Fusion and characterization of Simarouba oil-based Green Magneto-Rheological (GMR) fluids

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ABSTRACT

In the quest to produce futuristic smart materials and to take them to the next level, researchers have come across a lot of challenges in producing smart materials which is eco-friendly. In this search researchers have taken a deep look at liquids with a peculiar conduct and they are called Green Magneto-Rheological Fluids (GMRFs). GMRFs are suspensions containing meso-scale polarisable magnetic particles that nest in a non-magnetic natural liquid medium and prevails in liquid state in the absence of magnetic field while its viscosity shoots up and becomes a viscoelastic solid with the increase in magnetic field. In the present work, various carbonyl iron powder-based Green Magneto Rheological Fluids (GMRFs) have been synthesized by mixing lithium grease as a stabilizer to prevent redispersion difficulty. Effort is made to blend various GMRF samples based on Simarouba oil which is naturally decomposable, eco-rich and is inexpensive. The GMRF samples are characterized for magnetic, morphological and magnetorheological behaviour under steady shear conditions.

INTRODUCTION

Sophisticated smart materials can react to outside forces and in the search of smarter materials, researchers have taken a hard look at liquids with interesting behaviour and they are called smart fluids. Smart fluids are materials that respond to an external excitation field. When unveiled to an electric or magnetic field, their rheological manners exhibit noteworthy changes. These smart materials are commonly ascribed to as Magnetorheological (MR) fluids, Electrorheological (ER) fluids and ferro fluids. Among the three Magnetorheological (MR) fluids acquire consideration as they deliver highest yield stress. which can be employed in many applications[1,2].

Magneto-rheological fluid (MRF) are suspensions containing meso-scale polarisable magnetic particles that nest in a non-magnetic liquid medium and prevails in liquid state in the absence of magnetic field, while its viscosity shoots up and becomes a viscoelastic solid with the increase in magnetic field[3]. In late 1940's Jacob Rabinow discovered magnetorheological fluids at the US National Bureau of Standards[4,5]. Since then a lot of developments on magneto-rheology has considerably increased, notably in the last few decades. MRF fundamentally is a bi-phasic fluid containing meso-sized (~ 10^2 – 10^4nm) magnetic soft particles scattered in a non-magnetic carrier fluid (water or oil) without /with additives. Magnetic particles Conventionally blended MRFs have Carbonyl iron particles (CI >99% pure) or Electrolytic Fe (EI, purity >95%) by 10-60 volume % in non-oxidizing carrier fluids with surfactants/ coatings / thixotropies. CI are broadly used particles as they are micron –sized (2-10 µm), magnetically multi-domain, saturation magnetization (~ 200 emu/g), low remnant magnetisation and high magnetic permeability results in better MR response such as high yield stress (10-100 kPa), quick response in few millisecond[6]. These iron particles organize along the direction of magnetic field into strong chains also called as “fluxes” under the influence of magnetic field, with one pole of a particle being attracted to the contrary pole of other [7]. The moment particles are aligned along their respective flux lines they act as hurdle for the carrier fluid motion eventually increasing their viscosity.

Yield strength developed in the MRF in the presence of magnetic field is the most important rheological parameter and can be determined by Bingham plastic-model[8](BP model). BP model predicts the total shear stress (τ) developed in Magnetorheological fluids as shown in Equation. 1.

$$\tau = \tau_Y(H) + \eta_P\,(\dot{\gamma}) \tag{1}$$

Where τ_Y (H) is the dynamic yield stress, η_P is the post yield plastic viscosity and ($\dot{\gamma}$) is the shear rate. The major ingredient which affect the magneto-rheological characteristics of MRFs is the carrier fluid which offers a medium for the magnetic particles[9] (50-80 percentage by weight). Mineral oil is a descendant of petroleum not environmentally safe and will exhaust in few decades. Silicon oil has poor surface tension, drenches the surfaces instantly and contaminates. Also, these Synthetic oils are expensive. Considering these limitations an alternative non-edible vegetable oil like Simarouba oil, used as carrier fluid which is inexpensive, environmentally conducive and available in ample. This oil is chosen after gauging diverse properties eligible for a carrier fluid as shown in Table 1 below.

