Synthesis and Characterization of Magnetorheological Fluids with Super Paramagnetic Nanomaterials in Polymeric Matrix

V. Kancharla*, A. Fahmi, Q Liu, and N. Gindy*

*School of Mechanical, Materials and Manufacturing Engineering
University of Nottingham, Nottingham, nabil.gindy@nottingham.ac.uk

ABSTRACT

Magneto-rheological (MR) fluids represent an exciting family of smart materials that have the unique ability to undergo rapid (within a few µs) changes in their apparent viscosity on the application of an external magnetic field. Here a new type of magneto-rheological is introduced fluid with a mixture of nano sized (~15 nm) Fe_3O_4 particles and micro sized (1-8µm) iron particles dispersed in polymeric matrix. The nanoparticles are synthesized by co-precipitation technique and characterized using Transmission Electron Microscope (TEM) and X-Ray Diffraction (XRD). Rheological properties of MR fluid were studied in the presence of varying magnetic field. It is observed that, varying the strength of magnetic fields has a significant effect on the viscosity of the fluid.

Keywords: Magnetorheological fluids, Polymeric Matrix, Super paramagnetic nanoparticles, Co-precipitation, Rheology

1 INTRODUCTION

Nanomaterials are now-a-days being extensively investigated due to their potential applicability in many areas such as biology, medical and environment. For novel technological applications, these materials should be produced through a simple, inexpensive and controllable way in order to obtain nanoparticles of the required composition, size, shape with superior properties and functionalities. In the framework of modern nanotechnology, nanosized magnetic particles represent a key group of materials with great application potential. Since these particles are easily controlled by an external magnetic field they have proven themselves to be efficient in various industries. From this point of view, nanoparticles of iron oxides, particularly Fe_3O_4 (magnetite) nanoparticles have captured a dominant position due to their superior chemical and thermal stability, hardness, non-toxicity and biocompatibility. As one of the potential applications of the magnetic materials, magnetorheological fluids are being extensively investigated [1, 7].

Magnetorheological (MR) fluids are dispersions of magnetically soft, multi domain particles that are coated with a surfactant for stabilization in a carrier solvent. It is free flowing liquid in the absence of magnetic field but under strong magnetic field, its viscosity changes dramatically with in few milliseconds and exhibits solid like characteristics. The interaction between the particles causes the columnar structure aligned roughly parallel to magnetic field, thereby producing drastic changes in MR fluids rheological properties such as enhanced yield stress and viscosity [1, 5]. The degree of change in MR fluid characteristics mainly depends on the magnitude of the applied field strength. Also, size of magnetic particles and their concentration and dispersion in the carrier fluid plays a major role in determining the influence of the external field on the composite system [6].

In 1948, Jacob Rainbow developed MR fluids and developed an application device "a clutch" [9]. Since then, the applications of MR fluids have been greatly restricted due to agglomeration and sedimentation of magnetic particles dispersed in the carrier fluid. In late 90s an unexpected watershed occurred in the development of smart fluids when MR fluids are re-discovered [8]. In the effort to explicate MR characteristics and potential MR applications, various theoretical and experimental approaches have been adopted to both synthesis of MR materials and its associated applications. In MR fluids, critical factors, which include the stability against sedimentation and higher saturated magnetization, as well as the large magnetic field-induced yield stress and low viscosity in the absence of magnetic field, should be endowed for better applicability. Improving all these critical properties simultaneously, however, is very difficult to achieve [4]. But, with the current advances in synthesis of nano particles, it might be possible to overcome some of these shortcomings in MR fluids based on magnetic nanoparticles. Nanoparticles have greater ability to form a uniform dispersion in the carrier fluid, thus reducing the tendencies of settling and non-uniform mixing that are manifest when micro sized particles are used [6].

In this paper, the synthesis and characterization of magnetite nanoparticles used in the new MR fluid are reported. The fluid was prepared by mixing nanosized magnetite particles with micro sized iron particles in polymer matrix. MR fluids with different concentrations were prepared, but only results for 20 wt.-% are reported. Also the rheological properties of the fluid were studied using a rotational rheometer by controlling the magnetic field strength.

