NORMAL STRESSES IN THE SHEAR FLOW OF MAGNETORHEOLOGICAL FLUIDS

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This work reports an experimental and theoretical study on the normal force that appears in the shear flow of magnetorheological (MR) fluids subjected to magnetic fields. Experimental values of the normal force developed by these fluids were obtained using rotational plate-plate rheometry. Applied magnetic fields up to 343 kA/m were generated in the plate-plate measuring geometry. It was found that MR fluids develop a non-negligible normal force, both in the absence and presence of shear. This force increases faster than linearly with both the concentration of magnetic particles and the strength of the applied field. Three different regions in the normal force vs. shear rate curve are distinguished: (i) a normal force high-value plateau in the absence of shear and at very low shear, which may be associated to the state where the field-induced particle structures are not considerably deformed by the shear; (ii) a strong decrease of the normal force as the shear rate increases, which approximately coincides with the onset of the flow; (iii) a normal force low-value plateau at high shear, where particle structures are continuously broken by the effect of the hydrodynamic forces.

The theoretical model developed predicts semi-quantitatively the experimental values of the normal force. This model is based on the formation of magnetic field-induced particle structures. When the suspension is sheared these structures are tilted to a certain orientation angle, which is defined by the equilibrium between the hydrodynamic and magnetic torques exerted on the structures. The equilibrium between the cohesive magnetic forces and the tensile hydrodynamic ones is used to obtain the aspect ratio of the structures. This model includes both the viscoelastic response of the MR fluid under an applied magnetic field and the effect of the magnetic Maxwell stress. As a consequence of the latter, the MR fluid sample tends to be stretched along the field lines, pushing apart the rheometer plates. On this basis, the total stress tensor for our MR suspensions was calculated and, subsequently, the normal force as the integral of the stress over the total surface of the rotational plate. Due to the inclusion of the Maxwell stress, our theory predicts a non-zero normal force in the absence of shear. In the high shear rate regime, both the viscoelastic response and the Maxwell stress give comparable contributions to the normal force. Interestingly, we found that the magnetic term of the normal force contains an extra contribution corresponding to the cases where the magnetic field is inhomogeneous, which agrees well with our experimental observations.