STATISTICAL ANALYSIS OF BIMODAL MRP FLUID USING RSM

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CERTIFICATE

This is to certify that report entitled **“STATISTICAL ANALYSIS OF BIMODAL MRP FLUID USING RSM”** by **Ms. MANEESHA,** is the requirement of the partial fulfilment for the award of Degree of **Master of Technology (M. Tech.)** in **Production Engineering** at **Delhi Technological University**. This work was completed under our supervision and guidance. He has completed his work with utmost sincerity and diligence. The work embodied in this project has not been submitted for the award of any other degree to the best of my knowledge.

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ABSTRACT

Bimodal magnetorheological polishing (BMRP) fluid samples have been synthesized in the present study. BMRP fluid samples contain two types of carbonyl iron powder of CS and HS grades in different volumetric proportions. Carbonyl iron powder of CS grade varies from 14 vol% to 20 vol% and HS grades varies from 0 vol% to 6 vol% while silicon carbide abrasives with 800 mesh size has been kept fixed at 25 vol% and rest is base fluid. Design of experiment (DOE) with three factors and five levels has been used to develop the experimental plan for investigating the effects of process parameters on the response. The magnetorheological characterization of BMRP fluid samples have been carried out on (Anton Paar MCR301 with MRD 180 attachment) magnetorheometer at different current level. The response such as yield shear stress, maximum shear stress and maximum viscosity has been statistically analyzed using response surface methodology. An effective second order response surface model for the response was obtained with significant factors and their interactions.

Keywords: BMRP fluid, DOE, RSM, Characterization, Optimization.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

MR	Magntorheological
BMRPF	Bimodal MR polishing fluid
MAF	Magnetic abrasive finishing
MRF	MR finishing
MRAFF	MR abrasive flow finishing
MAP	Magnetic abrasive particles
RSM	Response surface method
VOL	Volume
SiC	Silicon carbide
CIP	Carbonyl iron powder
°C	Degree Celsius
ANOVA	Analysis of variance
%	Percent
MRNF	MR nano fluids
MNF	Magnetic nano particles
Wt	Weight
FF	Ferro fluids
TEM	Transmission electron microscopy
VSM	Vibration sample magnetometer
MRD	Magnetorheological device

PS	Polystyrene
XRD	X-ray diffraction
B	Magnetic flux
SEM	Scanning Electron microscopy
DOE	Design of experiment

Chapter 1 Introduction

In engineering components, surface finishing is considered to be an important factor in functional properties, such as power losses and wear resistance because of friction. There are various surface finishing techniques available for the final production of components having complicated shapes. The conventional finishing methods such as lapping and grindings are found to be unsuitable for smooth finishing of inner pipe surfaces having high purity piping systems which are used in aerospace components ,medical equipments, etc. This is necessary in order to prevent any kind of contamination of liquid and gas.

Nowadays, magnetic field controlled machining processes are getting much importance in deburring , cleaning , and super-finishing of metals as well as newer engineering materials. Magnetic abrasive finishing (MAF), Magnetorheological finishing (MRF), and Magnetorheological abrasive flow finishing (MRAFF) comprise of a group of non conventional machining processes wherein cutting forces are controlled by magnetic field. Magnetic abrasives that are produced by the various techniques are used as cutting tools. Magnetic field controlled machining processes are very environmental friendly as well as promising new technology with high efficiency amongst the other non conventional finishing processes, with low energy consumption as well as less cost, along with automation feature. Hence, these techniques are best suited for finishing surfaces of complicated parts which are not easy to reach by the available conventional techniques. This process have the ability to produce good surface quality of the order of approximately a few nano meters finish on flat, alongwith external and internal surfaces consisting of cylindrical type workpieces. MAF has multiple advantages such as controllability, self-sharpening, etc. Moreover, the finishing tool requires neither dressing nor compensation.

The magnetic abrasive particles (MAP) are considered to be the most significant parameter in the magnetic field assisted finishing process. The magnetic abrasive particles consist of ferromagnetic particles and hard abrasive particles. In the machining area upon application of magnetic field, the abrasive particles that are adhered to the ferromagnetic particles follow the motion of the ferromagnetic particles, and thus, the finishing is done. The area which has to be machined, the magnetic field is applied due to which the abrasive particles that are adhered to the ferromagnetic particles follow the motion of the ferromagnetic particles, and thus, the finishing is done. Researchers are found to have suggested multiple methods for MAP preparation, like, simply mixing method, bonding or alloying method, sintering method, gas atomization with rapid solidification, laser sintering method, etc.

1.1 Magnetorheological fluids

Magnetorheological (MR) fluids are defined as suspensions of micron-sized magnetizable particles (like, iron) present in a nonmagnetic carrier fluid (like, oil or water). The most essential characteristic of these fluid materials is that they can be reversibly and rapidly varied from a Newtonian-like fluid state to a stiff semisolid state under the application of a moderately strong magnetic field. This feature, known as the MR effect, is a direct consequence of the fact that, in presence of any magnetic field, the particles magnetize and thereby, form chain-like structures which align in the direction of applied field. This is depicted in Figure 1.1. The columnar microstructure, in turn, dramatically results in the increment of its resistance due to applied shear strain.

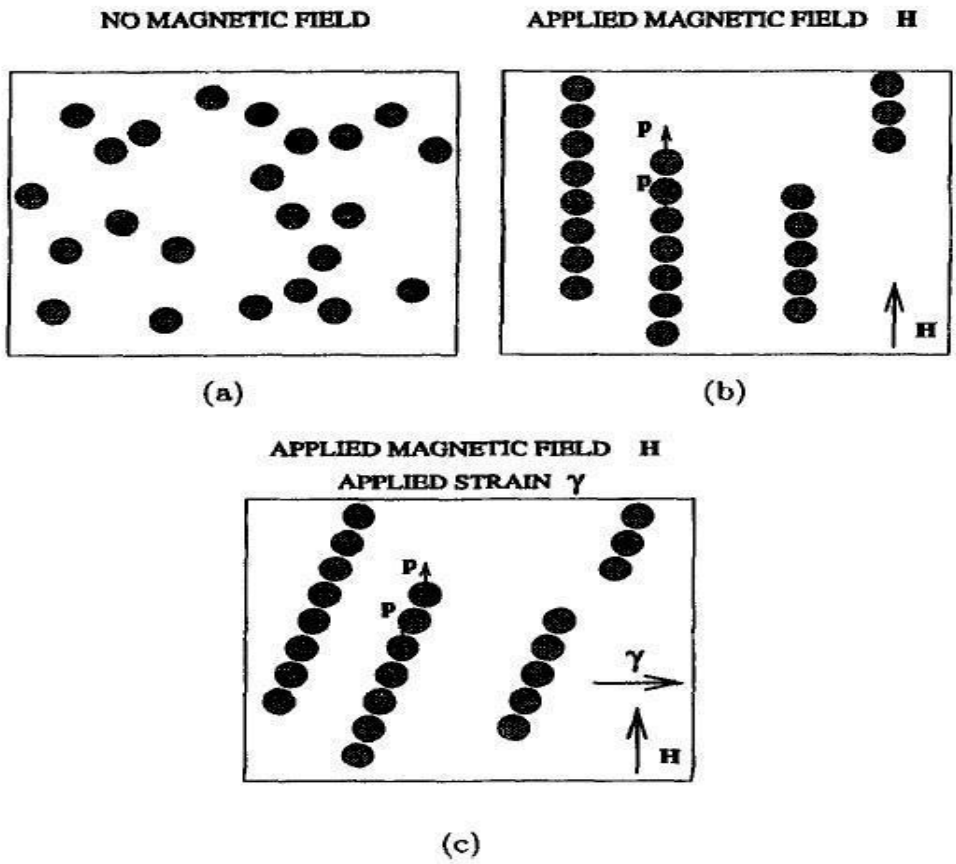


Fig.1.1 (a) behaviour of fluid flow in absence of magnetic field (b) the flow pattern of fluid after application of magnetic field (c) microstructure of MR fluid on application of shear strain rate [12]

This feature is the inspiration behind the design of new technology as well as various products such as brakes, clutches, semi active dampers, and numerous other robotic control systems.

