RHEOLOGICAL PROPERTIES OF MAGNETIZED BIDISPERSE MAGNETORHEOLOGICAL FLUIDS CONTAINING NEEDLE-LIKE PARTICLES

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Abstract. In the present study, a novel magnetic functional fluid, magnetized bidisperse magnetorheological fluids containing needle-like magnetic particles, was proposed to enhance magnetorheological effect. This is a fluid magnetized by a pulse-strong magnetic field of 8 T, before exposed to a weak external magnetic field for inducing the magnetorheological effect. The dynamic rheological measurements in the presence of a magnetic field using the magnetic field imposed-type rheometer (MCR302, MRD, Anton-paar) was carried out to investigate the effect of the initial magnetization on the rheological behavior. The results show that the storage modulus increases with the initial magnetization. Four element model fits the data well. The model shows that the magnetization increases the elastic elements of the fluid.

1. Introduction

Magnetic Functional Fluids (MFFs), dealt in the present work, are magnetic particle suspensions in which nm- and/or μm-sized magnetic particles disperse in proper carrier liquids. When such fluids are exposed to an external magnetic field, the magnetic particles are magnetized and forms chain-like structures along the magnetic field. These structures apparently increase the fluid viscosity. This effect is often called a Magnetorheological effect (MR effect). The effect can be regulated by magnetic field strength and direction [1]. Hence, the magnetic functional fluids have been applied to semi-active dampers and clutches [2]. The authors have been proposed a Bidispersed Magnetorheological Fluid (BMRF) containing Needle-like magnetic particles to enhance the MR effect [3]. The BMRF is a mixture MFF of nm- and μm-sized magnetic particles. Significant large clusters are known to be formed under an external magnetic field. The authors found that addition needle-like magnetic particles to BMRF render it more the MR effect. In the present work, to enhance further MR effect, we proposed a novel MFF, magnetized BMRF containing needle-like magnetic particles.

The proposed fluid is a fluid magnetized by a pulse-strong magnetic field of 8 T, before is exposed to a weak external magnetic field for inducing the MR effect. μm-sized magnetic particles have a multi-magnetic domain, in which magnetic moments randomly orients. Once a pulse-strong magnetic field applies to the particles, the magnetic moment orient to the field direction. After removing the magnetic field, the moments keep the orientation, which means that the particles are magnetized and have remanent magnetization and coercive force. Therefore, a significant enhancement of the MR effect is expected by applying a relatively weak magnetic field.

To understand the effect of the initial magnetization to the MR effect, most relevant are investigations of the rheological properties. In the present study, we carried out the dynamic rheological measurements in the presence of a magnetic field using the magnetic field imposed-type rheometer (MCR302, MRD, Anton-paar). And by fitting the obtained data by four element model, the effect of magnetization on the dynamic rheological properties was discussed.

2. Test fluids and dynamic rheological measurements

The test fluids are mixture magnetic functional fluids in which nm-, μm and needle-like magnetic particles disperse in polyalphaolefin. The nm-sized magnetic particle was maghemite with an averaged diameter of 10 nm (APG314, Ferrotec). μm-sized magnetic particle is carbonyl iron with an averaged diameter of 4~6 μm (OM grade, BASF). Needle-like magnetic particle is iron with averaged major axis length of 100 nm and an aspect ratio of 4.0 (MP-5, Dowa Electronics Materials Co., Ltd.). Their fraction was arranged to be 3.0 vol. % of nm-sized magnetic particle, 26.0 vol. % of μm-sized magnetic particles and 1.0 vol. % of needle-like magnetic particles, respectively. Smectite of 2.2 vol. % was added as an additive to increase fluid viscosity. We prepare two types of test fluids. One of them is magnetized fluid (Magnetized BMRF), which was initially magnetized by a pulse-strong magnetic field of 8 T. Another is non-magnetized fluid (Non-magnetized BMRF).

The dynamic rheological properties were measured by the plate-type magnetic field imposed-type rheometer (MCR302, MRD, Anton-paar) in the presence of the magnetic field of 150 mT. The gap between rotor and stator was set to be 1.0 mm.

3. Results and discussion

In order to verify the influence of initial magnetization on the dynamic rheological behavior, Fig. 1 shows the storage and loss moduli, G' and G'', of the non-magnetized BMRF and the magnetized BMRF. The solid lines are the fitting data with the four-element model. The model fits the experimental data well in a range of 70 ~ 140 rad/s. Of particular interest is that the storage modulus is significantly enhanced by initially magnetizing the BMRF with a pulse-strong magnetic field of 8T. The four-element model is a combination of Voigt and Maxwell models. The Voigt model is often used to describe the solid behaviors, and the Maxwell model describes the liquid behavior. With fitting the experimental data by the four-element model, it was found that the elastic elements in Voigt and Maxwell models increases by the initial magnetization. The magnetic dipole interaction force acts on the magnetic particles and forms the chain-like structures in the presence of a magnetic field. This elastic variation is thought to be due to a change of structure morphology. The morphology depends on the particle shape, size and fraction [4]. Because the µm-sized and the needle-like particles have a multi-magnetic domain, the remanent magnetization is induced by initially magnetizing the BMRF, resulting in that the magnetic particle assemblage are formed in the absence of magnetic field. This relatively huge magnetic assemblage may form further huge structures along the applied magnetic field. Consequently, the storage modulus of the BMRF may be enhanced by the initial magnetization.

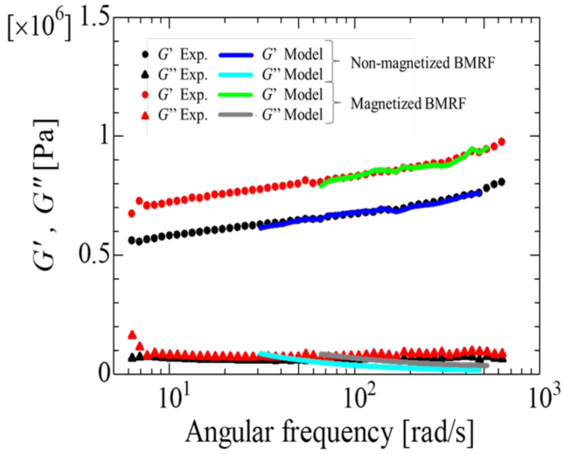

Fig.1. The storage modulus G' and the loss modulus G'' of non-magnetized and magnetized bidipsersed magnetorheological fluids. The plots are measured moduli. The solid lines are fitting data with the four element model.

Conclusions

We investigated the effect of the initial magnetization on the dynamic rheological properties of bidisperse magnetorheological fluids containing needle-like magnetic particles. The BMRF has an inherent potential to enhance the MR effect significantly. By initially magnetizing the BMRF to induce remanent magnetization, it was found that the MR effect is significantly increased. The analysis with fitting the four-element model shows that the initial magnetization enhances elastic properties.

References

[1] Yamaguchi H. *Engineering Fluid Mechanics*, Springer, 2008.
[2] Odenbach S. Ferrofluids -Magnetically Controllable Fluids and Their Applications, Springer, 2002.
[3] Ido Y., Nishida H., Iwamoto Y., Yokoyama H. Viscous properties of ferrofluids containing both micrometer-size magnetic particles and fine needle-like particles, Journal of Magnetism and Magnetic Materials, 2017, 431, 94-98.
[4] Iwamoto Y., Kondoh S., Ido Y., Yamamoto H., Nishida H., Yamasaki H., Yamaguchi H., Jeyadevan B. Influence of size on anisotropic thermophysical and rheological properties of magnetic suspensions, International Journal of Applied Electromagnetics and Mechanics, 2018, 58, 1-15.