Table 1. Properties of Simarouba

Properties	Value
Density @ 26℃	862 kg/m^3
Colour	Pale yellow
Viscosity @40℃ (Pa-s)	0.041(Pa-s)
Flash point	242^0C
Fire point	246^0C
Pour point	15^0C
Moisture content (% m)	0.37

EXPERIMENTAL

Three samples of GMRFs were readied considering the necessary desired properties. Simarouba oil, a non-edible natural oil was extracted from dried Simarouba kernel which is in plenitude in India. Commercially procured lithium grease is blended with Simarouba oil and stirred at 400 rpm with a mechanical stirrer at room temperature. Then the carbonyl iron particles (purchased from BASF, Germany is dispersed in the dispersion medium and mechanically stirred for 4-5 h to obtain a homogenous mixture. Three sample of GMRFs is named as sample A, Sample B and Sample C based on weight % as shown in Table 2 below.

Table 2. Constituent of GMRFs

Sample Designation	Carrier Fluid (Wt %)	Carbonyl Iron (~10 µ) (Wt %)	Lithium Grease (Wt %)
GMRFSC20	70	20	10
GMRFSC30	60	30	10
GMRFSC40	50	40	10

Anton Paar MCR 301 rotational rheometer with custom magneto attachment is used to measure the magnetorheological behavior of GMRFs samples under steady shear environment. Vibrating Sample Magnetometer (VSM), Scanning Electron Microscope (SEM) Test are used to characterize the carbonyl iron particles.

Magnetic hysteresis of CI particles

Vibration sample magnetometry (VSM) is used to evaluate the magnetic property of Carbonyl iron particles as shown in Fig.1 In between the sound magnetic coils of VSM, a cylindrical specimen of carbonyl iron particles was prepared and positioned, when the cylindrical specimen is subjected to mechanical vibrations under the influence of constant magnetic field. The pickup coils of VSM detect a voltage which is harmonious to the magnetic moment of the material. Thus, various magnetic properties such as coercivity, saturation magnetization, retentivity, etc. was determined from the drawn hysteresis (M-H) curve.

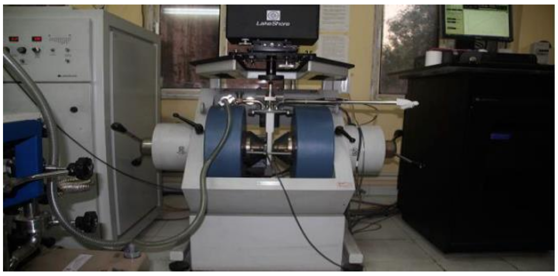

Figure 1. Vibration sample magnetometer (VSM).

SEM measurement procedure

SEM is used to detect the surface topological (and morphological) imaging of the CI samples with a very high resolution of over 50 Å. An immensely accelerated electron beams (~ 30KV) originated by field emission/thermionic emission through the electron guns are focused on specimen which is placed under an evacuated chamber. When the specimen is bombarded with beam of electrons, it ejects X rays, primary electrons, secondary electrons and Auger electrons. Backscattered primary electrons and secondary electrons are used for imaging. These sample discharge or bounced back electrons are gathered, and data is translated into three-dimensional image over the computer display. The mass of atom contained in the sample affect the image contrast.

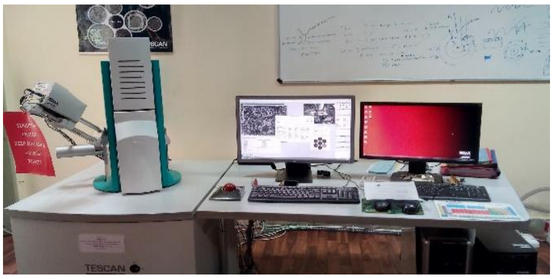

Figure 2. TESCAN, Scanning Electron Microscopy(SEM).