2 EXPERIMENTAL PART

2.1 Synthesis of nanoparticles

All the chemicals used were reagent grade used without further purifications. Magnetic nanoparticles were synthesised by the co-precipitation method, by adding a 1M Sodium Hydroxide (NaOH > 99%) solution into a mixed stock solution of 1.28M Ferric chloride hexa-hydrate ($FeCl_3.6H_2O$ > 99%) and 0.64M ferrous chloride tetra-hydrate ($FeCl_2.4H_2O$ > 99%) solution (molar ratio 2:1) under vigorous mechanical stirring (2000rpm) in the presence of N_2. The slurry was washed repeatedly with distilled water. Precipitated powder is magnetically isolated from the supernatant and 0.01M HCl was added to neutralize the anionic charge on the particle surface. The complete details of nano-particle synthesis had been reported else where [3].

2.2 Characterization of nanoparticles

The structural properties of Fe_3O_4 powder were studied using Siemens D500 diffractometer with CuKα radiation at 40kV, in the Bragg-Bretano geometry in the 2θ range of 20-70º, in steps of 0.02º at 1s per step. The size of coherent domains (particles) was calculated using Debye-Scherrer formula: $D_{hkl} = k\lambda / \beta\cos\theta$ Aº, where k is a constant = 0.9, λ- wave length of the radiation λ_{Cu} = 1.54056 Aº, β is the width at half height of the diffraction peak. The phase composition of the sample was evaluated using *Diffrac-Plus* peak identification software.

The particle size and morphology of the particles were studied using JEOL 4000FX Transmission Electron Microscope (TEM). The sample for TEM analysis was prepared by dispersing nanoparticles in acetone and placing a drop on a carbon coated copper grid and allowing it to dry in air.

2.3 Preparation of MR Fluid

The Fe particles used in this study are a blend of micron sized (1-8 µm, from Good Fellow Co.) and nano sized (~15 nm). Polymeric matrix was prepared by dissolving desired amount of polystyrene mixed with surfactants molecules in an organic solvent at 3000 rpm [2]. MR fluids of different particle content are prepared by mixing specific amounts of Fe particles (both micro & nano) and dispersing them into polymeric matrix.

2.4 Magnetorheological Properties

Rheological characterization of the MR Fluid was carried out by means of a commercial Rheometer (ARES - Rheometric Scientific), using a custom made Couette-type geometry with a brass cup and bob with a 1mm gap in between. The internal surface of the cup and the external surface of bob were sand blasted to prevent slippage across the wall surfaces. The rheological behaviour of MR Fluid specimen (Iron particles content 20 wt.-%) was investigated under steady state shear flow and when applied, the magnetic field was kept static. Since the smart fluid properties are a strong function of applied magnetic field, a custom made fixture is designed and made as a removable attachment for control and generation of uniform magnetic field in the fluid sample space. A current is passed through the electromagnet and a gauss meter is used to measure the magnetic flux in the air gap between bob and cup.

3 RESULTS & DISCUSSION

In order to determine structural properties and morphology of the synthesised nanoparticles, Transmission Electron Microscope (TEM) and X-ray diffraction (XRD) measurements are made.

3.1 X-Ray Diffraction

Figure 1 shows the results of X-ray diffraction analysis for the precipitated Fe_3O_4 nanoparticles. The peaks of Fe_3O_4 powder at 2θ = 30.26º, 35.32º, 43.14º, 53.14º, 53.60º, 57.17º, and 62.75º correspond to (220), (311), (400), (422), (511), and (440) Bragg reflection planes, respectively, and identified that Fe_3O_4 nano particles have a Face centred cubic structure. The crystallite size was estimated by power diffraction patterns from the measurement of half-height width of the strongest reflection plane (311) using Debye-Scherrer formula and equals 16nm.

