Frequency Sweep Response of a Simarouba Based Green Magneto-Rheological Fluid

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ABSTRACT

In the pursuit to ascertain sustainable smart fluids, arduous research has been put into developing Green Magneto-Rheological Fluids (GMRFs). GMRFs are colloidal suspensions of polarizable magnetic specks dispersed in a natural carrier fluid. Variable viscoelastic properties are detected in GMRFs under the influence of a magnetic field. In the advent of MR fluid based dynamic applications such as dampers, a GMRF provides a safe, biodegradable alternative. This paper characterizes the GMRF samples which comprise of Carbonyl Iron powder-based specks dispersed in a Simarouba carrier fluid in tandem with lithium grease to prevent settling of particles. The dynamic characteristics are investigated by means of a frequency sweep oscillatory shear test. The frequency sweep analysis is propitious in selection of magnetic specks of GMRFs in the fields of vibration mitigation and noise elimination. At low oscillatory frequency (< 1 rad s^{-1}) erratic values of storage and loss moduli are observed (noise) as a result of irreversible configuration of the magnetic specks which retort to the prevailing small strain (0.01 %). It can be inferred that the storage modulus is invariably greater than the loss modulus for all values of shear strain angular frequency. The values of G' and G" relies on several factors such as physical and magnetic nature of the specks, percentage weight of specks in the base fluid and the employed magnetic field strength

1. INTRODUCTION

Magnetorheological (MR) fluids are "smart" magnetic-field responsive two-phase liquid systems that exhibit a dramatic rheological change under the presence of a magnetic field[1,2,3]. Green Magneto Rheological Fluids (GMRFs) are colloidal solutions in an ecologically friendly fluid medium with polarizable magnetic microspheres. GMRFs display isotropic character in the absence of an intrinsic magnetic field. In the case of an actively applied magnetic field, the GMRF forms cylindrical structures which act as a viscoelastic solid. The yield strength of GMRF under the employed magnetic field is the most significant rheological parameter and can be evaluated by the Bingham plastic-model (BP model)[4,5]. BP model predicts the total shear stress (W) developed in magnetorheological fluids. Owing to the celeritous phase shift from fluid to a viscoelastic solid is the reason why GMRFs possess a myriad of applications. Possible GMRF applications include braking systems, aircraft landing gears and transmission systems amongst various other applications[6,7,8,9]. In the absence of a magnetic field, the liquid phase of GMRF has the essential roles of being a continuous medium for the microspheres and also of stimulating realignment in its presence. The dominant carrier fluid in the industry is silicone oil due to its unparalleled properties. Silicone oil however has insufficient surface tension, wets the surface quickly and is easily made impure. Further, synthetic oils possess other disadvantages such as being extremely uneconomical and harmful to the environment. Lot of research has gone into supplanting Silicone oil as the predominately used industry standard. For instance, Gangadhara Shetty et al have explored the use of Honge oil as a carrier fluid. However, an economical and naturally occurring carrier fluid has not supplanted silicone oil in the industry. In the current study, Simarouba oil is chosen and used to synthesize Green Magneto Rheological Fluids (GMRFs). It is a natural oil which is cold extracted from the dried kernels of the Simarouba fruit. The Simarouba oil is not only environmentally friendly but it is also extremely economical and available in abundance in India. GMRF's undergo recursive loading conditions for various applications, therefore it is imperative to study their yield properties in dynamic shear. Frequency sweep experiments analyse the effect of strain frequency on the behaviour of viscoplastic flow. Applications involving vibration control require a detailed understanding in order to study the viscous response of the GMRF when subjected to strain frequencies. The frequency sweep test is thus performed in oscillatory sheer conditions using a parallel rheometer (Anton Par 302) which is subjected to a robust magnetic field.

2. MATERIALS AND METHODS

2.1 Carbonyl iron

Carbonyl Iron Powder (CI):
Carbonyl Iron Powder of sizes 6.5 µm - 8.0 µm (D50 value) were acquired from BASF SE, Ludwigshafen, Germany. CI is a fine-grained powder, which is grey in colour. In nature, CI is mechanically soft, and has spherical micro particles. For further characterization, the complete specifications of the CI particles have been verified.

