VISCOELASTIC PROPERTIES OF NANOPARTICULATED MAGNETITE AND COBALT FERRITE BASED MR FLUIDS

M. VENKATESWARLU , B. RAJINI KANTH

Abstract: Magneto Rheological fluids are made up of soft magnetic particles dispersed in a carrier fluid. These MR fluids respond to magnetic field with a change in their rheological behavior. MR fluids exhibit rapid, reversible and significant changes in their viscosity and shear modulus when subjected to external magnetic field. These fluids are useful applications as dampers, shock absorbers and actuators. Here we have made an attempt and made nanoparticulated magnetite and cobalt ferrite based magneto rheological fluids from the magnetite and cobalt ferrites obtained from the simple wet chemical synthesis from the metal salts. Both the ferrites, were mixed with different weight percent solutions (10, 20, 30 wt%) of PVP to make the Magneto Rheological fluid samples. These samples were characterized by the Anton Paar Magneto Rheometer in both oscillatory, rotational measurement conditions. A remarkable change of viscosity with the applied field was observed for both the cases and in the higher wt% fluids the change is substantial. In the case of the magnetite based fluids the magnitude of the viscosity change was slightly higher than the cobalt based fluids. In the oscillation measurements the viscosity of cobalt based MR fluids increases with the field after reaching the maximum value and started decreasing unlike in the case of magnetite based MR fluids in which the viscosity continuously increasing with the field up to 750 mT. The effects of magnetic field on the volume fraction on the viscoelastic properties are also investigated. The higher the magnetic field the higher is the storage modulus and loss modulus, and lower the loss factor. The higher the volume fraction, higher the storage modulus and the loss factor. The variation in viscosity with respect to the magnetic field, storage, loss modulus and damping of the samples were measured and compared and presented in this paper.

Keywords: Magneto Rheological Fluid, Ferrous Ferrite, Cobalt Ferrite, Polyvinyl Pyrrolidone, Viscocity, Storage Modulus, loss Modulus and Damping.

Introduction: Magneto rheological (MR) fluids are dispersion of fine magnetically soft, multi domain particles. The apparent yield strength of these fluids can be changed significantly with in mille seconds by the application of external magnetic field. Magnetic rheological fluids are a class of soft materials, whose rheological properties (i.e. viscosity) may be rapidly varied by an applied magnetic field [1-4]. In the presence of Magnetic field the suspended magnetic particle interact to form a structure that resist shear deformation or flow. This change in the materials appears as a rapid increase in apparent viscosity or in the development of the semisolid state [5-6]. MR fluids are not affected by minor chemical impurities like water therefore less restrictive and cheaper manufacturing process may be employed. MR fluids are non-toxic, environmentally safe and compatible with most other material employed in automotive manufacturing. MR fluid require some agitation to periodically re disperse the polarized particles. Interest in MR fluids derives from their ability to provide simple, quite, rapid-response interfaces between electronic controls and mechanical system [7]. Stronger the field, greater the effect on the properties [8]. MR fluid devices are being used and developed for shock absorbers, clutches, breaks, and seismic dampers [4, 5]. The main aim of the present study is to compare the Magnetorheological properties of nano particulated Magnetite and Cobalt ferrite based MR fluids and study their viscoelastic properties and know their damping behavior for the application point of view.

Experimental: Synthesis and characterization of cobalt and magnetite nanoparticles : Pure chemicals(99.9%) of iron sulphate, cobalt sulpahte and NaOH were taken and in three separate beakers, solutions of $FeSO_4 \cdot 7H_2O$, and $CoSO_4 7H_2O$ and NaOH were made. After heating the Fe and Co sulphate solutions to 75 ºC and mixing the two solutions while stirring with a stirring rod. After getting the perfect mixture, NaOH solution was added to the mixture drop by drop. After reaching a PH of 10, a green suspension was formed and rapidly turned to black. The solution was heated to 90 ºC for 10 min while stirring. The black suspension was cooled to room temperature. The precipitate was filtered with a Büchner funnel. The black solid was washed several times with distilled water while in the funnel. The filter paper was pulled out of the funnel and placed it on a watch glass, and dried it in an oven at 100 ºC. The black powder was scrapped off of the filter paper. The collected powder was heat treated at around 600C in an ceramic boat for five and half hours similarly, Magnetite was also synthesized much details on these sample synthesis and characterization were presented in Ref [9-11].

