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Research paper

Dilution Dependent of Different Types of Redispersing Oils on Magnetorheological Greases

Norzilawati Mohamad[1], Abdul Yasser Abd Fatah[2]*, Saiful Amri Mazlan[1], Nur Azmah Nordin[3], Mohd Nabil Muhtazaruddin[2], Mohd Fitri Mohd Yakub[1]

[1]Advanced Vehicle System (AVS) Research Laboratory, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra (Jalan Semarak), 54000 Kuala Lumpur, Malaysia
[2]Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra (Jalan Semarak), 54000 Kuala Lumpur, Malaysia
[3]Nano-characterization, Structural Control and Processing Technology (Nano3) iKohza, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra (Jalan Semarak), 54000 Kuala Lumpur, Malaysia
[4]Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra (Jalan Semarak), 54000 Kuala Lumpur, Malaysia
**Corresponding author E-mail: yasser.kl@utm.my*

Abstract

This paper presents the influence of percentages of different types of oils as additives used in controlling the initial apparent viscosity of the magnetorheological (MR) grease without the occurrence of sedimentation. A series of MR greases without and with different types of oils (castor oil and silicone oil) as additives were prepared in the same weight fractions of carbonyl iron (CI) particles for comparison purpose. The rheological test was performed using shear rheometer using rotational mode under the variation of magnetic fields at constant room temperature. It was observed that initial viscosity of MR grease is reduced with increasing weight percentages of castor oil. In contrast, initial viscosity of the MR grease incorporated of silicone oil increased as the weight percentages are increased. The same trend is examined for both types of oils in off- and on-state condition. This indicates that the structuration of the magnetizable particles in the grease medium is affected by addition of different types of oils, indirectly improved the MR greases properties which applicable for industrial applications.

Keywords: *magnetorheological grease; castor oil; silicone oil; viscosity; rheological properties*

1. Introduction

Grease filled with soft magnetizable particles, also known as magnetorheological (MR) grease, is classified as a smart material due to its properties; responsive to the presence of magnetic fields, and reversible to the initial state rapidly at the absence of magnetic fields [1]. The first study related to the MR grease was reported by Rankin [2] in 1999 by replacing the carrier oil used in conventional MR fluid to overcome the settling and leaking problem. As an intermediate state between fluid-like MR fluid and solid-like MR elastomer, MR grease shows more flexible controllability of the MR properties such as apparent viscosity, shear stress and yield stress. [3], [4]. Under the absence of magnetic field, the magnetizable particles in MR grease are restricted from freely moving due to the high viscosity of the medium. However, as the magnetic field is subjected to the MR grease, the magnetizable particles force is over the viscosity of medium and tend to form chain structures along the of magnetic field driven. It is noted that once the magnetic field is removed, these properties of MR grease will be significantly back to initial state. Correspondingly, these MR grease properties can be appropriately employed to the industrial applications specifically seismic controllable dampers or other damping applications [5], [6].

Recently, MR grease has been recognized by the researchers due to its unique properties. However, these studies were limited to the preparation and rheological characterization of the MR grease. Park et al. [7] had investigated the stability of the MR grease under variation of magnetic fields. The maximum dynamic yield stress of 10 kPa is achieved at 342 kA/m without sedimentation. The study was continued by Mohamad et al. [8] by investigating the rheological properties of MR grease with optimal weight percentages of magnetizable particles under the influence of magnetic field. The results showed that MR grease with 70 wt% magnetizable particles has the highest yield stress and MR effect with 52.7 kPa and 952.38%, respectively. On top of that, a comprehensive study on comparing the different shapes of magnetizable particles used in MR grease was investigated [9]. It showed that the low weight percentages (30 wt%) of plate-like magnetizable particles-based MR grease was required to achieve highest performance compared to the spherical shape. In addition, another researcher [10], [11] reported that the stability of MR grease is improved without any reduction in rheological performances. This can be observed by adding nanoparticles as an additive. The above-mentioned studies have pointed out the development of MR grease with high performances and without considering the initial viscosity of the MR grease which is crucial in the industrial applications. An effort has been taken by [12] by introducing the kerosene oil as an additive in MR grease. The results showed that the initial viscosity as well as yield stress of MR grease with 5 wt% of kerosene oil is significantly reduced. However, the knowledge on several issues such as optimum weight percentages of additives used and understanding on structuration of MR greases with oils as additives towards rheological properties at high shear rate, is still incomplete. Therefore, the aim of this study is to investigate the influence of percentages of different types of oils as an additive towards initial apparent viscosity of MR grease without the occurrence of sedimentation. Additionally, the rheological properties and structuration of the MR grease are also taken into consideration. For this purpose, several samples of MR grease were prepared using two types of oils; castor oil and silicone oil. Different weight percentages of oils were prepared via a mechanical stirrer. The rheological properties such as apparent viscosity was characterized using commercial rheometer. The performance of MR grease with different oils were compared and discussed with MR greases without oil accordingly.

