Synthesis and characterization of cost effective and eco-friendly magneto rheological fluid for aerospace applications

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Abstract. The magnetorheological fluid is field dependent fluid which changes its rheological characteristics under the influence of external magnetic field. Being one of the critically investigating smart material in the field of rheology, the fluid finds its application in wide range of mechanical engineering. In this study two samples were prepared using a carrier fluid as the blend of silicon oil and flex seed oil with a magnetic particles i.e. electrolytic iron powder with a weight of 25gms. The prepared samples and a commercially available MR fluid were characterised using magneto rheometer and also the fluids were subjected to experimental simulation and the performance of synthesized organic based MR fluid was recorded and compared to commercially available MR fluid (ARUS). It was observed that the samples so prepared gives a healthy competition to commercially available MR fluid, hence in order to enhance the performance the composition of magnetic particles can be increased. The variation of viscosity with respect to shear rate is observed at different current values like 0A, 0.5A, 1A, 1.5A and 2A and it is comparable with standard oil. The variation of shear stress with respect to shear rate is observed at different current values like 0A, 0.5A, 1A, 1.5A and 2A and is comparable with standard oil. Initial yield strength of 40 Pa is observed for the synthesised fluid.

1. Introduction
The rheological properties of magnetorheological fluid (MRF) falls under the category of smart materials. MRF's rheological features can often be continuously, easily, and reversibly modified as functioning there under magnetic field, which is why this material shows very higher interest due to MRF response in real-time. MRF generally includes very small particles that are suspended in a non-magnetic fluid, i.e. micrometres-sized magnetic particles[1]. Based on its composition distribution of magnetic particles and also magnetic field strength MRF reaches yields stress up towards 100 kPa.

The achievement of MRF is obvious in many engineering disciplines, starts in an automotive engineering application such as in dampers, semi active suspension control and civil engineering applications such as MR fluid controlled seismic mitigation, bridge structure to the biomedical engineering field such as medical tactile device, haptic interface, forearm crutch. There has been much of research work on MRF, which perceive the maximum benefits in these applications and also developing in other fields also. There was a countless wide variety of research which perceives the benefits of the use of Magneto rheological fluid devices and at the same time other fields also. This well-documented achievement of MRF promotes cutting-edge applications and future reticule applications in MRF. Main mechanism is variation of fluid response to applied magnetic field. Behaviour of the fluid under magnetic field is now well established fact.
MR braking systems have been studied in depth in order to replace the conventional hydraulic braking system for automotive industries. Karakok et al. [1] and Park et al. [2] assessed MR brake medium sized for a car; however, the braking torque obtained in the study by the brake system was found to be inadequate. In later stages Hirani [3] experimentally investigated MR braking performance parameters to incorporate into a high-speed braking application and concluded that a gap of 1 mm is best suitable for practical applications. Many more attempts have been done to optimize the MR braking system design, torque and weight, considering various parameters essential for an automotive industry. Sawant [4] also made an attempt of evaluating MR braking system for vehicular application from a reliability perspective. Jagadeesha T. [5] modelled MR fluids using commercially available software and optimised number of turns, amount of current and strength of the magnetic field at predefined points. MR actuator was developed optimized MR fluid was introduced between the gap of the fixed plate and rotating disk under the influence of the magnetic field over the fluid territory and testing is done. Shreedhar Kolekar [6-8] Prepared Magnetorheological Fluid and Studied Rheological Properties. They also conducted Vibration analysis of simply supported magnetorheological fluid sandwich beam. In another study they prepared Silicon Oil based Magneto Rheological Fluid and an experimental Study was conducted using a Plate and Cone Type Rheometer. Vikram G. Kamble et al. [9][10]carried out the analysis of rheological properties of MRF fluid based on variation in concentration of iron. Chethan Arjun et al. [11] conducted a study on Vibration Characteristics of Engine Oil Based Magnetorheological Fluid Sandwich Beam. Rajeshkar V. Kurahatt et al. [12] worked on Synthesis and Characterization of Innovative Type Magneto-Rheological Fluid. Amol B. Kharage et al.[13] studied the Frictional Effect on Magnetorheological Fluid. From the literature survey it is found that there is lots of scope to develop biodegradable, cost effective MR fluid. The main motivation for this work is investigate using low cost and biodegradable MR fluid for aerospace applications.