Preparation of MR fluids and MR characterization : Both the ferrites, were mixed with weight percent solutions (10, 20, 30 wt%) of PVP to make the Magneto Rheological fluid samples. The MR samples were stirred using a homogenizer for half an hour with an average RPM of 2000. These samples were characterized by the Anton Paar Magneto Rheometer in both oscillatory, rotational measurement conditions.

Rotational measurement : The Sample was measured in Rotational mode to analyze the flow properties with a constant shear of 100 s^{-1} Magnetic field dependence of MR Fluid was studied with an Flux density upto 750mT and measured at 25 C. The viscosity of the sample was found to increase with respect to Magnetic Flux. The viscosity build up is due to the alignment of the MR fluid particles in the direction of the Magnetic Field. Table.1. shows the viscosity values at a typical field as the wt% increases the viscosity also increases. Fig. 1 shows the shear stress vs Magnetic field plot, here shear rate is kept a constant value. The equation for these fluids as suggested by Herschel-Bulkley fluids [12] is $\tau = \tau_o + k\,\gamma^n$, where τ = shear stress, τ_o = yield stress, the minimum stress is needed to start the flow, k = consistency (basically the viscous coefficient), γ = shear strain rate during the measurement, and n = the power law exponent, indicates if the flow is shear thinned(<1) or thickened (>1), and at n =1 the behavior is Newtonian.

Table1. 1 Viscosity of Cobalt and Magnetite MR fluids

Sl. No.	Wt%	Cobalt MR fluid (mPa) at 750 mT	Magnetite MR fluid(mPa) at 750 mT
01	10	3.94	14.45
02	20	24.3	10.35
03	30	34.58	21.11

Oscillation measurement : The viscosity of the sample was found to increase with respect to Magnetic Flux. The viscosity build up is due to the alignment of the MR fluid particles in the direction of the Magnetic Field. At low Magnetic field the particles in the sample are not oriented there by the viscous behavior is dominant. The dominance of viscous behavior can be seen from higher magnitude of Loss modulus G" when compared to G'. A remarkable change of viscosity with the applied field was observed for both the cases and in the higher wt% fluids the change is substantial. In the case of the ferrous ferrites based fluids the magnitude of the viscosity was slightly higher than the cobalt based fluids. The variation in viscosity with respect to the magnetic field, storage and loss modulus and damping of the samples were measured and compared.

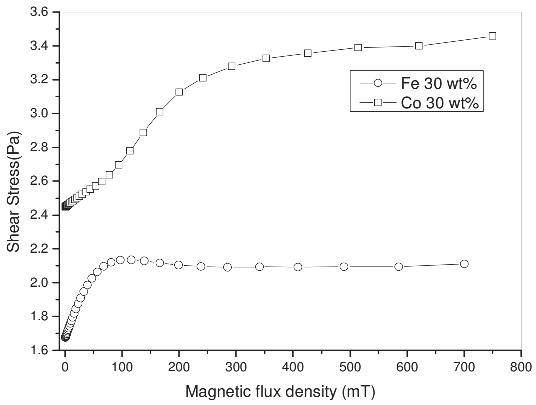

Fig.1 variation of shear stress with the applied magnetic field

The viscoelastic material would yield a stress with components both in-phase and out of phase. Hence, Viscoelastic behaviour can be described by the complex modulus.

$G^* = G' + iG''$

Where G′ is the storage (in-phase) modulus and G″ is the loss (out-of-phase) modulus, based on the theory of linear viscosity [13]. A useful quantity called the material loss factor may be defined from the complex modulus

$\delta(\omega) = G''(\omega) / G'(\omega)$ where ω is the angular frequency

The loss factor is measure of the ratio of the energy dissipated from the material per radian to the stored energy during the steady state sinusoidal excitation.

Figs. 2 and 3 show the storage and loss modulus variation with magnetic field from 0 to 750 mT. The storage modulus is continuously increasing for the magnetite based MR fluid and is more than the cobalt based MR fluid and there is a wide peak at 250 mT and small dip at 400 mT for the cobalt based MR fluid. Whereas the loss modulus is less for the Magnetite based MR fluid compared to cobalt based MR fluid and the variation of loss modulus in both the cases replicates the storage modulus plot.

