철입자 분산계의 자기유변 특성연구

조민성, 임성택, 최형진
인하대학교 고분자공학과

Magnetorheological Characterization of Iron Particle Suspensions

Min Seong Cho, Sung Taek Lim, and Hyoung Jin Choi
Department of Polymer Science and Engineering, Inha University

Introduction

Magnetorheological (MR) fluid, which is one of the smart materials with controllable properties by an external magnetic field, is a particular suspension of magnetically susceptible material dispersed in suspending medium. MR fluids are abruptly transformed within milliseconds from fluid-like to solid-like by applying magnetic field, by showing changes of rheological properties of MR fluids such as a yield stress and an enhancement of viscosity. Particles for MR fluids should be magnetized under an external magnetic field. It means that ferromagnetic, ferrimagnetic, and paramagnetic materials can be used as a dispersed phase of MR fluids. In addition, soft magnetic materials which are easy to magnetize and demagnetize, are superior to hard magnetic materials, considering the reversible control of rheological properties of MR fluids according to external fields. Figure 1 represents different schematic diagrams of magnetic hysteresis for soft and hard magnetic materials (Kasap, 2002).

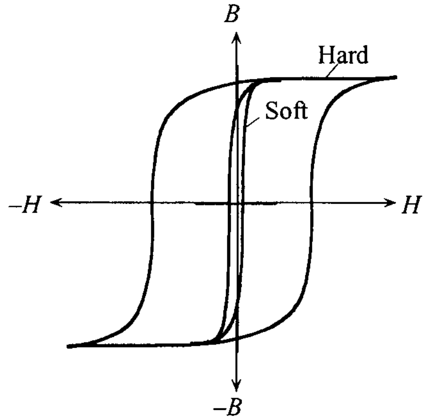

Figure 1. Magnetic hysteresis of soft and hard magnetic materials.

Comparing with similar systems of electrorheological (ER) fluids, MR fluids show superior properties such as yield stress which is a crucial parameter for both ER and MR fluids. In general, MR fluids can obtain 10 ~ 100 kPa of yield stress within possible magnetic field range and these are much higher value than 0.1 ~ 1 kPa for ER fluids (Ginder, 1996). In addition, because magnetic field is more stable than electric field, commercialization of MR fluids is faster than ER fluids (Lord Corporation, website). The possible application fields are active controllable dampers, torque transducers, and position controllers (Bica, 2002; Lord Corporation, website) similar to the ER fluids.

Although a large number of researches on MR fluids have been conducted, most of them are concentrated in both applications and yield stress as a function of magnetic field (Bossis et al., 2002; Shkel and Klingenberg, 2001) to find optimum formulation for each specific application. Therefore, profound studies on rheology of MR fluids are not enough as much as their applications.

In this study, the rheological properties of iron particle suspensions under applied magnetic fields are investigated including low magnetic field strength. Basic flow behaviors and yield properties are measured by steady state experiments, and viscoelastic properties are investigated using dynamic oscillation tests.

Experimental

Various kinds of iron particles, known as Carbonyl Iron (CI, kindly donated by BASF Company LTD., Germany), can be used for particulate materials for MR fluids. CIs have Fe content more than 99.5% and these are spherical with a density of 7.86 g/ml. Figure 2 shows SEM image of the CI particles.

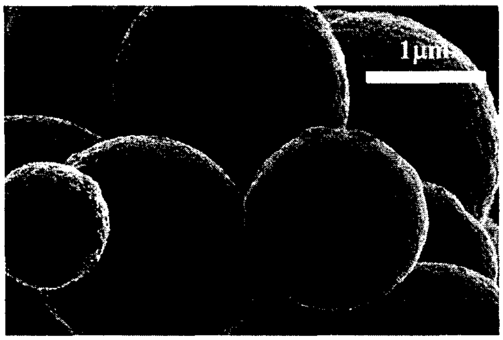

Figure 2. SEM image of Carbonyl Iron particles.

MR fluids are prepared by dispersing CI particles in mineral oil with different particle concentration up to 30 vol%. As dispersing stabilizers, either surfactants or nanosized particles such as fumed silica were added to MR fluids and their effect on MR properties also studied.

MR characterizations were performed via a rotational rheometer (Physica MCR 300, Stuttgart, Germany) equipped with a magnetorheological device (MRD 180, Physica, Stuttgart, Germany) at 20 °C. The coil current and magnetic field strength were controlled by a separate control unit and the rheometer software (US 200, Physica, Germany). The homogeneous magnetic field direction was set perpendicular to the flow direction (Fig. 3) (Wollny et al., 2002). A parallel-plate measuring system with a diameter of 20 mm was used at a gap of 1 mm. This measuring system is made of non-magnetic metal to prevent the occurrence of radial magnetic forces acting on the shaft of the measuring system. Unlike a conventional solenoid-type magnetic field generator, this system adopts the two-part cover system, which is used as a magnetic bridge and for setting a defined air gap.

