Synthesis and Magneto Mechanical Properties of MR Grease

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Abstract—**The development of Magnetorheological grease (MRG) became necessary in place of commercially available Magenetorheological fluids(MRF) to overcome the settling properties of MRF. Various formulations are synthesized and characterized for magneto mechanical properties. The development of the product is aimed for its application in the development of shock absorber of an UAV landing gear. This paper presents the methodology for the development of MRG from the locally available materials and to investigate rheological properties. The dependence of yield stress on the particle volume and magnetic properties are investigated**.

Keywords—Magnetorheological, smart fluids, Yield stress, viscoelasticity, storage modulus, loss moduls

I. Introduction

Magneto-rheological fluids (MRFs) are finding many engineering applications such as active control damping, polishing and grinding processes, flexible fixtures and medical devices. In order to overcome disadvantages associated with MRFs i.e settling of ferro particles, shear thickening in prolonged usage, there is a need to substitute the product with better performance characteristics. One of the solutions is to develop MRF with highly viscous carrier fluid, so that the ferro particles will not settle during off-state conditions. The carrier fluid chosen in the present study is general purpose aircraft synthetic grease. Due to this the fluid is named as "Magneto-rheological Grease (MRG)" At present there are no companies marketing the MRF without any settling issues, hence there is a need to develop such fluid to meet the requirements.

The studies made on MRG are very few in comparison with MRF. Various compositions of MRG are brought out by Andrew Kintz et al [1]. A study conducted by Sukhwani [2], compared the performances of MRF and MRG for brake application. In conclusion to the study MRF is recommended rather than MRG due to the requirement of MR effect rather than sedimentation stability. Gordaninejad et al [3] reported 75% increase in torque capacity as compared to commercial MR fluid. It is also brought out that the off-state condition the torque capacity of MRG is constant regardless of operating speed, whereas the torque capacity of MRF exhibited much dependence on the operating speed. Huseyin Sahin [4] studied the temperature effects of MRF and MRG from 10°C to 70°C and reported that the temperature will have significant effect on field-induced yield stress.

II. Method and Materials for MRG

A. Methodology for MRG formulation

The stability and redispersibility of MR fluids have been one of the most important issues of these materials. The stable MR fluids exhibit no particle settling. For dilute systems the dependence of the sedimentation velocity of a spherical particle can be obtained from Stoke's law as follows [5]:

$$V = \frac{2r^2(\rho_{sphere} - \rho_{fluid})g}{9\eta} \quad (1)$$

V is the particle velocity, r is the particle radius, ρ_{sphere} , mass density of the sphere, ρ_{fluid} is mass density of fluid, g is gravitational acceleration and η the viscosity of the carrier liquid. This shows that less viscous liquids will aggravate the settling of particles in MR fluids. Rankin and co-workers formulated a suspension with viscoplastic continuous phase (eg. Grease) to prevent sedimentation [6]. Hence a grease based formulation was chosen to develop the MRG.

B. Maaterials for MRG

The present study on Magnetorheological grease composition comprises magnetic responsive particles, a carrier fluid and at least one thickening agent. Numerous materials are available in the market for the above three categories. In order to reduce development time, locally available materials are chosen. Studies on rheological properties and dispersion stability of MR suspensions are studied by Byung Doo Chin et.al [7].

The magnetic responsive particles with high iron content, generally greater than or at least about 96.35% iron. The preferred carbon content should be less than 0.01%. Oxygen and Nitrogen are restricted to 1%. The selected magnetic responsive material is Carbonyl Iron ($Fe(CO)_5$) with particle size of 3-50 micron in size. Though it is preferred to 20% to 40% by volume, the present study considered by weight fraction for ease of weighing.

The carrier fluids form the continuous phase of the MRG composition. The preferred carrier fluid is either organic fluid or an oil-based fluid. There are other materials such as natural fatty oils, mineral oils, esters, synthetic cycloparaffins, synthetic paraffins, unsaturated hydrocarbon oils, glycol easters, eathers, silicate esters, silicone oils, silicone copolymers, synthetic hydrocarbons etc. However the preferred carrier fluid should be a nonvolatile and does not include any substantial amount of water. This can be varied from 5% to 65%, preferably about 15 to 45 percent by volume of the total MRG composition. In the present study the carrier fluid selected was Silicone Oil of 300 cSt. Silicon oil act as a good releasing agent, can be used between -40^{o}C to 280^{o}C with excellent water repellency and low toxicity.