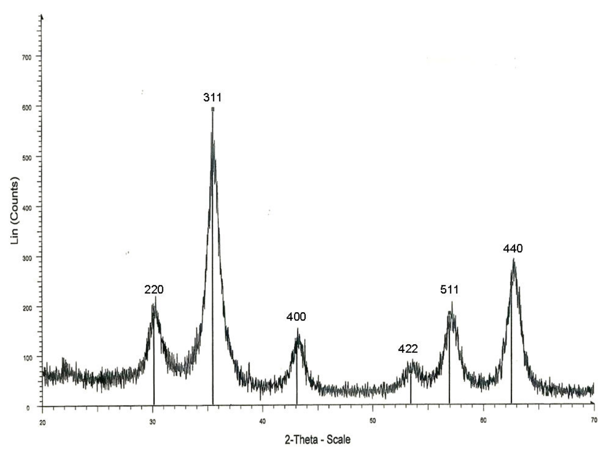

Figure 1: X-Ray Diffraction Measurement of synthesised Nano particles

3.2 Transmission Electron Microscope

In order to observe morphology and confirm the results of XRD measurements on particle size, a TEM micrograph of Fe_3O_4 particles was made.

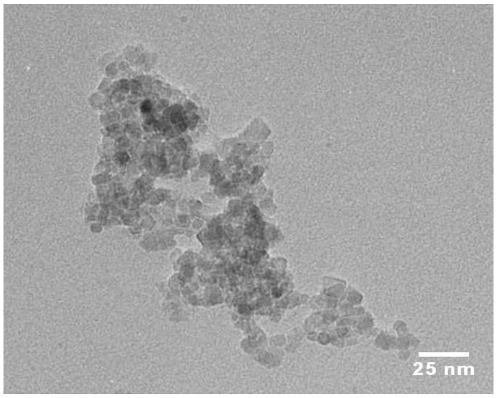

Figure 2: Transmission electron micrograph of magnetite

Figure 2 reveals, the Fe_3O_4 powder of is almost of single particles, though their morphology is somewhat irregularly shaped from oval to sphere. The average size of the particles calculated using ImageJ software is ~15 nm.

3.3 Rheological Properties

Figure 3 presents plotted profiles of shear viscosity vs. shear rate obtained for the studied sample. It is noted, the characteristic tendency of a pseudo-plastic shear thinning fluid. On the application of the magnetic field, a significant rise in apparent viscosity is observed.

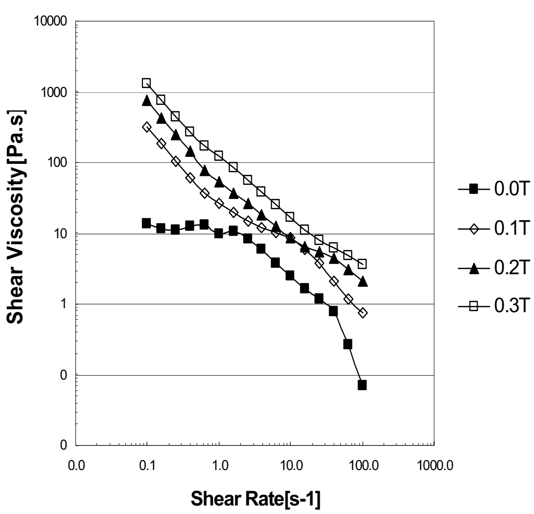

Figure 3: Rheological measurements under steady shear flow under different magnetic fields strength for MR fluid

Varying intensity of the applied magnetic field, from 0.1 to 0.3 T, the rheological profile is shifted to higher values of viscosity, for the whole range of shear rate tested, this meaning that there is a notable influence of the magnetic field on the flow behavior of the fluid.

4 CONCLUSION

A new MR fluid was prepared by mixing nanosized magnetite particles with micro sized iron particles in a polymer matrix. The nanoparticles were prepared by co-precipitation technique and characterized by XRD and TEM. Rheological properties of MR fluids were studied in the presence of varying magnetic field. It is observed that, varying the magnetic field has a significant effect on the viscosity of MR fluid, due to the induced particle alignment. The results to date are being used to design MR fluids of specific properties to suit different applications.

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