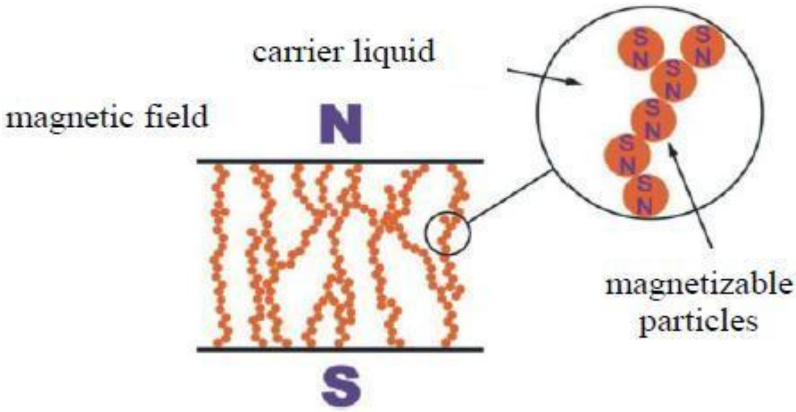


Fig.1.2 MR fluid in presence of magnetic field [13]

A typical MR fluid includes certain special additives like anti wear agents and surfactants that enhance its performance in the devices based on MR fluid. These additives may result in the formation of a nonmagnetic layer upon the inclusions which keep them from actually touching. The minimum inter-particle distance affects over the entire magnetic properties of the fluids. Analysing the magnetic response of the MR fluids and their dependence on the microstructure is very important for the design of improved MR fluids. Hence, the study of the effective magnetic properties of the fluids as a function of minimum inter-particle distance is crucial. Prediction of the magnetic properties of the fluids, however, is a very challenging task because of the oscillatory and highly nonlinear nature of magnetization of the constituents. As stated earlier, characteristic size of the particles is of several orders of magnitude lesser than the characteristic size of a sample, thereby, rendering standard finite element modelling to be impractical.

1.2 Properties of magnetorheological fluids

Typical magnetorheological fluids are nothing but micron sized, magnetic particles (mainly iron) suspended in an appropriate non magnetic carrier liquid like, mineral oil, synthetic oil, water or ethylene glycol. Here, the carrier fluid serves as the dispersed medium and ensures homogeneity of the particles in the carrier fluid. A number of additives (surfactants and stabilizers) are used for prevention of gravitational settling and promotion of stable particles suspension, change initial viscosity of the MR fluids and enhance lubricity. The stabilizers are utilized to keep the particles suspended in the carrier fluid, while the surfactants are adsorbed on surface of these magnetic particles in order to enhance polarization induced in these suspended particles on the application of magnetic field.

Typically, diameters of these magnetizable particles lie in the range of 3 to 5 microns. The functional MR fluids may be made with relatively larger particles. But, stable suspension of particles becomes more and more difficult as the size increases. The commercial quantities of relatively less costly carbonyl iron are commonly limited to sizes which are greater than 1 or 2 microns. The smaller particles which are easier to suspend could have been used, but manufacture of such particles is quite difficult. Significantly smaller ferromagnetic particles are mostly only available as oxides, like pigments that are commonly found in the magnetic recording media. The MR fluids that are made from such pigment particles are found to be quite stable because such particles are mostly only 30 nanometers in diameter. The main parameters of these fluids are presented in the table 1.1 below.

Table-1.1: Parameter of MR fluid

Property	Typical value
Initial viscosity	0.2-0.3 [Pa-s](at 25)
Density	3-4(g/)
Magnetic field strength	150-250(kA/m)
Yield point	50-100(kPa)
Reaction time	Few milliseconds
Typical supply voltage and current density	2-25 V, 1-2 A
Work temperature	-50 to 150

However, due to their lower saturation magnetization, those fluids that are made from these particles are typically limited in strength upto about 5 kPa and also, have a large plastic viscosity because of the large surface area.

When not under the influence of an applied field, MR fluids are well approximated as Newtonian liquids. It is found that for most engineering applications a Bingham plastic model is considered most effective at describing the quintessential, field-dependent characteristics of this fluid. A Bingham plastic is nothing but a non-Newtonian fluid in which the yield stress must be exceeded prior to initiation of flow. Thereafter, it is observed that the rate-of-shear vs. the shear stress curve is linear.

1.3 Disadvantages of conventional MR fluid:

- The large micron sizes of the particles are generally responsible for the settling due to gravity when the fluid is not in use for considerable time. However, introduction of another small size of particles (1.75) results in the improvement of the colloidal stability.

- It is observed with the help of microscope that under the influence of moderately strong magnetic field, the structural micro cavities are formed due to the association of micron sized magnetic particles. This results in the aggregation of the magnetic particles.

In order to overcome these disadvantages, the Bi-Modal MR fluids are used. The diffusion of small size micron sized magnetizable particles into the MR fluid is known as bi-model fluid.

1.4 Advantages of bimodal MR fluid over conventional MR fluid:

In the conventional MR fluids, under the influence of moderately strong magnetic field, association of micron sized magnetic particles results in the formation of micro cavities. But in the bi-modal fluids, these micro cavities are found to be filled by another small sized micron particle. The inclusion of other small micron size particles restricts field induced aggregation of micron sized magnetic particles. This leads to phase separation.

- The inclusion of another micron sized particles increases the re-dispersibility and reduces the sedimentation of the CIP Particles due to the dipole-dipole interaction.

- The inclusion of the micron sized particles increases shear yield stress and the viscosity of fluid.

- Amongst the various MR materials, it is observed that carbonyl iron (CI) has been used widely as a magnetizable particle for MR fluids because of its soft magnetic property, high magnetic permeability and common availability. However, its high density results in the serious sedimentation as well as poor re-dispersibility drawback and also, abrasion within the equipment. Most of the CI based MR fluids face an issue of sedimentation of the suspended particles due to the mismatch to the MR fluids for application in industrial purposes. Shear yield stress and the viscosity of conventional MR fluid are found to be less than the bimodal fluid due to the aggregation of its CIP particles.

1.5 Applications

Beginning of commercialization of MR technology dates to the year 1995 and the use of rotary brakes in aerobic exercise equipment. From this moment, it can be emphasised that the application of magnetorheological material technology in the real-world systems has grown up steadily. During the recent few years, a good number of products which are or near commercialization or commercially available have been developed, For example,

- The linear MR dampers in heavy duty trucks for use in real-time active vibrational control systems,
- The linear and rotary brakes for low-cost, positional, accurate and velocity control of the pneumatic actuator systems,
- The rotary brakes in order to provide tactile force-feedback in the steer-by wire systems,
- The linear dampers for the real-time gate control in the advanced prosthetic devices,
- The adjustable real-time controlled shock absorbers for the automobiles,
- The MR sponge dampers for use in washing machines,
- The magnetorheological fluid polishing tools,
- The very large MR fluid dampers for use in seismic damage mitigation, and in civil engineering structures,
- The large MR fluid dampers in order to control the wind-induced vibrations in the cable-stayed bridges.

1.6 Modes of MR fluid

(1) The valve mode;

(2) The shear mode;

(3) The squeeze mode;

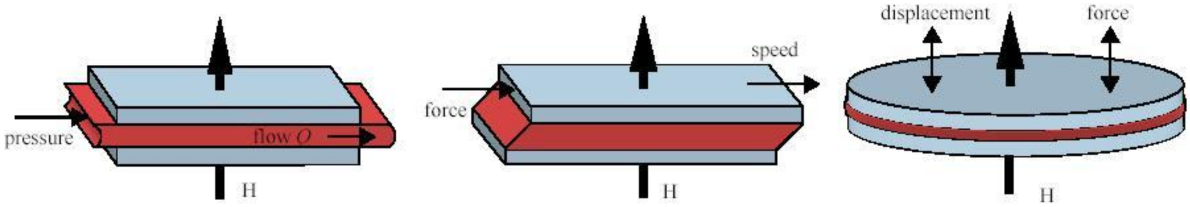


Fig.1.3 (a) valve mode (b) shear mode (c) squeeze mode

The MR brake operates in direct-shear mode, by shearing the MR fluid which fills the gap between the two surfaces (rotor and housing) moving with respect to each other. The rotor is fixed to shaft, which is placed in the bearings and can be rotated in relation to the housing. The resistance torque in MR brake depends on the viscosity of MR fluid which can be changed by the magnetic field. The MR brake allows for the continuous control of the torque. When no magnetic field is applied, the torque is caused by the viscosity of the carrier liquid, seals and bearings. MR brake is well suited especially for a variety of applications which includes precision tension control, pneumatic actuator control as well as haptic force feedback in applications like steer-by-wire. The MR clutch which is similar to the MR brake operates in direct-shear mode and transfers the torque between the input and the output shaft. There are two main types of constructions of MR clutch:

(1) Cylindrical, and

(2) Frontal.

In cylindrical model, the MR fluid works between two cylinder-like surfaces and in the frontal model, MR fluid fills the gap between the two discs. During work, the magnetic field produced by the coils increases the viscosity of fluid and also, causes transfer of the torque from the input to the output shaft. The useful torque is available only after 2-3 milliseconds from the time of stimulation. The MR dampers are semi-active devices which contain the magnetorheological fluids. After the application of magnetic field, the fluid changes from the liquid to the semi-solid state in a few milliseconds, hence, the result is an infinite variable, controllable damper which is capable of relatively large damping forces. The MR damper offer attractive solutions to energy absorption in the mechanical systems and structures.

Hence, they can be considered as “fail-safe” devices.