2.2 Electrolytic iron

Electrolytic iron powder (EI):
Electrolytic iron powder was obtained from Sigma-Aldrich Pvt Ltd. The EI appears dark grey in colour and the average particle size is about 9 µm. After a thorough analysis, this particle size value was chosen on the basis that the particle size decreases sedimentation and increases its efficiency.

2.3 Simarouba Oil

The Simarouba Glauca tree is found across Karnataka state in India and the seeds of these trees are the source of the Simarouba oil. The fruit of the tree is decorticated with a seed decorticator where in the kernels were segregated from the shell. The segregated kernels are fed into a mechanical screw seed oil extractor where they are crushed in the kernels and the oil is retrieved (cold pressed) with seed crushed waste retained as seedcake. Simarouba seeds have a yield of 35-40 % per kernel.

2.4 Synthesis of Green Magneto-Rheological Fluids (GMRFs)

Initially, the base fluids and additives are mixed together with an electric stirrer for about 10 minutes, so no lumps are created in the sample. Adding magnetic particles to each sample is done in percentage weights of 20, 30 and 40. The magnetic particles are introduced in intervals of ~11 minutes and the speed of the stirrer can be 450 to 1100 rpm[10]. Upon completion of this stirring process, ultra-sonification is performed for 16 minutes to ensure consistency. Thus, six GMRF samples were synthesized.

2.5 Frequency Sweep

Characterisation of GMRFs in unsteady shear environments is impertative for potential applications[11,12]. GMRF-enabled devices may experience disproportionate, iterative or spasmodic stress and such stressed may be in linear viscoelastic-range (LVE) or nonlinear viscoelastic-range (NLVE). Viscoplastic flow of the GMRF is produced upon exceeding critical values of applied strain frequency. To comprehensively investigate the viscoplastic flow of the GMRF governed by the strain frequency, a strain frequency sweep test is conducted using an Anton Paar MCR302 device with a parallel plate (PP20) geometry. Frequency sweep is the deviation of shear moduli against applied strain frequency (ω). While the GMRFs are analyzed in frequency sweep, the frequency range of the strain applied is selected to include all domains. The storage and loss moduli i.e. the shear moduli of the GMRF/MRF were noted as a function of the applied strain frequency (ω = 0.01 % to 100 %). The value of strain amplitude selected for this study is γ = 0.01 %. The values of magnetic field employed in this study are 86.5 mT, 365 mT and 1200 mT.

3. RESULTS AND DISCUSSION

3.1 Strain Frequency Sweep of Simarouba Based GMRFs

The response of the synthesized GMRF samples is graphically outlined in Figures 1-4. The applied magnetic fields are 86.5 mT, 365.2 mT, and 1.2 T which were chosen for distinction, as seen in the curves.

When a magnetic field is not applied, it seems that the synthesized samples have Newtonian shear activity that is typical of an MRF. The difference in the storage module (G') and loss module (G") with enhanced magnetic flux density allows cylindrical chain structure to be developed in the GMRF[13]. The graphs at smaller values of frequency, ω = 0.01 to 1 rad s^{-1} the detected response was quite noisy i.e. there was a lot of disturbance observed. This disturbance can be attributed to the invariable configuration of the magnetic specks, which consistently retort to prevailing small strain (γ = 0.01 %) at small oscillatory frequency. It must be noted that the storage modules (G') is typically greater than the loss module (G"), independent of the angular strain frequency applied. This can be ascribed to the small applied shear strain amplitude (0.01 %) that the GMRF acts under its LVE reign where the magnetic field governed structure is compact. Since the G' is always greater than the G" at any given ω, the damping factor (tanδ) will always be less than the unity (about < 1 for any GMRF / MRF). Generally, with the applied B and the magnetic particle volume fraction, the two moduli (G' & G") rise. This is attributed to the improved strength of the structure inside the GMRFs / MRFs. The effect is described as a drop in the value of the damping factor with a rise in applied B and concentration of magnetic particle. CI and EI derived GMRFs displayed decreasing tanδ values with increased applied B and magnetic particle weight fraction due to increased viscosity. The GMRF response was optimal for fluids with 40 percent of magnetic particles. EI-40 based GMRF displayed a relatively weak damping factor in comparison with CI-40 based GMRFs despite the latter possessing a higher structural strength (M_s of CI > M_s of EI). This may be due to the large particle size of the EI relative to the particle size of the CI. GMRF samples prepared with Simarouba oil (Kinematic viscosity~ 56.19 cSt, $\rho = 968.04\ \text{kgm}^{-3}$) display stellar characteristics for frequency sweep response curves. The Simarouba based GMRF specimen in Figure 4 with 40 % CI micro particles [GMRF SE 40] is viable for applications.