2. Methodology and Experimentation
In this section, the morphological characterization, synthesis plan and synthesis of MR fluid is presented. Also the rheological characterization of MR fluid along with commercially available MR fluid is presented. The samples so prepared are used in experimental setup to validate the results and to study the rheological behaviour under different operating conditions.

2.1. Synthesis of Magnetorheological fluid
The morphological study of the electrolytic iron powder which is employed in this study plays a critical role as the shape and size of particles involved largely affects the yield strength of MR fluid so obtained out of this. The electrolytic iron particles used is ASC100.29 which has density of 7.2 g/cc. SEM is carried out to see how the magnetic particles would align under applied magnetic field. The iron particles are used here have an average size of 10 µm and possess irregular shape resembling rod like structures.

The synthesis of magnetorheological fluid, was carried out using a blend of Silicon oil, Flax seed oil as a carrier fluid. Whereas the Electrolytic Iron (EI) power was taken as magnetic particles, so that magnetic flied could be developed throughout the fluid[6]. Grease was used as stabilizer to decrease the density of the iron particles and due to decrease in density iron particles the overall density difference between the carrier fluid and the magnetic particles drops down resulting in better stability of MR fluid. Triton X is used as a surfactant in order to avoid the additives particles floating on the surface of carrier fluid. figure 1 shows carrier fluid blend before and after mixing.
Figure 1. Carrier fluid blend before and after mixing.

For the study two samples were prepared using blend of silicon oil (70%) and flex seed (30%) oil as carrier fluid, EI particles as magnetic suspensions and grease and Titron X as surfactant and stabilizers and the results were compared with commercially available MR fluid. Figure 2 shows the synthesis plan. Table 1 gives the various composition of the blend prepared.

Table 1. Sampling strategy.

|   | Sample Composition  | Electrolytic iron powder | Triton X | Grease |
|---|---------------------|--------------------------|---------|--------|
| 1 | Silicon Oil(30%) + Flax Seed Oil(70%) (63gms) | (25gms) | (2gms) | (10gms) |
| 2 | Silicon Oil(25%) + Flax Seed Oil(75%) (63gms) | (25gms) | (2gms) | (10gms) |

The samples were prepared by mixing the silicon oil and flex seed oil in a container to obtain the blend of carrier fluid. Simultaneously the magnetical particles were mixed with grease and Titron X to obtain a thin coating over particles. The prepared blend of carrier fluid is supplemented to this mixture and is stirred mechanically for 24 hours at a speed of 1600 rpm to obtain a MR fluid. Further the samples are subjected to sonicator to have proper dispersion of constituents of fluid resulting in a stable MR fluid. Figure 3 shows the standard MR fluid purchased from ARUS for comparison.
Figure 3. Arus commercial fluid.

Standard magneto rheological fluid that are available in market is ARUS, the cost of ARUS oil is approximately Rs. 50000/litre. For the study ARUS MR fluid to check the properties and its performance, and to compare it with the MR fluid synthesised using magneto rheometer and MR brake setup respectively. In order obtain the best composition for magneto rheological fluid in terms of organic oil.

2.2. MR Brake Actuator Fabrication and Arduino setup

The Synthesized samples along with commercially available MR fluid was put for test practically by designing the various parts and Measurement setup compiled with Arduino and current sensor. figure 4 shows the schematic arrangement of experimental setup and figure 5 shows the actual fabricated setup.

Figure 4. Schematic representation of experimental setup.
Primarily the CAD models for various parts of actuator system was developed and the parts were machined to precise using CNC machining and is assembled to obtain the actuator of brake test setup. As shown in figure the various parts of actuator being top plates, bottom plates, stator, core, rotors and shafts. The actuator is coupled to DC motor with flexible coupling for the driving force the ACS 712 current sensor along with Arduino is employed to maintain Constant speed and record the torque obtained on application of magnetic field via MR brake actuator.