The thickening agent generally will be used in an amount effective to produce a composition with a grease-like consistency. The thickening agent will be generally used between 30% to about 90% by volume of the total volume of MRG. Generally the grease will have NLGI consistency number between 00 and 4 for the present study, Nyco Grease GN 22 is chosen and it is a NLGI 2 (JSD: XG-293 and NATO:G-395) which is a military qualified as per MIL-PRF-81322f Grade2. This is clay-thickened grease, based on synthetic hydrocarbon oil with a viscosity of 6 cSt at 100^{o}C. It is inhibited against corrosion, oxidation and contains anti-wear/extreme pressure additives. It can be used from -65^{o}C to +177^{o}C. All materials used in the present study are shown in Fig. 1.

. Fig. 1: Carbonyl Iron, Silicone Oil and Grease

All the above materials are considered based on weight proportions fusing an electronic weighing machine for the present development. Various iterations are formulated with different weight percentages. A total number of eight samples are synthesized for the purpose of characterization.

III. PREPARATION OF MAGNETORHEOLOGICAL GREASE

Various formulations and compositions are cited in the preparation of MRG by Andrew Kintz et al [6]. Seven different compositions and formulations are given in both volume and weight fractions. In a similar manner the present formulations are prepared using the above mentioned materials based on weight percentage. The details of samples made are shown in Table 1.

TABLE 1: MAGNETORHEOLOGICAL GREASE COMPOSITIONS

Material	ρ g/ml	% by weight (samples)							
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Iron powder	7.87	85	80	70	60	60	65	65	50
Grease	0.88	10	15	20	30	35	35	20	40
Silicone Oil	0.98	05	05	10	10	05	0	15	10

Before the preparation of the above samples the materials are to be accurately weighed individually in percentage weight as per the total weight of the MRG quantity required. The measurements of the materials are weighed on an electronic balance individually before mixing them.

During preparation of samples, the carbonyl iron powder is added slowly into the beaker containing grease. The mixing is done manually with a metallic spatula, in between adding few drops of silicone oil to ensure proper mixing. For the samples with small quantities of iron powder the mixture preparation was easy with manual mode. Samples with >80% of iron powder, there was difficulty in mixing manually with spatula. Hence the mixing is done with mortar and pestle. The preparation process of MRG is shown in the Fig. 2. All samples prepared are preserved safely in a air tight plastic containers with properly labeled over the container for further usage.

Fig. 2: Mixing process for preparing MRG

IV. RHEOLOGICAL STUDIES

The rheometric characterization of synthesized samples are carried out using modular compact rheometer (Physica MCR-301). The Physica MCR 301 rheometer performs a wide range of steady and dynamic tests in both CSS and CSR mode from generating simple flow curves to the dynamic analysis of complex fluids, melts, and co-polymers. The instrument is provided with environmental control accessories for testing from lower to higher temperature. This instrument supports characterizing the Magnetorheological fluids / greases with a magnetic field of up to 1.2T. Both On-state and Off-state characterizations are possible with the instrument with an additional attachment to the instrument. The quantity of the sample requirement being very small, hence no large quantities of samples preparations are required.

The instrument along with loading of samples and running the experiment are shown in the Fig. 3.

Fig. 3: Experimental setup for MRG characterization

During Off-state (without magnetic field) characterization the data such as Viscosity (η), Shear Stress (τ), Shear Rate ($\dot{\gamma}$), Storage modulus(G'), Loss modulus (G''), damping factor (γ) and complex viscosity (η^*) are investigated.

During On-state (with magnetic field) characterization, the magnetic flux (B) , shear stress (τ), viscosity(η) , current (I), Storage modulus(G'), Loss modulus (G''), damping factor (γ) and complex viscosity (η^*) are investigated. The experimental data were analyzed for the best performance sample. The analysis of data is given subsequently.

A. Viscous properties(off-state)

Initially all samples are evaluated for off-state condition.

(i) Viscosity vs Shear rate

The behavior of MRG *Viscosity vs Shear rate* is plotted to observe for pseudoplastic behavior of the samples. The graph is shown in Fig. 4.