Chapter 2 Literature Review

A literature survey is an indispensable and important module of any research project. It highlights the amount of study done in a specific chosen subject matter, pinpoints the gaps and flaws in the previous research, depicts the new scopes in that field of research which arises from those studies, shows the status of the research that is being carried out by the other contemporary research groups in the relevant field all around the world and eventually, saves funds, time and energy of a researcher from ending up in certain conclusions that have been found out already by some other research group at some other early point of time.

Ajay Sidpara [1] has proposed that MRF is based on a magnetorheological (MR) fluid that consists of carbonyl iron powder (CIP), polishing abrasives, water, and stabilizers. In order to understand and model this process with perfection, it is very important to study rheological properties (viscosity and yield stress) of the fluid under the influence of the magnetic field. Detailed study is conducted through the statistical design of the experiments (DOE) in order to characterize the rheological properties of the MR fluid. The three constitutive models viz. Herschel–Bulkley, Bingham Plastic and Casson fluid are used for the characterization of the rheological behaviour of the MR fluid. Response surface methodology (RSM) is applied to predict the effect of volume concentration of each component in MR fluid. Analysis of Variance (ANOVA) is carried out, and the contribution of each and every model term affecting the improvement in viscosity and yield stress is calculated. In order to estimate the saturation magnetization of the MR fluid, the M-H curve is plotted using vibrating sample magnetometer (VSM), and effect of temperature on yield stress and viscosity is discussed. Then the experimental results are thus discussed, and the optimum fluid composition is hence identified from the selected range. Based on the comparison of R2 values of all three constitutive models, the Hershel–Bulkley model better represents the experimental data obtained from the rheometer than Bingham Plastic and Casson Fluid, so it can be used for modelling the MR fluid in fluid flow analysis and simulation. From the ANOVA analysis by obtaining data from experiment performed on magneto rheometer, it is observed that magnetic field has the highest contribution on the yield stress and viscosity of the MR fluid, and it is 92.72% and 49.95%, respectively, among all the main factors and their interaction terms. Based on optimization study, higher yield stress and viscosity is obtained at 38%, 4%, 52% of CIP, abrasive, deionized water, respectively, and 0.6T magnetic field. The results of the experiments on MR fluids show that an increase in the volume fraction of CIPs and the magnitude of the magnetic field gives higher yield stress value. However, an increase in the water concentration leads to a decrease in the yield stress as well as viscosity.

Effect of temperature on yield stress and viscosity were discussed based on experimental results. Change in temperature significantly affects the physical structure of the MR fluid, which in turn impacts on the response parameters. Experimental results are fitted with Bingham Plastic, Casson fluid and Herschel–Bulkley.

Ajay Katiyar [2] has reported that magneto-rheological nano fluids (MRNF) can be implemented in a variety of smart actuation systems including fluid clutches, optics finishing, sealing, aerospace, automotive and civil damping applications. The system based on magneto-rheological nano fluids might prove itself an advanced step in the design of products with power density, dynamic performance and accuracy as key features. Also, for products that require controlled fluid motion by varying the viscosity, the structure that is based on the magneto-rheological nano fluids might be an improvement in cost and functionality. The research paper is mainly concerned with the preparation of paraffin oil based nanofluid containing varying percentages of Fe–Ni nano particles of (≤15 nm) size and study of their magneto-rheological behaviour. The results show big influence of particle concentration and magnetic field on the yield stress and viscosity. The optimum value of the concentration of particle is obtained as 10 wt.% of Fe–Ni within the range of magnetic flux density of 0 to 1.2T. The maximum yield stress and viscosity achieved for 10 wt.% of Fe–Ni nanoparticles are 240Pa and 2910 Pa s respectively at 1T magnetic field.

The Fe–Ni nanoparticles dispersed in paraffin base oil along with a mixture of ethanol amines and suitable stabilizers reveal good stability under applied magnetic flux density (up to 1 T). The effect of particle concentration on viscosity of MRNF under applied magnetic

flux density demonstrate that the MRNF containing more than 8.0 wt.% of Fe–Ni nanoparticles shows a remarkable increase in the viscosity ranging from 100 Pa s to 3080 Pa s. The MRNF containing 10 wt.% of Fe–Ni nanoparticles also show a remarkable increase in yield stress from 10 Pa to 240 Pa, when the applied magnetic flux density increases from 0 to 1 T. Hence ~24 times enhancement in Bingham property is noticed for magneto-rheological nanofluid containing 10 wt.% of Fe–Ni nanoparticles at 1 T magnetic field. Thus the prepared MRNF could find application in damping and nano finishing.

Rajesh Patel [3] aimed to microscopically observed the chain formation mechanism in magnetic nano-fluid based magneto-rheological (MR) fluid is distinct than that of the conventional MR fluid. The magnetic nanoparticles are filled inside the structural micro cavities formed during the mechanism of chain formation of large magnetic particles, while some of these magnetic nanoparticles are attached at the end of the chains formed by the large particles when external magnetic field is applied. The dipolar energy of the neutral medium becomes effective magnetic permeability ( ) times larger than that of the large particles in a magnetic nanofluid matrix. The aggregation of large particles restricts due to inclusion of magnetic nano particles (10nm) with large magnetic particles (3–5 μm), which results in field induced phase separation in MR fluids. Hence, the stability of MR nano-fluids are more than that of conventional MR fluid, which subsequently increase their application potentiality.

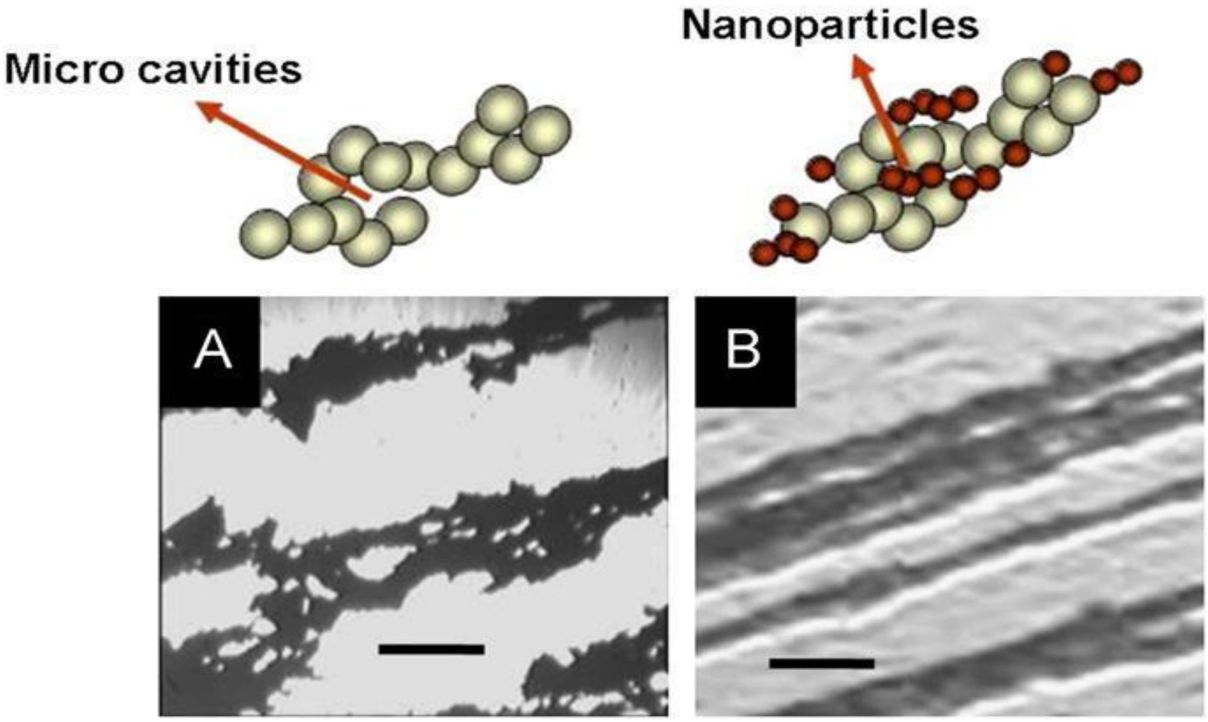


Fig. 2.1 (a) Shows magnetically induced chain formation in conventional MR fluid; micro cavities are observed. (b)In a bidispersed MR fluid with nano magnetic particles, nano particles fill the micro cavities and are also attached at the end of large particles [3]

The fig. 2.2 shows the magnetically induced linear chain like structures in conventional MR fluid. In this high networking of micron size magnetic particles, some micro cavities are visible. In the nano- fluid based MR fluids, due to dipolar interactions, small particles are attached to the large particles and subsequently fill the micro cavities in the linear network formed by large particles. The figure shows the field induced linear structure in nanofluid based MR fluid where micro cavities are not visible as they are filled by the small particles.