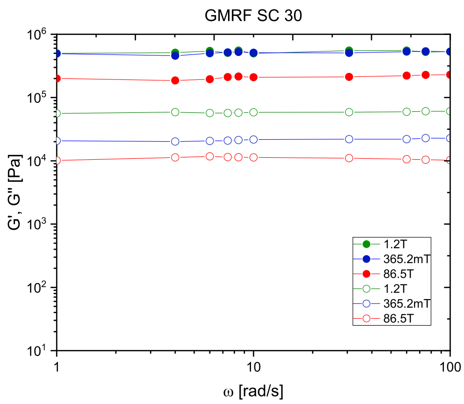

Figure 1. Frequency sweep plot of GMRF SC 30

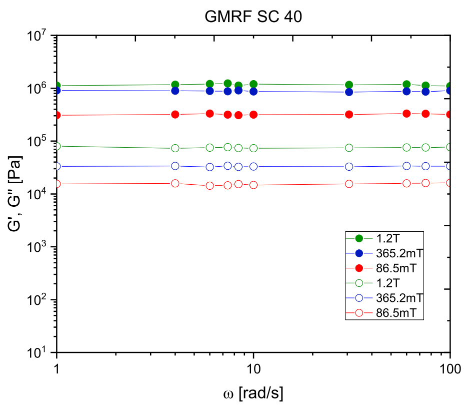

Figure 2. Frequency sweep plot of GMRF SC 40

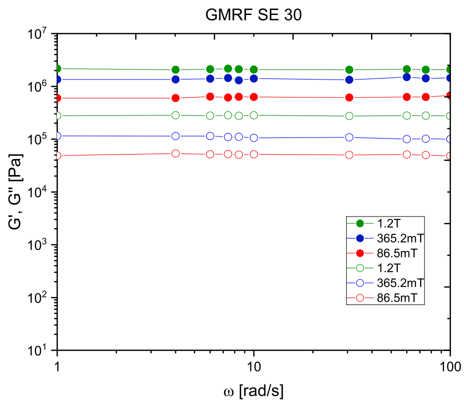

Figure 3. Frequency sweep plot of GMRF SE 30

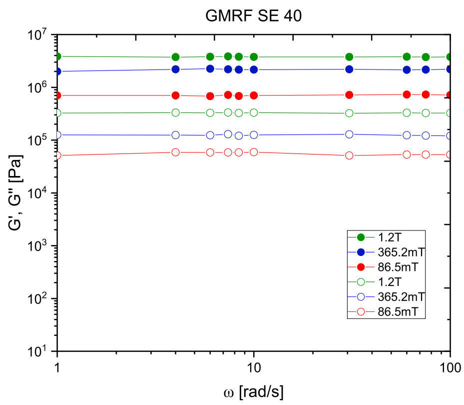

Figure 4. Frequency sweep plot of GMRF SE 40

4. CONCLUSION

A concise study of the nonlinear viscoelastic properties of GMRF is established through an investigation using the frequency oscillatory shear test conditions. The carrier fluid considered in the experimentation is Simarouba. The fluid is subjugated to three incisive magnetic field strengths of 86.5 mT, 365.2 mT and 1.2 T. Carbonyl Iron Microspheres are used as the solid phase component in the study and are in attendant in in three concentrations of 20 %, 30 % and 40 % by weight within the fluids under consideration .GMRF SE40 has a better damping factor compared to GMRF SC40, hence making it viable for practical applications. It is observed and concluded that that due to the irreversible structural layout of magnetic specks within the system, percentage weight of the specks and the applied field strength, the storage moduli are unalterably greater than the loss moduli for all applied values of strain angular frequency under consideration.

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