Rheometer measurement procedure

The Anton Paar MCR 301 (**Fig. 3**) is used to plot the flow curve (steady shear response) of GMRFs. Initially, the GMRFs sample was homogenized by shearing (~ 100 s^{-1}) after removing from the bottle for ~ 10 minutes. A small quantity of GMRFs sample is taken and placed on the lower plate of the rheometer. A 0.3 mm gap between upper and lower plate is maintained at room temperature (28^0C). GMRFs was subjected to shear rates ($\dot{\gamma}$) ranging from 0.01 s^{-1} - 1000 s^{-1}, their corresponding shear stress (τ), and viscosity (η) were documented at a fixed magnetic field intensity B (inclusive of B=0). A plot shear stress (τ) versus shear rates ($\dot{\gamma}$) and viscosity (η) versus shear rates ($\dot{\gamma}$) were obtained. Shear rate was confined to a maximum of 1000 s^{-1} to prevent the splash of GMRFs. After the completion of the test sample was subjected to cyclic decreasing magnetic field to relive them from any remaining magnetic field and thus completely demagnetize. The entire steps (mentioned above) is repeated for another value of B. The magnetic field was increased in the order of 0 mT, 86.5 mT, 181.5 mT, 365.2 mT, 956.3 mT and 1200 mT.

Figure 3. Anton Paar MCR 301 (Custom Magneto Attachment).

RESULTS AND DISCUSSION

Magnetic properties

The magnetic properties of CI particles were measured at 298 K (25^{o}C) and 398 K (125^{o}C) using Vibration Sample Magnetometer (VSM). The measurements were done at room temperature and at elevated temperature (125^{0}C) to check the magnetic behavior of CI at high temperature applications of GMRFS. The hysteresis curve for CI at 298K (25^{0}C) and 398 K (125^{0}C) is quite similar. Fig. 4 shows the hysteresis curve for CI particles at room temperature. The saturation magnetization of the CI sample at room temperature is ~ 220 emu/g and drops to ~ 210 emu/g at a elevated temperature of 398 K. A narrow hysteresis loop indicates soft magnetic nature of sample. The magnetic nature of CI is highly wanted and desirable for its instant response.

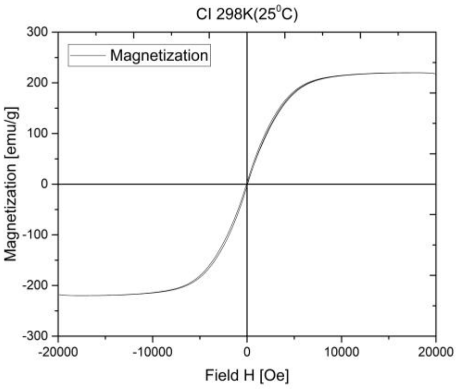

Figure 4. Hysteresis curves for CI powder at 298 k (25^{0}C).

Morphological properties

The extent of yield strength generated by the MR fluid is influenced by the morphological properties of magnetic particles present in the MR fluid. Fig. 5 & Fig.6 displays the morphological characteristic of pure CI powder at 5000 X and 15000 X respectively. The spherical shape of CI particles as observed limits magnetic shape anisotropy and increase the strength of bond amidst the magnetic particles leading to an increment in the yield strength developed in the MRF.

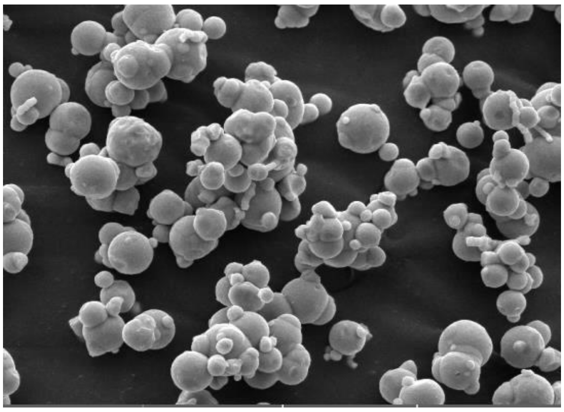

Figure 5. SEM image of CI powder at 5000 X magnification.