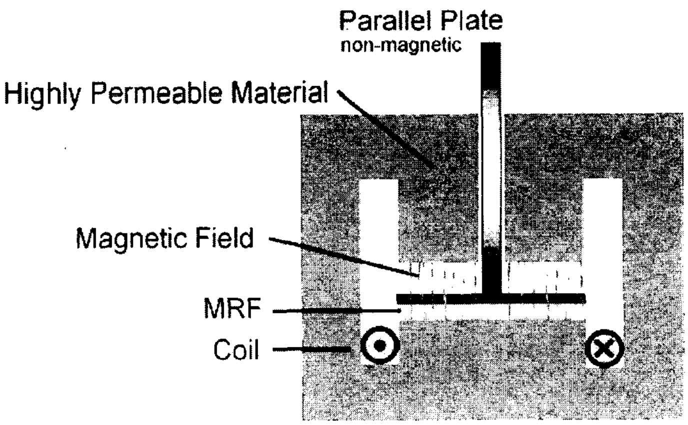

Figure 3. Schematic diagram of measuring system for MR fluids

Results and Discussion

Figure 4 shows shear stress as a function of shear rate under different external magnetic fields from 0 to 185 kA/m of magnetic field strength. CI concentration is 30 vol% and it is rather concentrated particle suspension, so that non-Newtonian flow behavior is observed in data measured at zero external field. With the increase of magnetic field, the shear stresses are leveled up in the whole shear rate region. Yield stress for each condition can be obtained by extrapolating the stress values

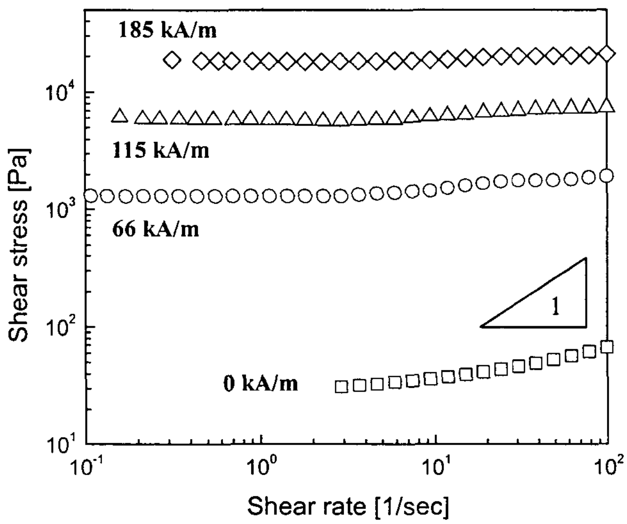

Figure 4. Shear stress versus shear rate of a MR fluid (30vol% of CI) at various magnetic field.

from the plateau region of stress to a zero shear rate limit. This MR fluid shows about 20 kPa of yield stress at 185 kA/m, which is sufficient enough to be applied to commercial fields. In addition, yielding behavior which shows constant shear stress with increasing shear rate, was maintained for all magnetic fields tested and it means that particular structures constructed within fluid under the applied magnetic field are continuously broken by shear deformation until 100 1/sec of shear rate. In other wards, particle structures developed under external magnetic fields are remained until 100 1/sec of shear rate.

Acknowledgement

This study was supported by research grants from the Korea Science and Engineering Foundation (KOSEF) through the Applied Rheology Center (ARC), an official KOSEF-created engineering research center (ERC) at Korea University, Korea.

Reference

Bica I., 2002, *J. Magn. Magn. Mater.* **241**, 196.

Bossis G., Lacis S., Meunier A., Volkova O., 2002, *J. Magn. Magn. Mater.* **252**, 224.

Ginder J. M., Davis, L. C., Elie, L. D., 1996, *Int. J. Mod. Phys. B* **10**, 3293.

Kasap, S. O., 2002, *In* Principles of Electronic Materials and Devices, 2nd Ed., McGraw-Hill, pp. 589 – 662.

Lord Corporation, *http://www.rheonetic.com/fluid_begin.htm.*

Shkel Y. M., Klingenberg D. J., 2001, *J. Rheol.* **45**, 351.

Wollny K., Lauger J., Huck S., 2002, *Appl. Rheol.* **12**, 25.