Energy Dissipation Enhancement of Smart Magnetic Grease for Sustainable High-Speed Devices

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ABSTRACT

Magnetic grease or Magnetorheological (MR) grease is a type of smart material wherein grease acts as a carrier medium to suspend the magnetic particles which are controllable with the presence of magnetic field. Possessing high yield stress and anti-sedimentation of magnetic particles, MR grease is highlighted because it has more advantages compared to MR fluid. Unfortunately, the fluidity of MR grease is quite low indirectly causes pumpability to suffer and necessitating more power consumption for the devices to begin operating. In order to sustain the performances of the devices, high fluidity of MR grease with low energy dissipation has been introduced with the presence of variable sizes of cobalt ferrite ($CoFe_2O_4$) as an additive. Therefore, 1wt% $CoFe_2O_4$ is incorporated in this study to reduce the initial off-state viscosity and the energy dissipated by MR grease during the shearing process. To analyze the behavior effect of MR grease, the samples undergo rheological tests in different values of the magnetic field. Based on the findings, the presence of micron-sized and nano-sized of $CoFe_2O_4$ additives significantly decreases the viscosity and improved the dissipation energy of the materials. The significant contribution of this work is believed to propose an innovation of smart magnetic grease for valuable future of sustainable applications.

KEY WORDS

Magnetic Grease, Viscosity, Energy dissipation, Cobalt Ferrite

1. INTRODUCTION

Magnetorheological (MR) grease, which is composite grease embedded with magnetic particles, particularly carbonyl iron particles (CIP) has piqued the interest of many scholars due to its promising and tremendous properties over the last decades[1–4]. The semi-solid state and thixotropic properties exhibited by the grease has significantly encountered the sedimentation and leakage issues that occurred in fluid-type MR materials[5,6]. When an external magnetic field is induced to this magnetic composite, the magnetic dipoles of magnetic particles would tend to align along with the direction of magnetic fields resulting in the formation of particles' chain-liked structure in the grease. The change in the structure has improved the viscous behavior of the MR grease including shear stress and yield stress, which then denoted to the stability and strength of the material[7]. Therefore, MR grease has wide potential to be used in advance devices, particularly semi-active brakes[8], clutches[9] and dampers[10]. Commonly, high-speed devices require MR grease with high viscosity during the operation (on-state condition) to generate high yield stress and, maintain its chain-like structure under high stress with presence of magnetic fields. However, in the absence of applied magnetic field, which corresponds to the off-state condition of MR grease, a high viscosity exhibited by the fibrous structure of grease has drawbacks, especially during the initial state of operation which indirectly causes pumpability suffers and necessitates more power consumption for the devices to begin operating[11,12]. Hence, more carbon is released to the environment as more energy is needed during the operation. Therefore, a solution is needed to develop a novel smart magnetic grease that improves fluidity while minimizing energy dissipation during initial operation.

As for now, a few types of solid additives have been successfully utilized and improved the viscous behavior of MR grease including chromium oxide (CrO_2)[13], molybdenum disulphide (MoS_2)[14], and graphite (Gr)[15]. The studies of additives thus far have been discovered to influence the rheological performance of MR grease however, the knowledge about the role of the additive sizes in altering the fluidity of MR grease that predominantly contributes to the reduction of dissipation energy is considerably limited. Therefore, this research aims to investigate the significant changes in the fluidity of MR grease as well as the dissipated energy by utilizing two different sizes of additive. For this purpose, $CoFe_2O_4$ has been chosen due to promising advantages such as strong anisotropy, good chemical stability and high mechanical strength [16] that is expected to provide most effective approach towards the desired properties of MR grease.

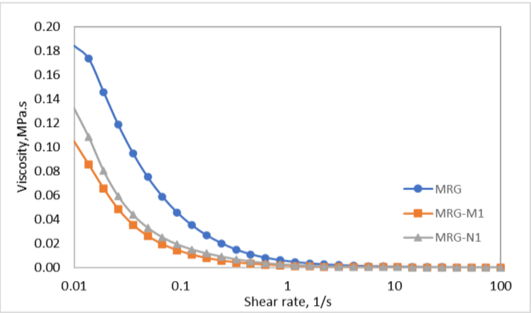
2. METHODOLOGY

Prior to the fabrication of MR grease, 30 wt.% of grease will be stirred for 5 minutes to loosen the internal structure of the based grease using a mechanical stirrer at 300rpm. Afterward, 70 wt.% of carbonyl iron particles, CIP will be added into the stirred grease and the mixture is continuously stirred for 2 hours to ensure the homogenous distribution of CIP in the grease. The mixture is denoted as MRG. Meanwhile, for the MRG with 1 wt.% of $CoFe_2O_4$ as an additive, particularly for each micro- and nano-sized particle, 29 wt.% of grease are used while the amount of CIP is maintained. The mixture is then stirred continuously at 300 rpm. The samples are denoted as MRG-M1 and MRG-N1 which indicated the MR grease with 1 wt.% of micro-sized $CoFe_2O_4$ and MR grease with 1 wt.% of nano-sized $CoFe_2O_4$, respectively.

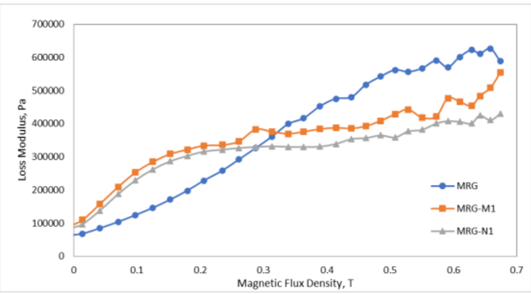
Then, the samples have been characterized in terms of rheological by using Rheometer, model MCR 302 from Anton Parr, Grazz, Austria. The MR grease samples tested under rotational mode, and induced with various currents values which respective to magnetic fields applied. A parallel plate (PP) of the rheometer's sample stage that has a diameter of 20 mm is used and the gap between the parallel plates is kept constant at 1 mm. During the test, the shear rate applied within the range of 0.01 to 100 s^{-1} under various currents, and the test is carried out at room temperature. The dissipation energy of the materials is also investigated in terms of modulus.

3. RESULTS AND DISCUSSION

The findings of this research regarding the fluidity and energy dissipation of MR grease are presented in Figure 1.



(a)



(b)

Figure 1: Graph of MR grease samples (a) viscosity versus shear rate and (b) loss modulus with increment of magnetic flux density applied towards the samples.

It can be seen clearly in Figure 1(a) that the presence of the micro and nano $CoFe_2O_4$ additive has successfully decreased the viscosity of MR grease by 44.4% and 27.78%, respectively as compared with MRG. These results show that the additives contribute to the reduction of initial off-state viscosity. Meanwhile, as shown in Figure 1(b), as the magnetic flux density increases, the loss modulus of all the MR grease samples also increases. The decrement of loss modulus of MR grease samples indicates less energy is dissipated during the shearing process. As compared with pure MRG, the loss modulus of the MRG-M1 and MRG-N1 are lower after 0.3T of magnetic field applied which correspond that this additive significantly reduces the dissipation of energy of the materials. However, nano-sized of additive has the most significant effect on the loss modulus at higher value of magnetic field as compared with other samples. This contribution led to a better understanding on the role of different sizes of additives regarding on the MR grease behavior. Furthermore, these findings serve as a reference in the future when applied in many devices to prolong the life span and sustain the performances of the devices, especially for MR damper and MR brake.

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