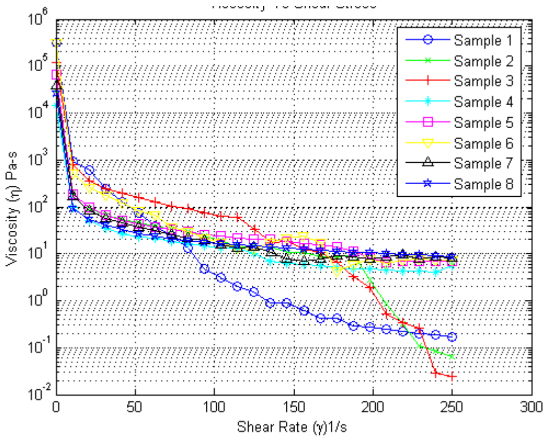

Fig. 4. Viscosity vs Shear rate (off state condition)

It is evident that the samples 1,2 and 3 are lowering their viscosity and the shear rate increases. This is due to shear thinning of the MRG or due to the presence of high iron content, proper shearing may not be occurring. The rotating disc may be slipping during the test. It is also observed that the compositions are very thick and are not moving that easily during sample preparation. The other samples are behaving better, with not much reduction in the viscous properties. On observation if is found that the sample no.4 is behaving more linear. It is concluded that this sample is considered for further studies.

(ii) Shear stress vs Shear rate

All samples are evaluated for shear stress vs shear rate during off-state condition. The behavior of MRG with processed data using quadratic curve fitting is shown in Fig. 5.

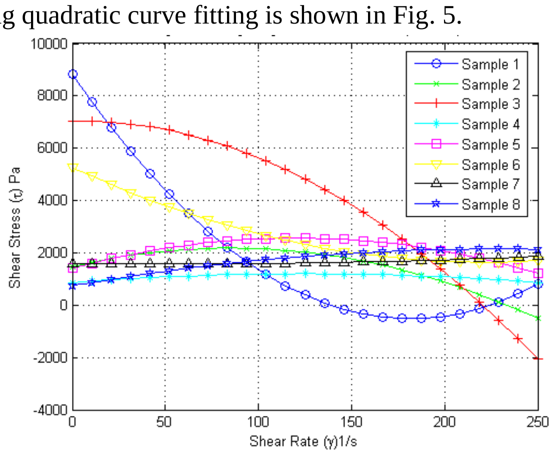

Fig. 5. Shear stress vs Shear Rate (off state condition)

From the graph it is once again clear that the samples 1,2,3 and 6 are not having any linear behavior, Where as other samples thixotropic behavior shows not much change. With increasing shear rate the change in shear stress is marginal.

B. Viscous properties(On-state)

All samples are investigated for on-state condition with the application of magnetic field up to 1.2T due to limitation in the instrument.

(i) Viscosity vs Magnetic flux

The viscous behavior of MRG under the influence of magnetic field is an important parameter. This will reveal the behavior of MR fluid and its viscous effects, which are essential for application in various devices. The behavior of Viscosity vs Magnetic flux is shown in Fig. 6.

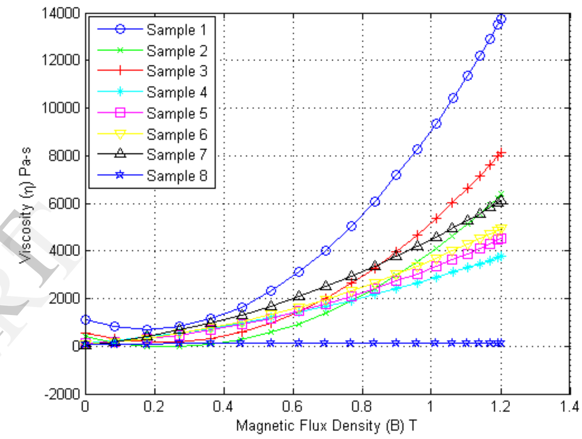

Fig. 6. Viscosity Vs Magnetic Flux (On-state condition)

The graph indicates that sample 1&2 shows high variation in the viscosity change even up to14000 Pa-s, whereas sample 4 show only 4000 Pa-s. Sample 8 did not respond much under the magnetic field. This may be due to lower content of iron powder.

(ii) Shear stress vs Magnetic flux

To investigate the shear mode behavior under the influence of magnetic field, the graph is shown in Fig. 7.