2. Methodology

2.1. Samples preparation

Spherical carbonyl iron (CI) particles with OM grade series purchased from BASF Germany were used as received without any further chemical treatment. The average diameter and density of the CI particles are 5 µm and 7.874 g/cm^3, respectively. Commercial grease (NPC Highrex HD-3 Grease, Nippon Koyu Ltd, Japan) was selected as suspending medium. The density and viscosity of grease provided by manufacturer were 0.92 g/cm^3 and 190 cSt. The plant-based castor oil and petroleum-based silicone oil with different viscosities were chosen as additives. A series of MR grease samples with different percentages of oils were prepared. In this study, a constant total weight percentages of CI particles; 70 wt% was used to prepare the samples. Meanwhile, the additives were varied from 0 to 15 wt%. At first, the CI particles were dispersed in these oils. Subsequently, the suspension was mixed with grease using mechanical stirrer for two hours at room temperature until homogeneity was achieved. The same process was repeated for the MR grease without oil for comparison. The details of composition are listed as follows:

Table 1: Compositions of different MR greases

Types	% by weight			
	CI particles	Grease	Castor oil	Silicone oil
MRG1	70	30		
MRG2	70	25	5	
MRG3	70	20	10	
MRG4	70	15	15	
MRG5	70	25		5
MRG6	70	20		10
MRG7	70	15		15

2.2. Samples characterization

The viscoelastic properties in terms of apparent viscosity was characterized using commercial rheometer (MCR 302, Anton Paar) equipped with electromagnetic apparatus (MRD 70/1T). Samples with 1.0 mL was used to fill up the base plate and rotational mode was performed using a measuring parallel plate with diameter of 20 mm and constant gap distance of 1.0 mm. The apparent viscosity of MR grease samples was measured by varied the magnetic field applied from 0 to 0.9 T. The magnetic flux density was controlled by adjusting the coil applied current from 0 to 5 A. It is remarked that all samples were characterized at the room temperature condition. The apparent viscosity of the samples was calculated using the equation (3). The equations (1) and (2) represent the shear rate, $\dot{\gamma}$ and shear stress, τ of the samples measured according to the parallel plate measuring system.

$$\dot{\gamma} = \omega . R/H \quad (1)$$

$$\tau = 2. M/\pi .\ R^3 \quad (2)$$

$$\eta = \tau \,/\, \dot{\gamma} \quad (3)$$

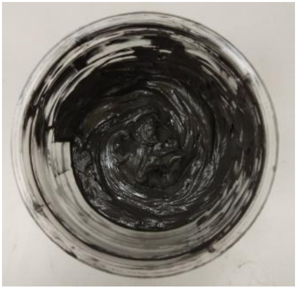
3. Results and discussion

Fig. 1 (b-g) depicts the MR grease samples with incorporation of two types of additives; castor oil and silicone oil with different weight percentages ranging 0 to 15 wt%. The MR grease without the addition of additives (Fig. 1a) is used as sample reference. From observation, MR grease incorporated of castor oil is more diluted compared to the MR grease with silicone oil for oil percentages ranging between 5 and 10 wt%. In contrast, by addition of 15 wt% of oil, another layer was seen directly on top of both types of MR grease. In short, the oil which was used as redispersing agent in the MR grease is not homogeneously dispersed in the grease medium and slurry formation is observed. This phenomenon happened due to the oil separation process occurred in the grease medium which directly increased the penetration value [13]. The excessive of oil additions will lead to the severe oil separation and directly diminish the grease properties. On top of that, the sedimentation will take place over the time for MR grease with oil percentages of more than 15 wt%. In addition, there is no sedimentation phenomenon for MR grease with oil content lower than 10 wt%. Besides that, it is expected that the dispersion of CI particles suspended in the grease are improved by the addition of oil.