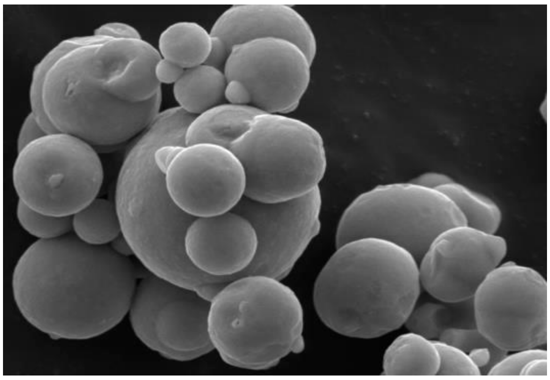

Figure 6. SEM image of CI powder at 15000 X magnification.

Rheological measurements

The measured flow curves of GMRFSC20, GMRFSC30 and GMRFSC40 are shown in Fig.7, Fig.8 and Fig.9 respectively. The magnetic field (B) applied is in the subsequent order: 0 mT, 86.5 mT, 181.5 mT, 365.2 mT, 956.3 mT and 1200 mT which match to the curves from bottom to top for both shear stress vs shear rate and viscosity vs shear rate in such order.

All the three GMRF (Green Magneto rheological Fluids) exhibit shear-thinning flow behavior.

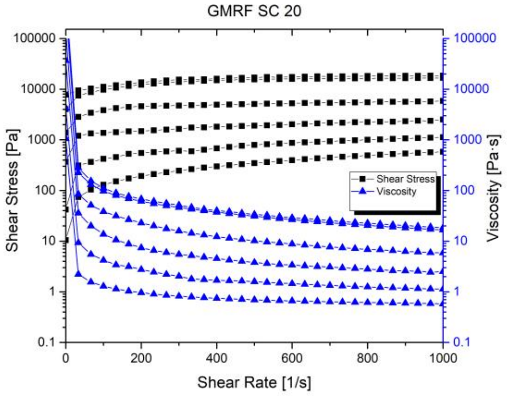

Figure 7. Flow curve and viscosity curve of GMRF SC 20.

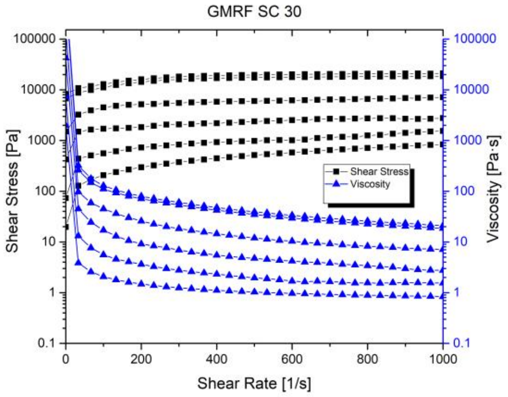

Figure 8. Flow curve and viscosity curve of GMRF SC 30.

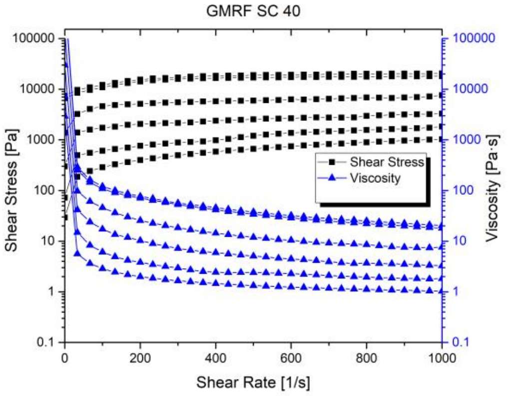

Figure 9. Flow curve and viscosity curve of GMRF SC 40.

The viscosity of all the three GMRFs displays a steep drop in low shear rate range and relatively flatten out in the high shear rate range. It is observed from the flow curves that there is an increase in the shear stress and viscosity value for all the GMRF samples with the magnetic particle concentration and magnetic field strength. This behaviour is due to amplified strength of the particle columns repelling applied shear stress. In the pre-yield regime the shear stress rises quickly and the GMRF behave as viscoelastic solid. In the post yield regime, the shear stress turns out to be steady and GMRF behave as viscoplastic fluid.