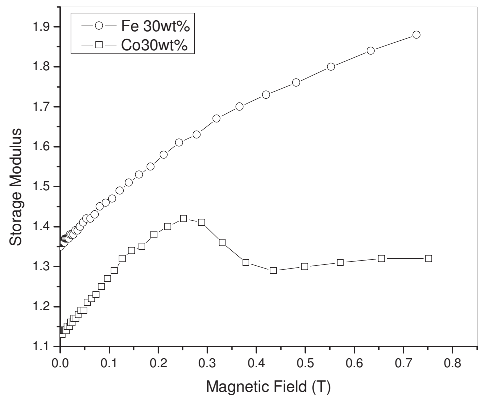

Fig. 2 Storage modulus vs magnetic field

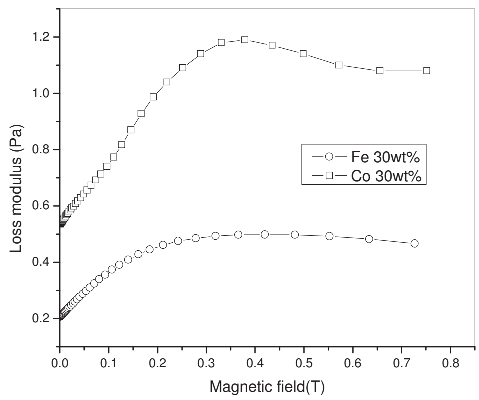

Fig. 3 Loss modulus vs magnetic field

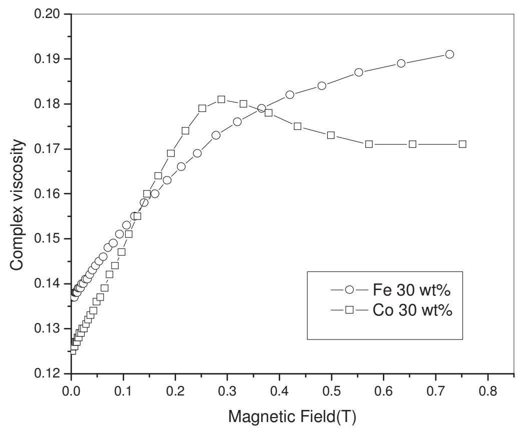

Fig. 4 Complex viscosity vs magnetic field

Fig. 4. shows the resultant of these two modulus's, the cobalt based MR fluid complex

viscosity crosses the Magnetite based MR fluid at 250 mT as shown in the figure.

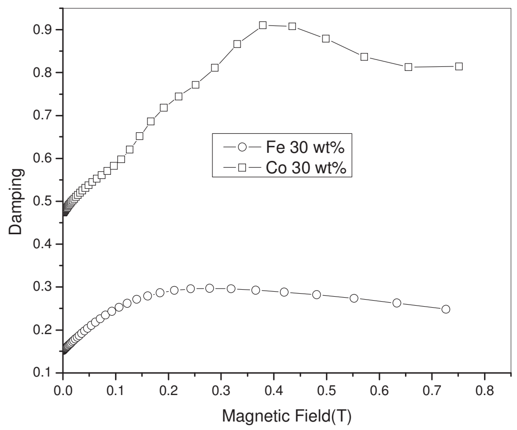

Fig. 5 Damping vs magnetic field

Fig.5 shows the damping behaviour of the present samples with the magnetic field. The cobalt based MR fluid has more damping than the magnetite based MR fluid.

Table.2 Damping values of Cobalt Magnetite MR fluids

Sl. No.	Sample	Damping value (max)	Field (mT)
01	Cobalt MR fluid (30 wt%)	0.91	380
02	Magnetite MR fluid(30 wt%)	0.30	278

Table.2. shows the maximum damping values for both the fluids. Cobalt based MR fluid has large value of damping at a higher field compared to the magnetite based MR fluid. Further study of improving the properties of cobalt based MR fluids which were expected to be potential candidates for the damping application, by varying the preparation conditions (controlling the particle size) is underway.

Conclusions : We have made nano particulated magnetite and cobalt ferrite based magneto rheological fluids from the magnetite and cobalt ferrites with 10, 20, 30 wt% of PVP to make the Magneto Rheological fluid samples. These samples were characterized by the Anton Paar Magneto Rheometer in both oscillatory, rotational measurement conditions. The effects of magnetic field on the volume fraction on the viscoelastic properties are also investigated. The higher the magnetic field the higher is the storage modulus and loss modulus, and lower the loss factor. Damping value is high for cobalt based MR fluids as compared to magnetite based MR fluids.

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