Fig. 2 and 3 show the apparent viscosity patterns of MR grease incorporated of castor and silicone oils under the influence of shear rate with the magnetic field ramped up. It is found that the apparent viscosity of both types of MR grease increased with the increment of magnetic field and decreased along with increasing of shear rates. The same pattern was observed for both types of MR grease with the increment of oil percentages. This phenomenon has confirmed that MR grease possessed the shear-thinning behavior [14]. Besides that, the both types of MR grease show an unstable graph pattern at 0A is due to the freely movement of the CI particles in the medium. By comparing to the reference MR greases sample, the movement of CI particles is expected to be less restricted to the medium owing to the lubrication that is provided by the oil. However, it is observed that at 3 and 4A of current applied, the apparent viscosity of both types of MR grease is harder to be measured by rheometer. This is due to the thick chain structure formations which lead to the samples harden as subjected to the magnetic field. In brief, the strong attraction caused by the dipole-dipole interaction between interparticle of CI particles will create a stronger solid-like structures of MR grease which will indirectly increase the apparent viscosity.

(a) MRG1

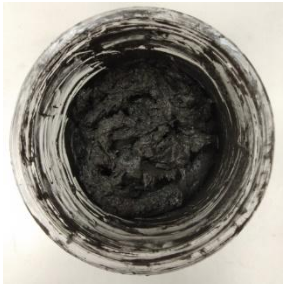
(b) MRG2



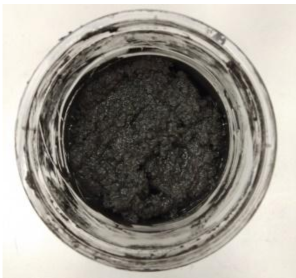
(c) MRG3

(d) MRG4

(e) MRG5



(f) MRG6



(g) MRG7

Fig. 1: Images of MR greases incorporated of different weight percentages and types of oil; castor oil and silicone oil

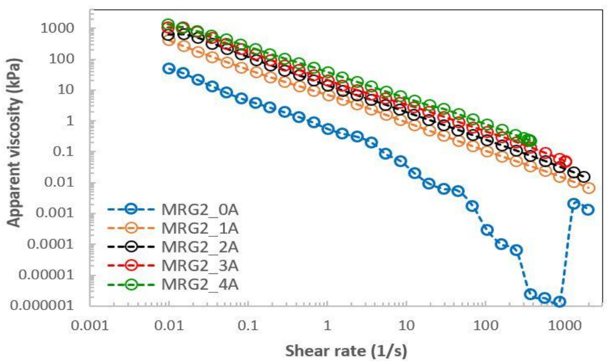


Fig. 2: Apparent viscosity of MR greases with castor oil (5 wt%) as function of shear rates under different currents

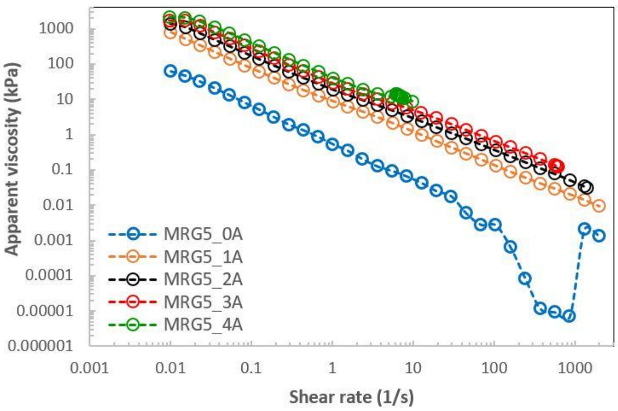


Fig. 3: Apparent viscosity of MR greases with silicone oil (5 wt%) as function of shear rates under different currents

