Conference Report II

Euromech Colloquium No. 492: Shear-banding Phenomena in Entangled Systems

3 – 5 September 2007 University College London, U.K.

Certain entangled fluid systems, in particular those containing wormlike micelles of surfactant molecules, exhibit a phenomenon called shear-banding in which regions having different fluid properties spontaneously appear within flow of a single fluid. This area first came into prominence during the Newton Institute programme (Cambridge, UK) on the Dynamics of Complex Fluids, January – June 1996. At that stage the generic picture considered two static shear-bands with an interface whose normal was in the flow gradient direction, and models were beginning to be proposed which could effectively model this scenario.

Over the intervening years this picture has changed, with the theoretical prediction of an instability to 2D waves, experimental observations of banding in a different direction, and controversy over the use of stress-diffusion to regularise the governing equations. Given the importance of these fluids outside the laboratory in a large range of industrial applications, it was clear that more detailed discussions were needed.

Euromech colloquium 492 was held at University College London from the 3rd to 5th of September 2007. The ethos of Euromech-sponsored colloquiua is that they should be small meetings, specialized in content and informal in character. One aim is to enhance the scientific exchange within Europe; but the meetings are not limited exclusively to European researchers. The meeting had a single track of presentations and discussion, attended by all the delegates. The programme attracted 27 invited delegates of whom 22 gave presentations, from across the spectrum of theoretical and experimental work. Each half-day session had approximately 90 minutes scheduled for discussion, and in every case this time was used to the full, with active discussion both during and after the talks. Points which were discussed repeatedly included:

Turbidity

In several of the experiments, observations of shear-banding were produced by scattering some form of light off the interface between the shear bands. The only reason such scattering would occur is if there is a difference in turbidity (or opaqueness) between the two bands. Observations seem to predict that the higher shear-rate band is turbid, although ideally a combination of local velocity measurements and direct observation would be used to confirm this. The question arose as to exactly what structures in the high-shear band are causing the turbidity.

Steady bands?

There are plenty of published works on shear-banding which show evidence of steady, stable bands, most of which pre-date the work presented at this colloquium. However, there are issues with time-averaging (in, for example, NMR experiments) or spatial averaging (in stress birefringence) which mean these may have been observations of fluctuating systems, reported as steady. The question arose as to whether there has, in fact, been any observation of steady shear bands; one participant claimed to have seen them in polymer melts but most had seen fluctuations in all their systems. Related to the turbidity question above, there was discussion as to whether in fact a steady high-shear rate band exists at all or whether this is a fluctuating, transient state.

Slip and wall anchoring

One session was devoted to the effects of wall-slip and wall boundary conditions. In experiments, observations with roughened walls showed clearer shear-banding than with smooth walls; theoretical work showed that the precise boundary condition chosen could make huge differences to the macroscopic behaviour of the system. There was active discussion of the slip issue, including the problem of how to know exactly what is going on close to a wall, and whether a "slip layer" could in fact be pure solvent with all structure excluded.

Shear-banding in different systems

There were a variety of interpretations of the definition of shear-banding, with participants presenting very different phenomena in very different systems. Possible alternative sources of shear-banding included granular media, entangled polymer melts, and partially aggregated networks of carbon nanotubes.

Stress diffusion

Stress diffusion is now largely accepted as a necessary physical mechanism to regularise shear-banding systems and allow communication between the bands. However, until now there have not been any estimations of the magnitude of the diffusion constant, *D*.

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The first detailed coupling of models to experiments is now happening and allows us to predict the size of *D*, but the size of this estimate is seen to vary strongly according to whether or not the model includes strong coupling between microstructure and concentration. Further work is needed to design an experimental paradigm which could make clear observations of *D*.

■ Normal stresses

There was discussion of the role of normal stress differences, both in interfacial instabilities and within the high-shear band itself. It was argued that very high alignment should produce extremely high values of N_1, perhaps providing a mechanism for instability within the high-shear band. Preliminary theoretical work on systems in which the high-shear band would be intrinsically unstable, though, had produced no superficially steady flows at all, so this theory needs further work.

■ Vorticity banding

There were several observations and some theoretical efforts in the realm of vorticity banding, in which the normal to the interface between bands is in the vorticity direction. These observations were in some cases similar to the Taylor rolls seen in a purely elastic curvature-drived instability in Couette flow; however in one case there was an observation of different phases (identified by turbidity again) swapping places periodically. After much discussion of these observations, still no mechanism had been proposed. Other observations, of a steady wave-like form on the standard interface, can now be predicted well by the simple fluid models like Johnson-Segalman.

■ Observation of shear-banding from flow profiles

Both theory and experiment showed that a shear-banding system could produce a relatively smooth monotonic observed flow profile even with only moderate diffusion. This opened further questions about what exactly we mean by shear-banding; along with the discussions of vorticity banding above, it became clear that a range of phenomena need to be encompassed within the general shear-banding heading. Distinctions between phase transitions, elastic instabilities and constitutive instabilities become blurred in real, physical systems and couplings between all of these will be needed to fully explain observations.

The meeting opened with a keynote lecture from Pam Cook (with Lin Zhou, Paula Vasquez & Gareth McKinley) on "Modeling the inhomogeneous response in steady and transient flows of wormlike micellar solutions", and finished with a summary presentation from Mike Cates. Despite London Transport's best efforts (throwing a tube strike into the mix) Prof. Cates was able to describe the meeting as "the best conference I've been to in 10 years". We're very grateful to Euromech for providing funding for such an enjoyable meeting.

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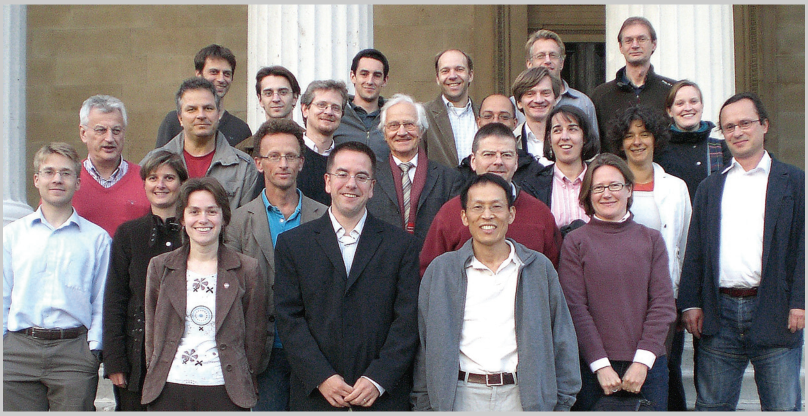
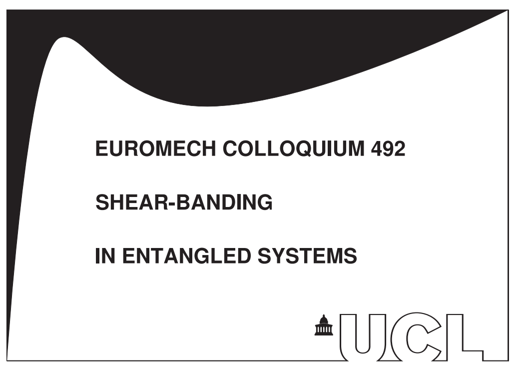
Figure 1 (left): Group photo from Euromech Colloquium 492 at UCL.

Figure 2: Conference logo of Euromech colloquium 492.





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