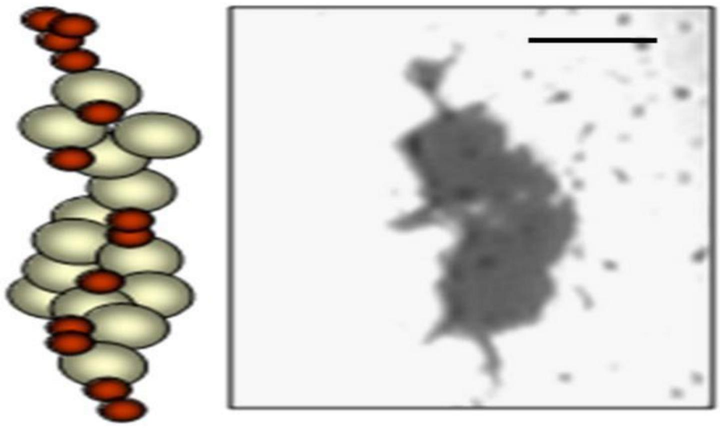


Fig.2.2 Schematic and microscopic pictures of magnetic field induced chain of micron size particles with attached magnetic nano particles at both ends [3]

It shows a microscopic realization of the prediction that when a small particle is a member of a chain, it is predominantly attached to the end of the chain. It is observed that small particles are attached at both ends of the chain formed by large particles and micro cavities are also filled by small particles.

In this bidispersed system, the magnetic nanoparticles and micron size magnetic spheres are of the same family (i.e. iron oxide). Due to the dipole–dipole interactions, the individual dipoles are arranged in a head to toe manner and tend to form a string like structure in the direction of the force field. The dipole moment of a magnetic particle is proportional to its magnetic core volume. Due to the presence of micron size magnetic spheres in a ferrofluid the aggregation parameter calculated for ferrofluid is

$\lambda = (\mu_0 M_S H \pi d^3)/6 k_B T$

where µ -saturation magnetization of the particles

H- free space permeability and applied magnetic field

- Boltzmann constant

T- absolute temperature

The coupling is the key quantity that determines the equilibrium structure of a suspension of magnetic particles as a function of applied magnetic field. The coupling parameter for micron size particle is very much larger than that of nanomagnetic particles which suggests that the dipolar interaction between the micron size magnetic particles is much stronger than that for nanomagnetic particles. The current microscopic study shows that when a small particle is a member of an MR fluid it attaches at the end of the field induced chain formed by the large particles and fills the cavities formed by high networking of large particles. Dipolar interactions and energy considerations also agree with the experimental observations. It is also observed that micron size particles show large response at low magnetic field and magnetic nanoparticles of ferrofluid shows low response even at large field value. Small particles attached at the end of the chains formed by large particles reduce the aggregation of large particles, which can cause the phase separation and subsequently gives more stability to the nanofluid based MR fluid than the commercially available mono dispersed MR fluids.

R.Y. Hong [4] reported that Ferro fluids (FFs), prepared from Fe_3O_4 ferromagnetic nanoparticles (FMNPs) by ball milling and agitation, were characterized using a rotating rheometer and a capillary rheometer. The effects of temperature and surfactant dosage on the viscosity of dilute FFs were measured using the capillary rheometer. Rheological properties of the high-concentration FFs, which are prepared using high-energy ball mill were measured by using a rotating rheometer. Yield stress under the applied magnetic field was also obtained using rotating and capillary rheometers. The constitutive equations of the FFs with/without applied magnetic field were correlated using the Herschel–Bulkley (H–B) model. Finally, a general constitutive equation of the shear stress was proposed, and thereby, a theoretical model for the yield stress threshold under the applied magnetic field was derived and was compared with experimental measurements.

By experimental measurement and theoretical analysis, we can draw the following conclusions:

(1) FMNPs could be dispersed in water by adopting bilayer-surfactants with proper dosages and using a high-energy ball mill. The obtained FFs with high solid content demonstrated excellent stability.

(2) For low-concentration FFs, the dominating factor influencing the viscosity is the temperature.

(3) FFs with moderate or high solid content demonstrated the shear-thinning behaviour.

(4) FFs even with high solid content could be described by the H–B model, every time when the FF is found to be subjected to the applied magnetic field or not.

(5) FMNPs exist as aggregates in FFs and these aggregates further formed chaining structure under applied magnetic field. Based on chaining structure of the FFs, a theoretical model was derived to predict the yield stress of FFs under applied magnetic field.

(6) A general constitutive equation was proposed to calculate the shear stress of FFs subjected to applied magnetic field. Other kinds of FFs were prepared and characterized, and similar rheological properties were obtained.

Hyoung Jin Choi [5] reported that most magnetic materials possess serious sedimentation problem due to their large density when they are adopted as magnetorheological (MR) materials. They fabricated novel core–shell structured polystyrene (PS)/ Fe_3O_4 micro beads via a facile method, in this communication. Porous morphology of the PS that is obtained by etching silica particles and the loaded Fe_3O_4 was observed via both TEM and SEM images. XRD pattern confirms the crystalline structure of the as-synthesized iron species. The VSM data indicate the change in the saturation magnetization before and after introducing organic PS core. Finally, MR performances of the PS/Fe_3O_4 based MR fluid were investigated via a rotational rheometer and sedimentation stability was found to be improved with a decreased density of the synthesized micro beads. In this work, novel PS/ Fe_3O_4 particles with micro porous PS as a core material and Fe_3O_4 as a shell material were prepared to improve sedimentation stability for the MR fluid. Micro porous structure of the PS spheres along with the loaded Fe_3O_4 particles on the surface was confirmed via SEM/TEM image. In this work, novel PS/Fe_3O_4 particles with micro porous PS as a core material and Fe_3O_4 as a shell material were prepared to improve sedimentation stability for the MR fluid. Micro porous structure of the PS spheres along with the loaded Fe_3O_4 particles on the surface was confirmed via SEM/TEM images. XRD pattern verifies the accurate crystalline structure of synthesized Fe_3O_4 particles. VSM graph indicates that introducing hollow PS spheres makes saturation magnetization decease from 57 emu/g for pure Fe_3O_4 to 27 emu/g for PS/Fe_3O_4 composite particles. Although MR characterization exhibits lower shear stress value compared with pure Fe_3O_4 based MR fluid, the typical MR behaviour was well preserved. Further effort should be paid on fabricating PS/Fe_3O_4 composite particles with much smaller PS core and thicker Fe_3O_4 layer which is considered to be a crucial role in presenting superior MR properties. Finally, the sedimentation rate was noted to get much improved due to the decreased density mismatch between PS/Fe_3O_4 composite particles (1.90 g/cm^3) and medium oil (0.96 g/cm^3).

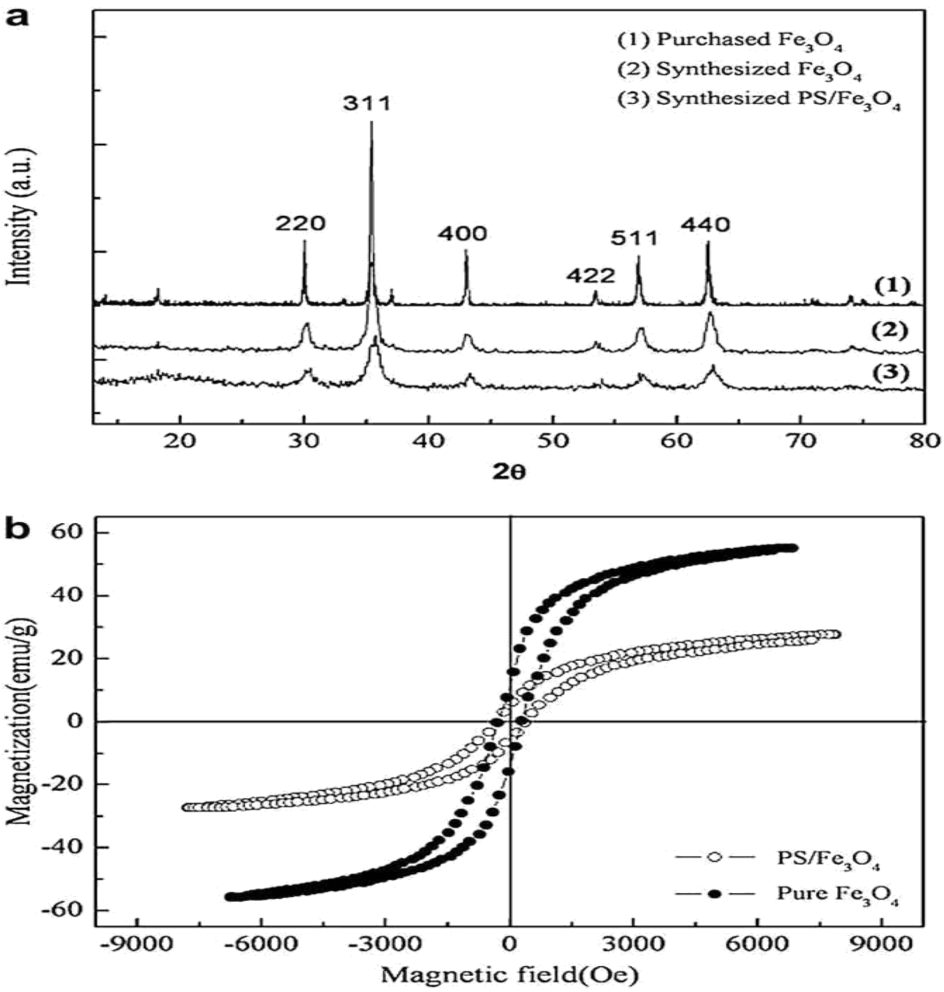


Fig.2.3 (a) XRD pattern of purchased Fe_3O_4(1), synthesized Fe_3O_4(2) and PS/Fe_3O_4 particles (3), and (b) VSM data for pure Fe_3O_4 (closed symbol) and PS/ Fe_3O_4 particles (open symbol) [5]