Furthermore, the effect of different types of oils towards the apparent viscosity as function of shear rates can be seen in Fig. 4 and 5. Fig. 4 shows the MR grease incorporated of castor oil has lower initial apparent viscosity for all percentages compared to the reference MR greases in the absence of magnetic field. A similar pattern was observed for MR greases incorporated of silicone oil for 5 and 10 wt%. However, the MR grease with 15 wt% of silicone oil has higher initial apparent viscosity than reference MR grease at 0A. This proved that silicone oil has higher viscosity compared to the castor oil, although both oils have similar density. The reduction of apparent viscosity is may due to the entanglement of the fibrous structures in the grease became loosened along the shearing direction [15]–[18]. This medium condition allows the CI particles to freely move in between of greases structuration with the presence of oils as lubricant. In contrast with the presence of magnetic field at 2A (Fig. 5), only the MR grease incorporated of 5 wt% castor oil has the lowest initial apparent viscosity compared to the reference MR grease. The initial apparent viscosity of the MR grease increased parallel with increasing of oil percentages. It is remarked that MR grease with silicone oil has higher initial apparent viscosity than MR grease with castor oil in off-and on-state condition. In general, the apparent viscosity is increased with the increment of magnetic field and inversely proportional to the shear rates. This happened due to the stronger chain structures of CI particles were easily formed as the gap between interparticle is reduced that owing to the loosened grease structuration. In addition, the friction between closely packed CI particles is also increased by increasing of magnetic field [19]. This phenomenon will lead to the higher apparent viscosity of MR grease. As a conclusion, the changes of grease structuration in terms of entanglement of fibrous structures are pronounced in the rheological properties of the MR greases.

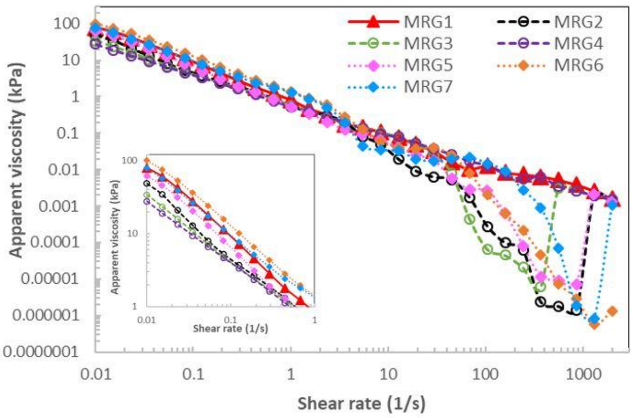


Fig. 4: Apparent viscosity of various percentages of oils based-MR grease as function of shear rates at 0A

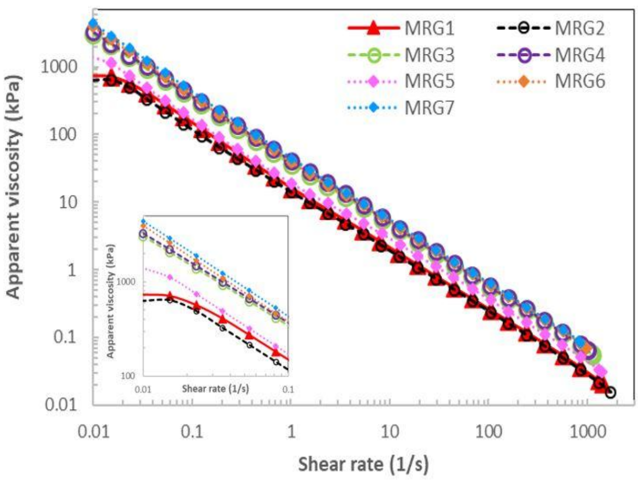


Fig. 5: Apparent viscosity of various percentages of oil-based MR grease as function of shear rates at 2A

4. Conclusion

In this study, the influence of percentages of different types of oil used in MR grease has been investigated. Several types of MR greases incorporated of castor and silicone oils were prepared and compared with the reference MR grease. The experimental results have shown that the MR grease with incorporation of silicone oil has higher initial apparent viscosity than MR grease with castor oil for both; off- and on-state condition. It has also been observed that MR grease with incorporated both oils; castor and silicone oils, has reduced the off-state apparent viscosity, however significantly increased the on-state apparent viscosity. In addition, it is found that by addition of oil less than 10 wt% able to form a stable MR grease without occurrence of sedimentation. This is owing to the entanglement of the fibrous structuration which affected by addition of oil and shearing direction that lead to the oil separation. Finally, it can be concluded that the degradation of grease structuration is significantly altering the rheological properties of MR grease with excessive addition of oil.

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