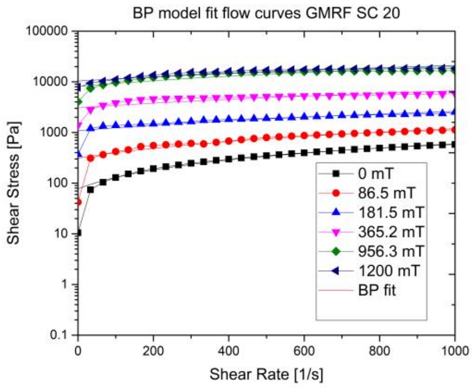

Figure 10. BP model fit flow curves of GMRF SC 20.

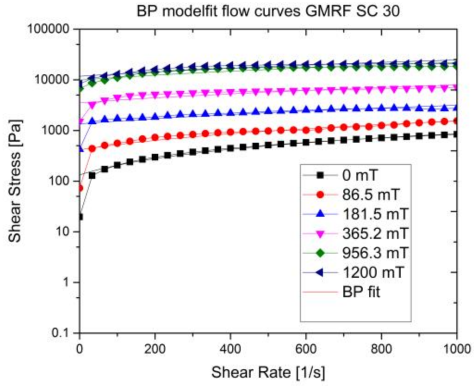

Figure 11. BP model fit flow curves of GMRF SC 30

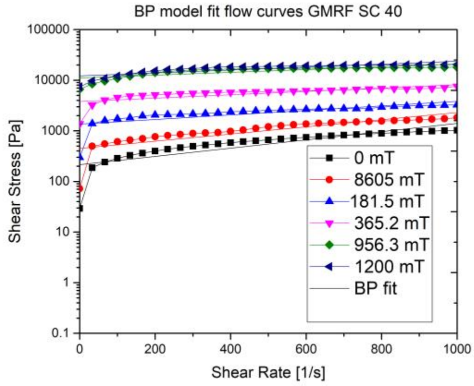

Figure 12. BP model fit flow curves of GMRF SC 40

The shear stress vs shear rate curves of all GMRF samples were fit by Bingham model as shown in Fig.10, Fig.11 and Fig.12 and the dynamic yield stress is derived from the plot of Bingham fit.

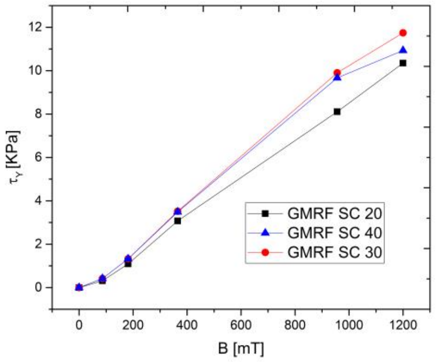

Figure 13. The derived plots of yield stress (τ_Y) vs applied field (B)

'Field dependent yield stress (FDYS)' is the variation of yield stress as a function of applied field strength and provides information in choosing the optimum applied field which correspond to maximum yield strength. Fig 13 shows an increase in the τ_Y with the increase in the applied field due to an increase in the strength of columnar structure as the particles interact and align along the direction of the field. In addition to the test conditions the increase in τ_Y can be attributed to the magnetic saturation resulting in a linear increase with B up to a certain level and further increase due to high interparticle interaction. Increase in the concentration of magnetic particle decreases the inter particle spacing with increase in magnetic body interaction increasing the column strength eventually resulting in high yield strength. GMRF SC 40 produces a maximum value of yield strength of 10.96 KPa.

CONCLUSION

Green Magnetorheological fluid is synthesized by using Simarouba oil as carrier fluid which is extracted from dry kernel of Simarouba seeds. Carbonyl iron particles are characterised for magnetic and morphological characteristics using VSM and SEM respectively. GMRFs of different particle concentrations, containing carbonyl iron particles of different compositions were subjected to steady shear conditions ranging from pre-to well beyond yield point response regions (post-yield) of GMRFs were extracted via Bingham plastic model fit of the obtained stress vs shear rate response curves. The yield strength scaled with saturation magnetization, magnetic particle concentration and applied magnetic field strength due to strong column formation. The cost of the GMRFs produced is 80% lesser than the commercially available MRFs.

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