Hyoung Jin Choi [6] reported that the Magnetic nano-sized carbonyl iron (CI) particle was prepared and adopted as an additive for micron-sized CI based magnetorheological (MR) fluid, in which the magnetic nanoparticle was fabricated via decomposition of penta carbonyl iron ($Fe(CO)_5$). Magnetic property and morphology of the nanoparticle were confirmed via vibration sample magnetometer (VSM) and transmission electron microscopy (TEM), respectively. MR fluids, consisting of micron-sized CI and carrier fluid, were thoroughly investigated under the different external magnetic field strengths via a rotational rheometer. Their flow behaviours at a steady shear mode were examined with and without a nano-sized magnetic additive under magnetic field strength. The MR fluid with magnetic CI nanoparticle added demonstrated slightly higher yield behaviours, suggesting that micron-sized CI and magnetic CI nanoparticle particle were being oriented in magnetic field direction under applied magnetic field and with strengthened structure.

Magnetic nanoparticle was synthesized and then added into the micron-sized CI based MR fluid. The MR fluid with magnetic CI nanoparticle added demonstrated slightly higher yield behaviours and higher shear stresses in a broad range of shear rate, suggesting that micron-sized CI and magnetic CI nanoparticle were being oriented in magnetic field direction under applied magnetic field and with strengthened structure.

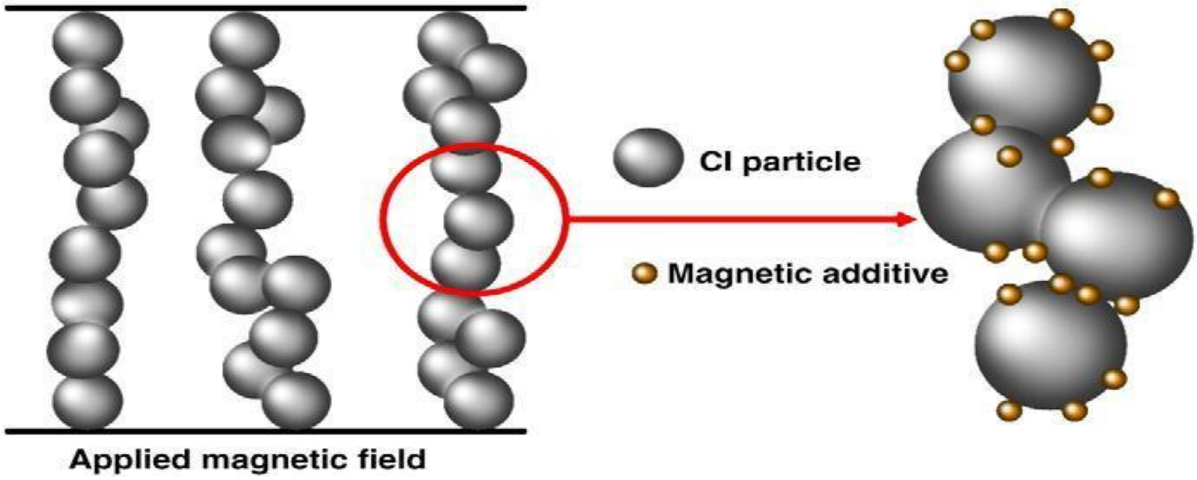


Fig.2.4 Schematic diagram of chain formation of micron-sized CI and magnetic nano particle additive in MR fluid [6]

Hadi Hezaveh [7] has purposed to synthesis and rheological behaviour of Fe_2O_3 magnetic nanoparticles ferro fluids in paraffin base as well as their magneto viscous effects has been investigated. In order to prepare the ferro fluids, ball mill and ultrasonic bath were used. Then rheological behaviour of the system was studied using a standard rotating rheometer. Oleic acid was used to stabilize ferro fluids. Also the effect of magnetic field on the fluid was analysed. However, this increase in viscosity is limited to the specific rate of the magnetic field. Moreover, a novel correlation for the prediction of temperature dependency of fluid has been presented.

In this study, synthesis of Fe_2O_3 magnetic nanoparticles and their rheological properties in paraffin base fluid have been investigated. Also, magneto viscous effects of the system have been reported. Using ball mill and ultrasonic bath, ferro fluids have prepared and oleic acid was used to stabilize them. The experiment shows that in low concentrations, ferro fluids behave almost Newtonian; however they become non-Newtonian by increasing nanoparticles concentration. Moreover, a novel correlation for prediction of temperature dependency of fluid has been presented. Shear thinning behaviour of the system shows that as shear rate increases, the particles begin to find new direction as per the stress applied. Moreover, by increasing the shear rate, the agglomeration in the system gradually vanishes and viscosity decreases. Investigations reveal that on application of the magnetic field, the viscosity increases significantly at constant shear rate. However, this increase in viscosity is found to be limited to a specific rate of the magnetic field. It is shown that small magnetic field can even make noticeable changes in the viscosity of the ferro fluids.

L.Ve´ka´ s [8] has aim for this paper is to investigate In this paper we investigated the rheological and magneto rheological behaviours of an extremely bidispersed (nano–micro) magnetizable fluid (sampleD1) for comparison of a commercial magnetorheological fluid (MRF-140CG; LORDCo. (USA)) with the same magnetic solid volume fraction, by means of the Physica MCR-300 rheometer with a 20 mm diameter plate–plate magnetorheological cell (MRD180). D1 sample is a suspension of micrometer range Fe particles in a transformer oil based magnetic fluid as the carrier. For both the types of samples, these experimental data for zero and non-zero magnetic field conditions were fitted to equations derived from the Newtonian and Cross type flow equations, and also, the Herschel–Bulkley model. The primary advantage of both the rheological equations for the quantitative description of the magnetic field behaviour of samples is that they can be used in regular CFD codes to compute the flow properties of the magnetorheological fluid and of the bidispersed magnetizable fluid for practical applications.

R.Y. Hong [9] has reported that the Magnetic nanoparticles were synthesized by the co-precipitation of Fe^{2+} and Fe^{3+} using ammonium hydroxide NH_4OH). The obtained nanoparticles were characterized by X-ray powder diffraction, scanning electron microscopy, transmission electron microscopy, Fourier transform infrared (FT-IR) spectroscopy and vibrating sample magnetometer. For preparation of a bio compatible water-based magnetic fluid, a two-step method is used to modify the nanoparticles by dextran. The influences of this dextran molecular weight on the morphology, size, coating efficiency and magnetic property of magnetite/dextran nano composite were studied. The magnetite/dextran nano composite was dispersed in water to form a magnetic fluid by means of ball milling. Rheological property of the magnetic fluids was investigated using a rotating rheometer.

