Characterization of Rheological Properties of Novel Magnetorheological Fluids

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Abstract

Characterization of an MR fluid and examination of the changes to their rheological properties under various operating conditions is important before its integration with various mechanical devices. The purpose of this study is to conduct such a characterization study on three novel MR fluids, using a commercially available fluid MRF 132AD, as a benchmark. The rheological property changes in these fluids are measured and reported at various magnetic field intensities, shear rates, strain amplitudes, Rheology of the fluids is measured and documented under both rotational and oscillatory shear conditions. A modular rheometer is used for all experimental purposes. The novel MR fluids exhibit stable rheological properties comparable to the commercial fluid and are stable under continuous deformation over a period of time.

Introduction

Magnetorheological (MR) fluids are suspensions of micron sized iron particles in a viscous medium that display controllable and reversible changes in their rheological properties under externally applied magnetic fields. Each MR fluid is unique in its properties and responses to externally applied conditions. These properties are dependent on the nature, size and density of the particles, fluid structure, carrier fluids, additives, magnetic field applied and temperature among many other factors. The composition and synthesis procedure of the fluids also define these characteristics as settling rate, which is an important consideration for MR fluid integration in various mechanical devices. When the fluid flow is normal to the direction of the applied magnetic field, the largest changes in the MR fluid properties are noted.

Material Background on UNR Fluids

Each fluid under study is unique in composition and synthesis procedure. For the purpose of this paper, the three novel MR fluids will be referred to as UNR1, UNR2 and UNR3. The compositions of the fluids, particularly the base fluid and the stabilizing polymers used for these fluids, are as mentioned below:

UNR1: Ferromagnetic particles dispersed in a carrier medium of PAO, with Polyisobutylene as a stabilizer.
UNR2: Carbonyl iron particles, surface grafted with butyl acrylate, in a carrier medium of N-octyl-pyrrolidone.
UNR3: Carbonyl iron particles, surface grafted with pentafluorostyrene, in a carrier medium of N-octyl-pyrrolidine.

MRF 132AD is the commercial benchmark fluid used in this study.

The polymer coating on the iron particle surface in fluids, UNR2 and UNR3, has been achieved through a process called the Atom Transfer Radical Polymerization (ATRP). A schematic of the polymerization in ATRP fluids is presented in Figure 1.

Experimental Setup

A modular shear rheometer (Paar Physica MCR 300) having parallel plate geometry, with computer data acquisition and temperature control, is used for the test purposes. A fixed plate gap of 1mm and a fluid volume of 0.3 ml under the gap are used as standard experimental settings for all the samples tested. Figure 4 shows the shear rheometer and the arrangement schematic used. The rheological properties of the MR fluids are established under varying magnetic field intensities with temperature control. Rheological properties of MR fluids change with the external magnetic field applied, mostly noticeably the shear stress and viscosity. A number of oscillatory and rotational shear tests are performed to obtain a complete viscous, elastic and plastic behavior of the MR fluid.

The following properties are considered for the characterization: off state viscosity, shear yield stress, ability of the fluids to maintain a high shear stress over a period of time, viscoelastic properties and settling rate.

Experimental Results

The off state viscosities of the fluids under study are presented in Figure 5. Low off state viscosity is desirable in MR fluids for use in devices. The off state viscosity in the polymer coated novel MR fluids can be controlled by the polymer coating fraction on the iron particles, shown in Figure 6.

In an external magnetic field, MR fluids change to a semi-solid state. Under strain, the MR fluids exhibit viscoelastic properties. The viscoelastic properties of the fluids under consideration are studied under a strain sweep test and a frequency sweep test in the pre yield region. Figures 9 through 12 present the storage modulus and loss modulus of the fluids being studied, as functions of strain amplitude and frequency.

Material Background on UNR Fluids

The rheological properties of the various novel MR fluids are examined and reported using the commercial MR fluid MRF 132AD as a benchmark. The novel MR fluids exhibit stable and desirable rheological properties such as, low viscosity and high yield stress which are comparable to the benchmark fluid. Their ability to retain the high shear stress for long periods of time is significant. A lower advantage of the novel fluids over the commercial fluid.

Summary

The rheological properties of the novel MR fluids can be controlled by the percentage of polymer coating on the iron particle surface. But higher polymer fractions would result in lower yield stress. The settling rate for the MR fluid containing pure iron particles is significantly higher than the ATRP fluids. The particle settling rates of the novel fluids compared to the commercial benchmark fluid is presented in Figure 13.