Abstract

Some experiments on flow and orientation in fibre suspensions

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Glass fibre 2 mm x 8 μm was de-sized, separated and mixed under vacuum into Newtonian resins, with viscosity ~ 10 to 100 poise, and carefully matched refractive indices, to give a clear mixture. Small amounts of 300 μm nickel particles and opaque fibres were included as tracers for velocity fields and fibre orientation distributions. The mixture was injected at relatively low speeds, ~ 2 to 20 mm s^{-1}, into parallel sided and diverging moulds.

At 2.6% vol fibre, which is approximately the maximum theoretical volume fraction for a random three-dimensional array of rigid rods, plug flow profiles across the mould gap (12 mm deep) were found. Preferential fibre alignment due to the expanding flow from the gate was found at an upstream position in the parallel-sided mould, but this decreased significantly as material flowed down the mould. In a diverging mould some preferential alignment due to the expanding flow was found, but very much less than predicted by a simple continuum theory regarding a fibre as an embedded material line element. An experiment using coloured tracer portions of fibre-resin mixture showed that the deformation expected in a uniform continuum did not occur.

On the basis of the experiments, as well as visual observation when the refractive indices were not precisely matched, the fibre resin mixture was determined as having a clumpy structure - relatively rigid regions of interlocking fibres being separated by resin rich regions. A wide range of fibre surface treatments, and different mixing methods did not alter this picture. Preferential fibre orientation therefore requires deformation and/or rotation of these clumps, which is resisted by forces arising from the viscosity of the resin matrix and the elasticity of the fibres in bending. Consistent with this idea was the finding that higher preferential alignment is produced by higher injection speeds. This alignment does not relax in stationary material, but can do so during flow - even plug flug in the parallel mould. This is believed to be due to the effect of shear stresses transmitted from the mould walls, which help to free the clumps, causing them to rotate and/or permitting the deformation to relax.

Further experiments at lower concentrations showed behaviour closer to that expected on the basis of classical theory of fibre rotation, modified by various degrees of interaction.

The work shows that, in some regimes at least, constitutive theories, and predictions of orientation in fibre suspensions should take account of a clumpy structure, the possibility of deformation of these clumps to produce preferential alignment, and the competing process of alignment loss due to relaxation of this deformation and/or rotation of the clumps.