. The aqueous solution employed, 50% by weight, is well within the mesophase region[3,4]. Due to the high viscosity of this solution, all texture relaxation effects take place over a very long time. Thus, after the sample had been squeezed between the plates to obtain the desired gap thickness, a suitable rest time was needed before the experiment started. It was found that 5 to 6 hours were sufficient to ensure a good reproducibility of the results.

In a typical experiment, after the sample had been sheared at some preset values of shear rate and total deformation, the texture of the sample was observed during relaxation, checking for band formation. Depending on conditions, bands would appear after a time ranging from a few seconds up to several minutes. They would subsequently vanish within about two hours. When conditions were such that bands would not form at all, the sample was kept under observation for at least two hours for good measure.

The time scale of texture change was large enough to allow for detailed observation. In particular, it was possible to scan the sample along its thickness by focussing the microscope at different depths. In most cases, it was found that the banded texture did not fill the sample throughout its thickness. Periodic scanning allowed to follow the evolution of the banded texture at several depths in the sample.

RESULTS AND DISCUSSION

For a fixed value of gap thickness and shear rate, observations were made at several values of the total deformation. Generally, for large enough deformations, the banded texture would appear, whereas it would not at sufficiently small deformations. It was thus possible, by trial and error, to determine a threshold value for band formation.

Figures 2-4 report borderline results of band formation for three values of the thickness. In each of these graphs, the abscissa is the shear rate and the ordinate is the total shear deformation. It can be noticed that the threshold value of total shear units for band formation is a decreasing function of the shear rate.

A striking result is the strong effect of the sample thickness on threshold values. Figure 5 compares the threshold lines (obtained by gross interpolation in the previous figures) for the three thicknesses used in this work. Up to one order of magnitude differences are found between the 150 μm and the 500 μm gap values. The direction is that increasing values of the thickness favour band formation.

As mentioned in the Introduction, an interpretation of the phenomenon is missing. The strong influence of the thickness, however, appears to exclude the possibility that

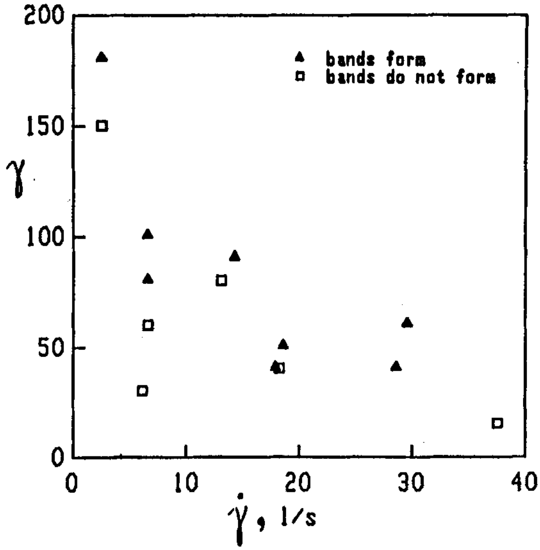

FIGURE 2. Results showing the threshold for band formation. The sample thickness is 150 μm.

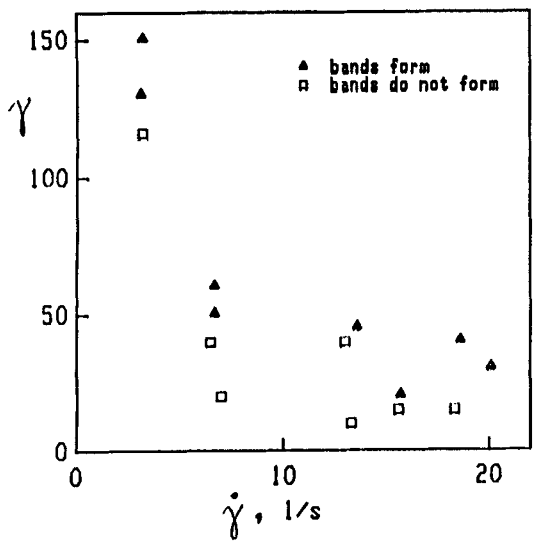

FIGURE 3. Same as in Figure 2. Sample thickness is 300 μm

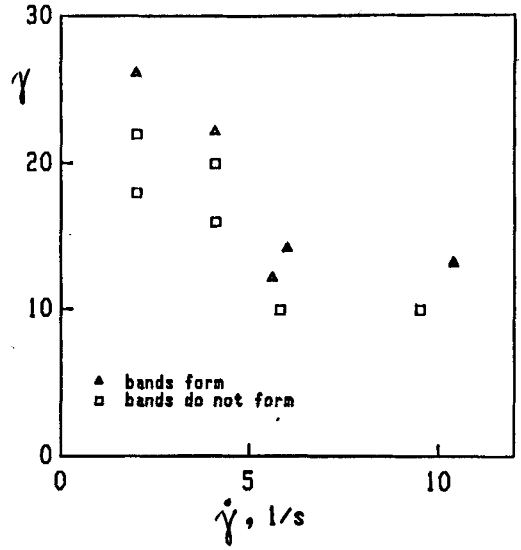

FIGURE 4. Same as in Figure 2. Sample thickness is 500 μm

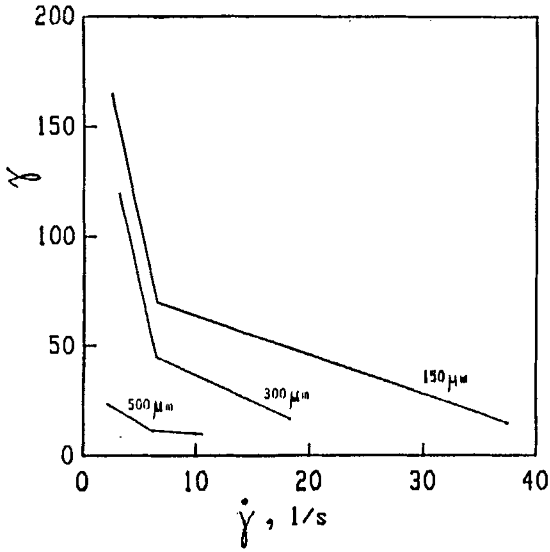

FIGURE 5. Threshold lines for band formation at different sample thicknesses.

the formation of bands reflects a bulk property. On the contrary, it suggests that some sort of instability might be responsible for the observed effects. The results in Figure 5, together with the observation that band formation does not occur throughout the sample thickness, speak in favour of some sort of inhomogeneity along the thickness which might even be present during flow. Extensions of this work to explore such a possibility are in progress.

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