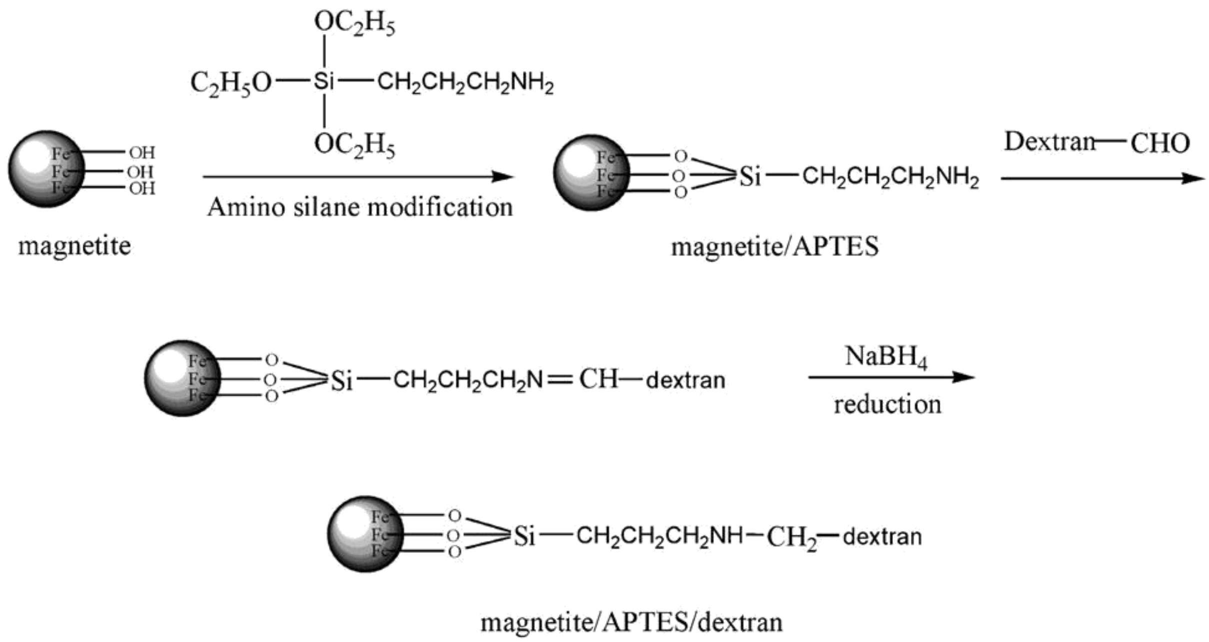


Fig.2.5 Synthesis route for the dextran-coated magnetite nanoparticle [9]

By physical characterization and chemical synthesis in the present investigation, the following conclusions can be drawn.

(1) Magnetite/dextran nano composite was prepared through a two-step method. This route comprises of the first introduction of amino-silane group onto the magnetite surface and the second coupling of oxidized dextran via formation of Schiff's base.

(2) The molecular weight of dextran plays an important role on the size, morphology, coating efficiency, and magnetic property of MNPs/aggregates.

(3) The surface modification of MNPs with dextran is propitious to the stability of MF. The viscosity of MF increases with the increasing molecular weight of dextran.

(4) An external magnetic field can enhance the interaction among MNPs, therefore, the viscosity of MF increases under the external magnetic field. The magnetic field could also rearrange the MNPs, leading to the formation of orderly microstructures. In the absence of magnetic field, viscosity of the MF increases linearly with the solid content. On the application of an external magnetic field, the viscosity increases quadratically with the solid content.

(5) Our previously proposed constitutive equation is recommended for describing the rheological property of the water-based MF containing dextran-coated MNPs.

G.R. Iglesias [10] aimed to investigate the stability and re-dispersibility of magnetorheological fluids (MRFs). These are disperse systems where the solid is constituted by ferro- or ferri-magnetic microparticles. On the application of the external magnetic field, they experience reversible and rapid increases in viscosity and yield stress. The problem considered is initially of all the determination of their stability against sedimentation, an essential issue in their practical application. Even though this problem is generally faced through the addition of thixo-tropic agents to the liquid medium; they proposed the investigation of the effect of the magnetic nanoparticles addition, in this work, so that the dispersion medium is actually a ferrofluid. A volume fraction of the nanoparticles not higher than 3% is found to be enough to provide a long-lasting stabilization to MRFs containing above 30% iron micro particles. In the unavoidable event of settling, the important point is the ease of the re-dispersion of the sediment which is indirectly evaluated in the present investigation by means of measuring the penetration force in the suspension, by using a standardised hardness needle. Moreover, it is found that those nanoparticles' addition results in soft sediments by avoiding short-range attractions between the large iron particles. Ultimately, performance of the designed MRFs is evaluated by obtaining their steady-state rheograms for different volume fractions of magnetite and different magnetic field strengths. Yield stress is reported to be strongly field-dependent, and also, it can achieve the expected high values in standard magnetorheological fluids but with improved stability and redispersibility.

Using an inductance-based method for the evaluation of the sedimentation ratio of magnetorheological fluids, we have found that the addition of no more than 3% magnetite nanoparticles by volume to a suspension of micron-sized iron ones is sufficient to achieve stable magnetorheological fluids with high iron content (32%). In addition, a method based on the evaluation of the hardness of the sediment by measuring the force of penetration of a standard probe led us to the conclusion that the use of a ferrofluid as carrier liquid in our formulation avoids the formation of compact sediments during long shelf or storage periods. A volume fraction of nanoparticles as low as 1.55% v/v is enough to achieve such easy re-dispersibility. It is confirmed that the benefit of using a base ferrofluid comes from the protecting effect of nanoparticles surrounding the iron micro particles and avoiding short-range attractions between them, thus hindering the occurrence of compact sediments. Magnetorheological determinations indicate that the same addition of magnetite nanoparticles provides an excellent magnetorheological response, comparable to that obtained in more standard fluids, where the liquid carrier contains stabilizing and thickening compounds. On the contrary, an excess of nanoparticles (above 7% by volume) leads to a decline in the MR response of the fluids. This is likely the consequence of the formation of an excessively thick cloud of magnetite nanoparticles around the iron spheres, leading to a weaker magnetic interaction, probably lower than required for an optimum MR response.

Kruti Shah [11] has investigated the effect of a new kind of magnetorheological polishing (MRP) fluid was prepared using plate-like iron particles and non-magnetic abrasive silicon carbide particles with the same volume fraction and its field-dependent rheological properties. It has been shown that abrasive particles make the bonding structure around the cross-link chain like structure of iron particles under the application of the magnetic field. As a result, yield stress increases with the increase in the magnetic field which has been analyzed using three different models; Bingham plastic model, Casson model and Herschel-Bulkley model. The flow index in the Herschel-Bulkley model indicates shear thinning behaviour of fluid. It has been identified that in the Herschel - Bulkley model all data fit well with better ($R2$) value compared to Casson and Bingham model. Hence, the Herschel- Bulkley model is fit for the characterization of the magnetorheological polishing fluid. The shear thinning behaviour has been also observed at higher magnetic fields. Thereby, it is finally remarked that those results presented in this work can be usefully utilized to develop more advanced MRP fluid which may provide some higher precision processing.

2.2 Research Gap:

As thoroughly study of many research paper and journal summarized in literature review, it is found that the research is continuously on progress in the field of magnetorheological fluid.

MRP fluids are used for getting very high level of surface finish on the metal surface but there is a problem in conventional MR fluids due to settling down of large particles due to its density which are of micron size. Secondly the formation of structural micro cavities in the applied magnetic field during MR finishing. On the formation of structural micro cavities, decreases the value of yield shear stress. To reduce or eliminates the problem of formation of micro cavities, introduce very small size (micron size or nano size) particles so that they fill the micro structural cavities and enhance the value of yield shear stress of the MRP fluid so that surface finish of upto nano level can be obtained.

2.3 Motivation and objectives

High demand of magnetic abrasive particles is found for finishing purpose in electronics industries and aero space. The research objectives of present work is aimed on

- To Synthesis bimodal MRP fluid samples.
- Rheological characterization of MRP fluid at different current using the magnetorheometer.
- Statistical analysis of bimodal MRP fluid using response surface methodology.

Chapter 3 Experimental Work

Magnetorheological polishing fluids (MRP) are the mixing of normal MR fluid with the abrasive particles. MR polishing and conventional MR fluid are differing from each other only by the use of abrasive particles in the former fluid. By using the abrasives in the MR fluid, accuracy as well as higher surface finish can be achieved.

3.1 MR fluids:

Magnetorheological fluids (MRFs) are suspensions of micron- sized ferro- or ferrimagnetic particles in a carrier liquid. The suspended particles are magnetically multi-domain and perfectly soft; consequently an applied magnetic field induces the magnetic dipoles in each particle, which results in strong inter particle interactions. This results in the formation of a network of particles' aggregates throughout the entire suspension, and thus, the fluid's movement is restricted within a gap. The opposition force found to be proportional to corresponding magnetic flux density.

Components of MR fluid

1-Carbonyl iron powder-micro or nano size

2- Carrier fluid (water, synthetic oil)

3- Additives (fibrous carbon, silica, oleic acid etc.)

3.2 MR polishing fluid:

Magnetorheological polishing fluids (MRPFs) are suspensions of micron- sized ferro- or ferri magnetic particles along with abrasives in a carrier liquid. The suspended particles are magnetically multi-domain and perfectly soft and abrasives are hard; consequently an applied magnetic field induces the magnetic dipoles in each particle, which results in strong inter particle interactions.

Components of MR fluid

1-Carbonyl iron powder-micro or nano size

2- Non magnetic abrasive particles (aluminium oxide, diamond, silicon carbide etc.)

3- Carrier fluid (water, synthetic oil)

4- Additives (fibrous carbon, silica, oleic acid etc.)

3.3 Bimodal MR polishing fluid

Bimodal MRP fluid contain two types of carbonyl iron powder of CS and HS grades in different volumetric proportions along with base fluid and abrasive particles. Both the iron powder are of different sizes. The carbonyl iron powder of CS grade varies from 14 vol% to 20 vol% and carbonyl iron powder HS grade varies from 0 vol% to 6 vol% while silicon carbide abrasives with 800 mesh size has been kept fixed at 25 vol% and rest is base fluid.

