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Synthesis and characterization of magneto-rheological (MR) fluids for MR brake application

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ABSTRACT

Magneto rheological (MR) fluid technology has been proven for many industrial applications like shock absorbers, actuators, etc. MR fluid is a smart material whose rheological characteristics change rapidly and can be controlled easily in presence of an applied magnetic field. MR brake is a device to transmit torque by the shear stress of MR fluid. However, MR fluids exhibit yield stress of 50–90 kPa. In this research, an effort has been made to synthesize MR fluid sample/s which will typically meet the requirements of MR brake applications. In this study, various electrolytic and carbonyl iron powder based MR fluids have been synthesized by mixing grease as a stabilizer, oleic acid as an antifriction additive and gaur gum powder as a surface coating to reduce agglomeration of the MR fluid. MR fluid samples based on sunflower oil, which is bio-degradable, environmentally friendly and abundantly available have also been synthesized. These MR fluid samples are characterized for determination of magnetic, morphological and rheological properties. This study helps identify most suitable localized MR fluid meant for MR brake application.

1. Introduction

Magneto-rheological fluid (MRF) is a type of smart material whose rheological properties (e.g. Viscosity) can be rapidly varied by applying a magnetic field. It is a free-flowing liquid state in the absence of a magnetic field while its viscosity increases on application of magnetic field [1].

For an MRF, the yield stress can be controlled which can be increased or decreased with the strength of the magnetic field as shown in Equation (1).

$$\tau = \tau_{y(H)} + \mu_p \dot{\gamma} \quad (1)$$

where, τ_y is the yield stress due to the applied magnetic field H, μ_p is the constant plastic viscosity and $\dot{\gamma}$ is the shear-strain rate. The typical properties of MR fluid are as shown in Table 1.

Many MR fluid applications operate under different modes like valve mode, shear mode and squeeze mode. The MR brake (MRB) is a device to transmit torque by the shear stress of MRF. Hence, MRB operates in a direct-shear mode, shearing the MR fluid filling gap between the two surfaces.

In the shear mode, the MR fluid is located between surfaces moving (sliding or rotating) in relation to each other with the magnetic field owing perpendicularly to the direction of motion of these shear surfaces as shown in Fig. 1 The characteristic of shear stress versus shear rate can be controlled by the magnetic field [5].

As shown in the Fig. 2, MRB consists of a rotating disk immersed in MRF, enclosed in an electromagnet. The yield stress of a fluid varies as a function of magnetic field applied by an electromagnet.

In MRB, the gap between stator and rotor is filled with low (off-state) viscosity MRF. On the application of magnetic field, MRF changes its state from liquid to semi-solid. Each magnetic particle forms north and south poles and hence, the opposite poles attract each other which results in strong bonding between them. This aligns them in a strong chain. Due to such chaining action, yield strength of fluid increases, which opposes the friction between stator and rotor and hence fulfills the braking function [2]. The strength of chain formed by magnetic particles due to bonding is a function of relative speed between stator and rotor, applied magnetic field and volume percentage of magnetic particle.

MRBs have been explored recently as an alternative to conventional hydraulic brakes for road vehicle applications. Park et al.

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Table 1
Properties of typical MR fluids [2–4].

Property	Typical value
Initial viscosity	0.2–0.5 [Pa s] (at 25 °C)
Density	3–4 [g/cm^3]
Magnetic field strength	150–250 [kA/m]
Yield point	50–100 [kPa]
Reaction time	15–25 ms
Work temperature	−50 to 150 °C
Typical supply voltage and current intensity	2–25 V, 1–2 A

[7] and Karakoket al. [8] have assessed MRBs for a typical medium sized car; however the braking torque generated by this brake application has been found to be inadequate. Sukhwani and Hirani [9] experimentally evaluated MRB performance parameters for high speed MR brake application and advocated MR gap of 1 mm. Attempts have also been built in the recent past to optimize MRB design torque and weight meant for automotive application. Patil and Sawant [10] have made an attempt to evaluate MRB system intended for vehicular application from a reliability perspective.