A driver is connected to the dc motor which converts 240V AC to 180V DC, the speed of the motor can be controlled using potentiometer knob. For precisely controlling the dc motor speed an Arduino controller is used in the place of knob. The values are tabulated, the voltage values obtained for different speeds are obtained are titled as speed, voltage, also the desired speeds are tabulated as speed act. The curve fitting is carried out between voltage and speed, the voltages corresponding to desired speeds are obtained by using MATLAB. The current sensor is connected in series with the circuit, for measuring the torque being developed in the motor which gives input to Arduino and will be read by system as shown in figure 6. table 2 gives the voltage values at different speeds and corresponding pin value.
Table 2. Voltage values at different speeds and corresponding pin value.

| Speed_act | speed | Voltage | Pin Value |
|-----------|-------|---------|-----------|
| 50        | 52    | 0.72    | 37        |
| 100       | 94    | 0.85    | 45        |
| 150       | 150   | 1.03    | 53        |
| 200       | 194.2 | 1.17    | 61        |
| 250       | 251.6 | 1.35    | 69        |
| 300       | 302   | 1.51    | 77        |
| 350       | 343   | 1.64    | 85        |
| 400       | 399   | 1.82    | 93        |
| 450       | 444   | 1.96    | 101       |
| 500       | 502   | 2.14    | 109       |
| 550       | 550   | 2.29    | 117       |
| 600       | 598   | 2.45    | 126       |

3. Results and Discussions

The scanning electron microscopy is employed to determine the morphological state of the particles of electrolytic iron powder. The surface topography, shape and size of the particles does influence the dominant characteristics of MR fluid. The study shows that the average particle size distribution is around 10 µm with irregular shape and rod like structure which implies a better yield strength of MR fluid so developed. Figure 7 shows the SEM of the particles used.

![SEM images of iron particles](image-url)
The variation of viscosity with respect to shear rate is observed at different current values like 0A, 0.5A, 1A, 1.5A and 2A. shown in figure 8. The graphs were plotted for every value of current to compare the behaviour between standard fluids and synthesis fluid. Viscosity is decreasing with respect to shear rate because due to increase in shear rate the resisting power of MR fluid decreases so viscosity is decreasing.

Figure 8. Graph of Viscosity (mPa.s) vs Shear rate(1/s).

The variation of shear stress with respect to shear rate is observed at different current values like 0A, 0.5A, 1A, 1.5A and 2A. shown in figure 9. And the graphs are drawn at each value of current to compare the behaviour between standard fluid and synthesis fluid. Shear stress is increasing with respect to shear rate for both fluid and due to increase in current value shear stress is also increasing.

Figure 9. Graph of Shear stress (Pa) vs Shear rate (1/s).

The max shear stress obtained for the MR fluid prepared was found to be nearly 100 Pa at 2.5 A current Which was less than the value obtained in the reference paper. Hence the composition of the present MR fluid needed to be changed by increasing the magnetic particles percent.
4. Conclusion
The low cost, biodegradable magnetorheological fluid synthesized in this study. The blend of organic oil along with flax seed oil is used to form the blend and different combinations is tried out. By keeping the magnetic particulate suspended in the fluid constant with a variation in amount of organic oil two samples were prepared. The magneto rheological characterization of the samples along with commercially available MR fluid was carried out for the comparison. Also, the samples were experimented over a MR brake test setup equipped with Arduino to maintain constant speed and current sensor to measure torque. It is seen that the in house developed samples shows competitive results to that of commercially available MR fluid. In order to enhance the performance of synthesised MR fluid i.e. eco-friendly MR fluid one can increase the weight percentage of magnetic particles in the carrier fluid. The variation of viscosity with respect to shear rate is observed at different current values like 0A, 0.5A, 1A, 1.5A and 2A and it is comparable with standard oil. The variation of shear stress with respect to shear rate is observed at different current values like 0A, 0.5A, 1A, 1.5A and 2A and is comparable with standard oil. Initial yield strength of 40 Pa is observed for the synthesised fluid

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