3.4 Magnetorheometer:

The experiment of magnetorheological characterisation is performed on Magnetorheometer. The rheological properties of all these fluid samples are tested by using a stress-controlled rheometer (Anton Paar MCR301 with MRD 180 attachment), using parallel plate geometry with 20mm diameter and a gap of 1mm between parallel plates. The measuring plates are sand blasted (Fig. 3.1) to avoid the slippage of MR fluid with plate geometry due to rotation of the shaft of the measuring system, and it also prevents wearing out of the plate geometry due to the abrasive action of constituent particles in the MR fluid during experimentation.

Approximately, 0.315ml MR fluid is filled in a constant gap between parallel plates during the experiment as shown in Fig.3.2. The top plate rotates while the bottom plate remains stationary. A coil is placed below the bottom plate while flux returns are mounted above and around the upper disk, so as to complete the magnetic circuit. After putting the sample between the upper rotating plate and the stationary bottom plate, the magnetic circuit is closed using the flux returns. Homogeneous magnetic field and shear flow direction of MR fluid was set perpendicular to each other. Variation of shear rate is from 0 to 1000 per second for each experiment. A thermal unit is also incorporated into the MRD cell in order to maintain the temperature of the specific sample at a constant value. The value of temperature is keeping constant which is 25 during all experiments. During the rotation of the upper plate, the torque is measuring by using sensor, and thus, to compute the corresponding force that is applied onto the moving plate, and shows the shear stress value at a required point on the plate. The MRD cell enables application of magnetic flux density (B) up to 1 Tesla.

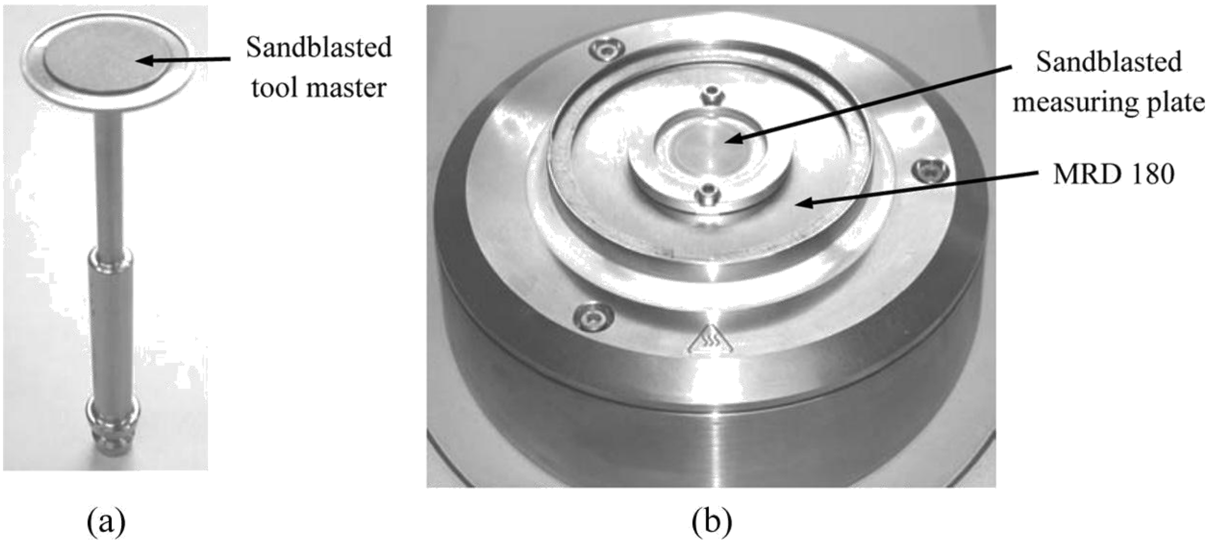


Fig.3.1 Sand blasted (a) tool master and (b) measuring plate with magnetorheological device (MRD 180) [1]

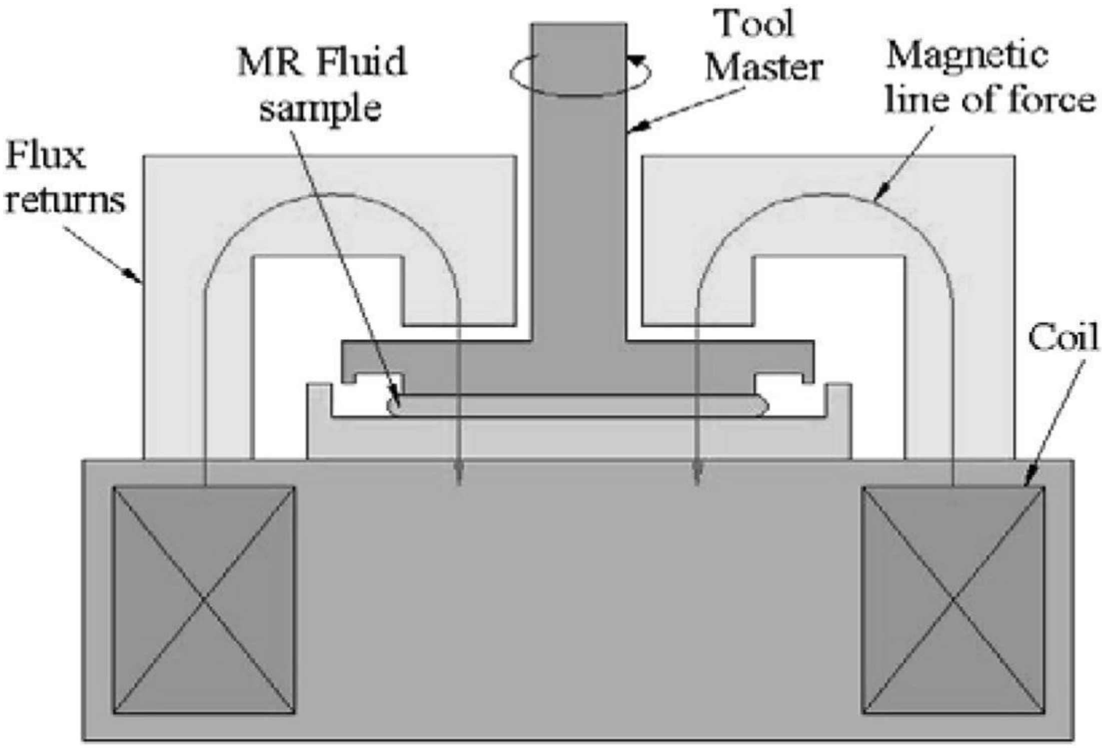


Fig. 3.2 Schematic diagram of MCR 301 rheometer [1]

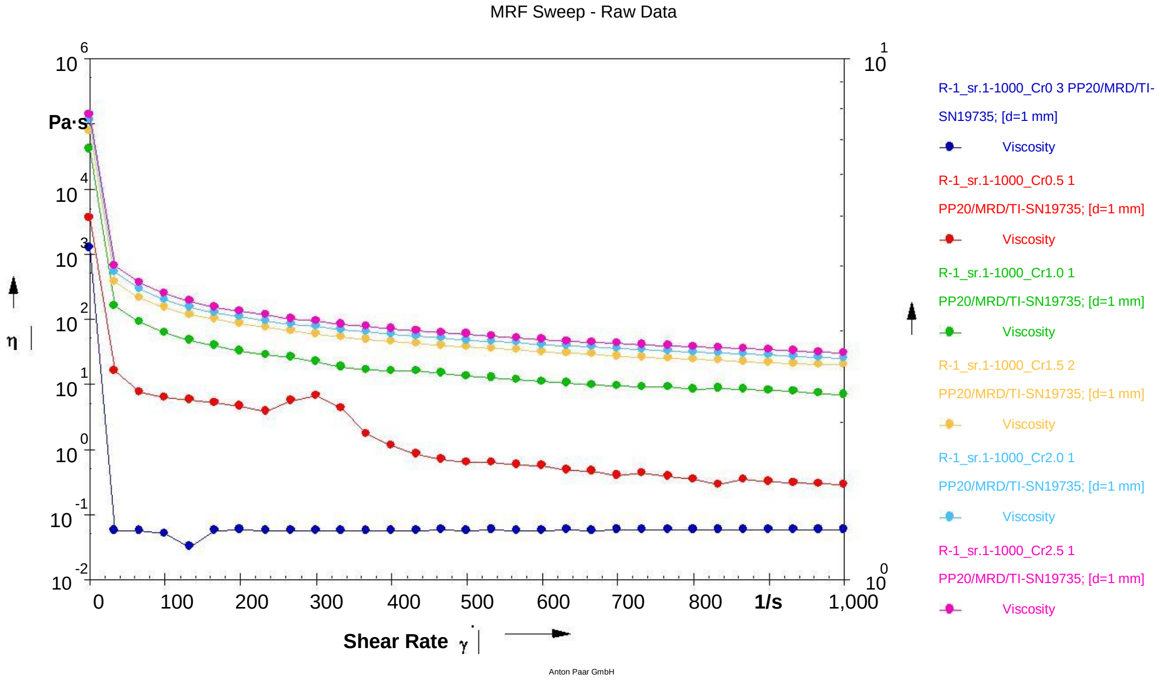


Fig.3.3 shows the curve of viscosity vs shear rate of bimodal MRP fluid at different current