To reduce the sedimentation of MR fluid particles Fang et al. [11] introduced single-walled carbon nanotube (SWNT) in the CI based MR fluid. Shetty and Prasad [12] synthesized MR fluid with a non-edible vegetable oil such as Honge oil as a carrier liquid and they reported that the yield stress produced is only 25 kPa. Sarkar and Hirani [1] discussed the synthesis of MR fluid and its application in braking point of view. Choi et al. [13] encapsulated CI particles with poly methyl methacrylate as core–shell structured particles to improve dispersability of the MR fluid. Jiang et al. [14] added wire-like iron nanostructures into the conventional CI based MR fluid and thus, synthesized a type of dimorphic MR fluid. Present work makes an endeavor to explore best suited MRF synthesized typically for MRB. Earlier, some research studies based on MR fluid synthesis and characterization for general purpose have been attained; however, past literature doesn't provide evidence of MRFs synthesized for vehicular MRB [1,2,4,12–14].

In the present work, research findings of synthesis and characterization of MRF samples aimed at MRB, based on carbonyl iron (CI) and electrolytic iron (EI) powder with oleic acid and grease as additives have been reported.

2. Synthesis of MR fluid

Six MRF samples were synthesized based on the following requirements from brake application point of view.

2.1. Requirements

2.1.1. Low off-state viscosity

The field-independent viscosity (η) is the most critical off-state property of MRFs. The MR-fluid viscosity is most influenced by two

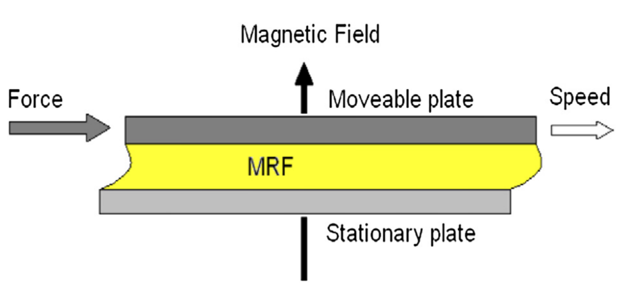

Fig. 1. Shear Mode [6].

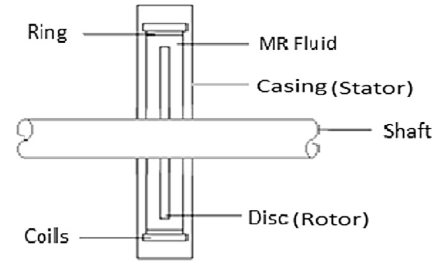

Fig. 2. Schematic of MRB.

factors: the intrinsic viscosity of the carrier fluid and the particle volume fraction [2]. Higher the particle volume fraction, higher is the MR-fluid viscosity. In case of high OFF state viscosity, the vehicle will experience more drag as compared to the low OFF state viscosity even though brake is not applied.

2.1.2. High yield stress

The material of the particles has an impact on the maximum yield stress since its value increases with the square of the saturation magnetization of the particles. Another factor influencing the maximum yield stress is the particle volume fraction [2,6]. An increase in the particle volume fraction leads to an increase in the output torque of the MRB. A number of researchers have shown that the maximum yield stress increases non-linearly with growing particle volume fraction and its value is nearly 50–90 kPa [13,14]. For brake application, high yield stress results into high braking torque.

2.1.3. Less In-Use-Thickening (IUT)

If an ordinary MRF is subjected to high stress and high shear rate over a long period of time, the fluid will thicken. This phenomenon is called In-Use-Thickening (IUT) [2,6]. Due to this increased OFF state viscosity owing to IUT, drag increases and results in the power loss when brake is not applied.

2.1.4. Wide temperature range

MRF meant for MRB should withstand to broad temperature range as the brake may be operated at subzero temperature as well as prolonged time which shall result in temperature rise. Commercial MRF is reported to be able to withstand from 80 °C [3].

2.2. Selection of MRF components

MRF typically comprises a liquid carrier, magnetic particles and additives. The subsection below highlights the selection of these components.

2.2.1. Liquid carrier

Carrier liquid is the major constituent of MRFs (50–80 percent by volume) [12]. The commonly used carrier liquids are mineral oil, synthetic oil and silicone oil.

The mineral oils are neither biodegradable nor environmentally friendly, whilst synthetic oils cost more [2]. Synthetic oil possesses important properties like higher flash point, does not thicken at higher temperatures, lower friction, high shear strength and high viscosity index. Silicone oil has good temperature-stability and good heat-transfer characteristics, oxidation resistance [12,13], very low vapor pressure, and high flash points. There is little change in physical properties over a wide temperature span and a relative flat viscosity temperature slope and serviceability from −40 to 204 °C [2,4]. Thus, for the proposed study, synthetic oil and silicone oil were selected.