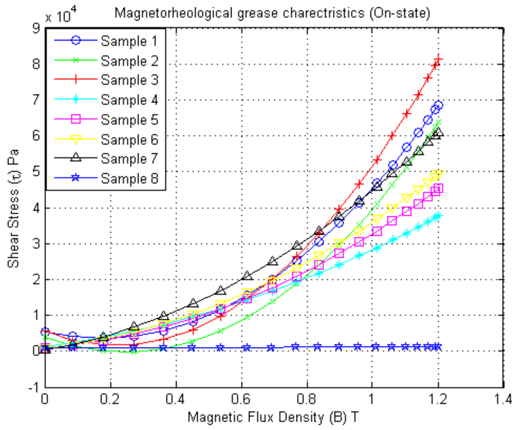

Fig. 7. Shear stress vs Magnetic flux (On-state condition)

The plots of magnetic flux vs shear stress shows that Sample 2 is showing highest shear stress. Whereas sample 8 is not responding. Sample 4 goes up **to 40000 Pa**. This is considered high from an application point of view.

C. Dynamic strain sweep

Dynamic strain sweep was performed on all samples during the Off-state as well as On-state. This is to investigate the elastic moduli (G') at low strain amplitudes. The experiment is conducted in oscillatory mode. The results are shown below in Fig. 8 and Fig 9.

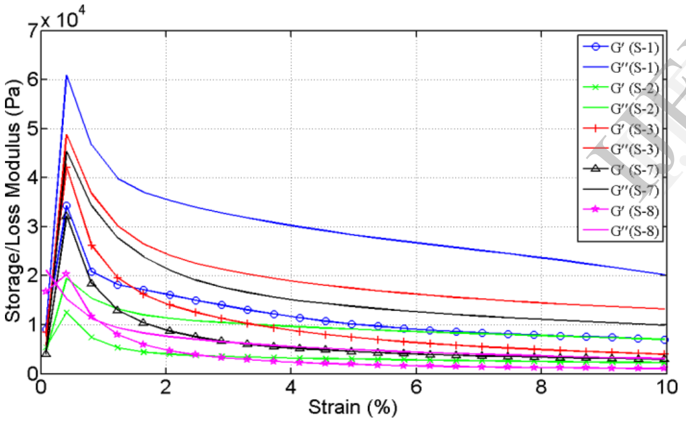

Fig. 8. Storage/Loss modulus vs Strain (Off-state)

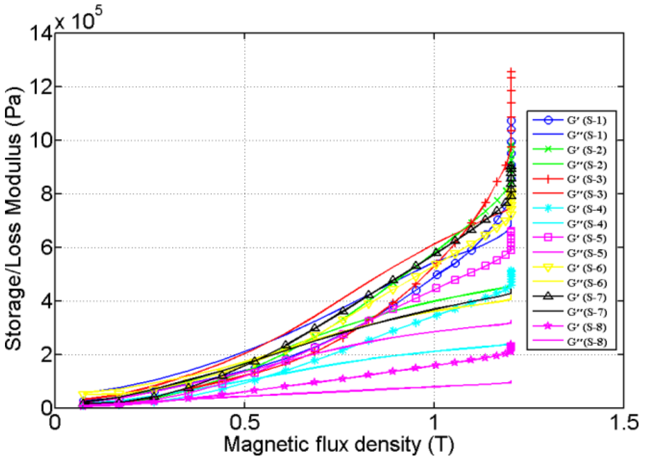

Fig. 9. Storage/Loss modulus vs Strain (On-state)

On observation of the above graphs, it is evident that during off-state condition, all materials are exhibiting G''>G'. This indicates the liquid state behavior. During on- state condition all materials are exhibiting solid like behavior as G''<G'. Under the influence of magnetic field, the materials are changing their viscous properties.

V. CONCLUSION

Mangnetorheological grease with different composition were prepared using, carbonyl iron, silicone oil and grease. Iron content >70% by weight and <50% by weight did not show any promising results. Higher percentage of iron results nonlinear behavior whereas lower percentage is not showing significant MR property. MRG sample 4 with 60% iron powder reveals good magnetorheological characteristics to be used in the development of devices. In future the temperature effects, higher shear rates and dynamic properties are to be studied in continuation of the work.

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