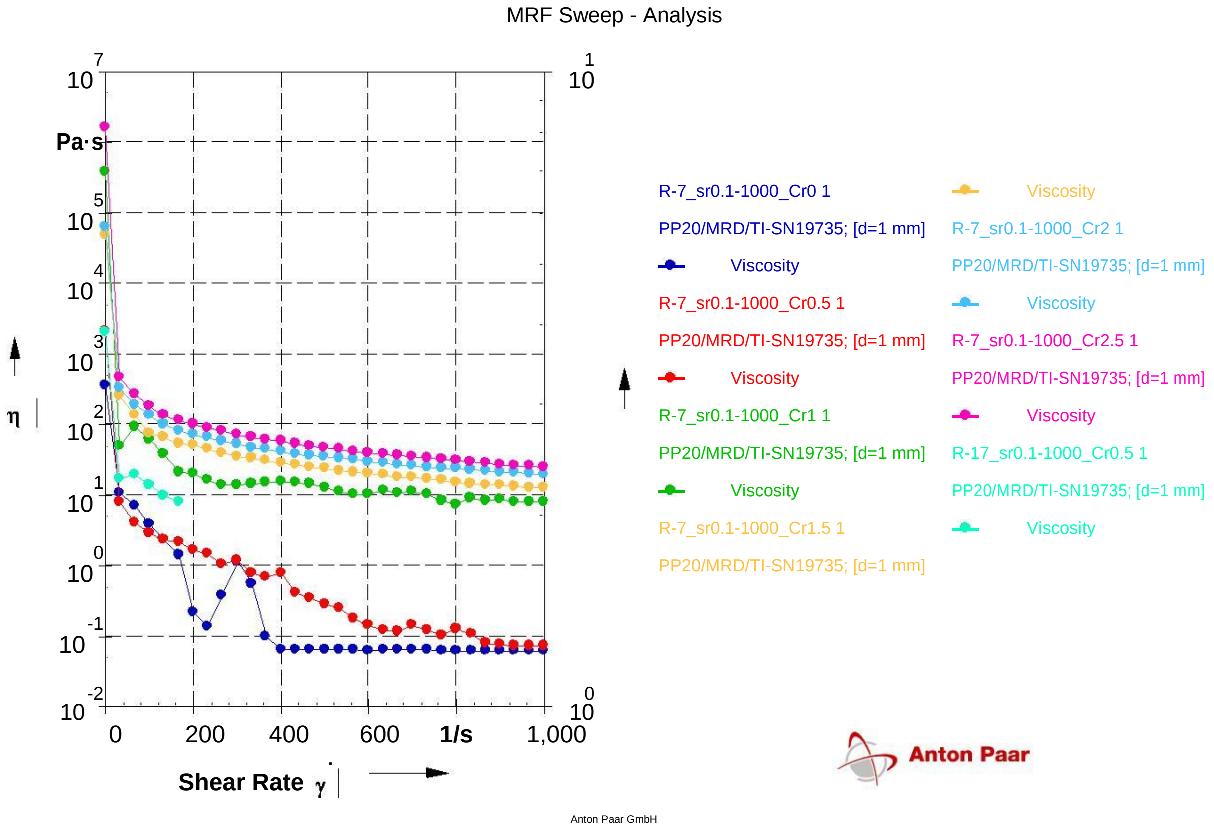


Fig.3.4 shows the curve of viscosity vs shear rate of mono disperse MRP fluid at different current

3.5 Design of experiments

We have considered three factors of variables (carbonyl iron powder of CS grade, carbonyl iron powder of HS grade, current) and 5 levels range from -1.68 to +1.68 as shown in the table 3.1.

Table-3.1: Actual response value corresponding to Coded levels.

Parameters/Levels	-1.68	-1	0	+1	+1.68
Iron powder of CS grade	14	15.5	17	18.5	20
Iron powder of HS grade	0	1.5	3	4.5	6
Current I	.5	1	1.5	2	2.5

After applying design of experiment (DOE), the experimental plan has been developed for conducting the experiment on magnetorheometer which is shown in table 3.2.

Table 3.2: Experimental plan

Std.	RUN	FACTOR1 (%VOL) A:CS	FACTOR2 (%VOL) B:HS	FACTOR3 (Ampere) C:I	YIELD SHEAR STRESS(Pa)
10	1	1.68	0.00	0.00	4357
4	2	1.00	1.00	-1.00	2356
13	3	0.00	0.00	-1.68	1080
16	4	0.00	0.00	0.00	1869
8	5	1.00	1.00	1.00	7311
18	6	0.00	0.00	0.00	1863
12	7	0.00	1.68	0.00	3591
2	8	1.00	-1.00	-1.00	1556
20	9	0.00	0.00	0.00	1866
1	10	-1.00	-1.00	-1.00	1137
11	11	0.00	0.00	0.00	1650
14	12	0.00	0.00	1.68	6855
7	13	-1.00	1.00	1.00	4384

15	14	0.00	0.00	0.00	1862
6	15	1.00	-1.00	1.00	5170
5	16	-1.00	-1.00	1.00	3040
9	17	-1.68	0.00	0.00	1527
3	18	-1.00	1.00	-1.00	1256
19	19	0.00	0.00	0.00	1866
17	20	0.00	0.00	0.00	1869

3.6 SAMPLE PREPARATION:

After the development of experimental plan by using DOE, total nine MRP fluid samples have been prepared with varying concentration of carbonyl iron powder using different grades.

Table-3.3: specification of material used

Material used	Density of material
CIP CS grade(4.75µm) CIP HS grade(1.75µm) SiC (800 mesh size) Base fluid (paraffin oil 80% vol + AP3 Grease)	-7.87 gm/cm^3 -3.22 gm/cm^3 -.812 gm/cm^3

Step-1: Calculate the amount of carbonyl iron powder CS grade, carbonyl iron powder of HS grade, SiC abrasives of 800 mesh size and base fluid for all nine samples.

RUN-1: concentration of this run is – 20 vol % CIP CS grade

3 vol% CIP HS grade

25 vol% SiC (800 mesh size)

52 vol% base fluid

Weight of CIP CS grade= .20*10*7.87gm

=15.74gm

Weight CIP HS grade= .03*10*7.87

gm =2.36gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.52*10*.812gm

=4.22gm

RUN-2: concentration of this run is – 18.5 vol % CIP CS grade

4.5 vol% CIP HS grade

25 vol% SiC (800 mesh size)

52 vol% base

fluid Weight of CIP CS grade= .185*10*7.87gm

=12.20gm

Weight CIP HS grade= .045*10*7.87 gm

=3.54gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.52*10*.812gm

=4.27gm

RUN-3: concentration of this run is – 17 vol % CIP CS grade

3 vol% CIP HS grade

25 vol% SiC (800 mesh size)

55 vol% base fluid

Weight of CIP CS grade= .17*10*7.87gm

=13.38gm

Weight CIP HS grade= .015*10*7.87

gm =2.36gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.55*10*.812gm

=4.47gm

RUN-7: concentration of this run is – 17 vol % CIP CS grade

6 vol% CIP HS grade

25 vol% SiC (800 mesh size)

52 vol% base

fluid Weight of CIP CS grade = .17*10*7.87 gm

=13.38 gm Weight

of CIP HS grade = .06*10*7.87 gm

=4.72gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid= .52*10*.812gm= 4.23gm

RUN-8: concentration of this run is – 18.5 vol % CIP CS grade

1.5 vol% CIP HS grade

25 vol% SiC (800 mesh size)

55 vol% base

fluid Weight of CIP CS grade= .185*10*7.87gm

=14.56gm

Weight CIP HS grade= .015*10*7.87

gm =1.18gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.58*10*.812gm

=4.47gm

RUN-10: concentration of this run is – 15.5 vol % CIP CS grade

1.5 vol% CIP HS grade

25 vol% SiC (800 mesh size)

58 vol% base

fluid Weight of CIP CS grade= .155*10*7.87gm

=12.20gm

Weight CIP HS grade= .015*10*7.87 gm

=1.1805gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.58*10*.812gm

=4.71gm

RUN-11: concentration of this run is – 17 vol % CIP CS grade

0 vol% CIP HS grade

25 vol% SiC (800 mesh size)

58 vol% base

fluid Weight of CIP CS grade= .17*10*7.87gm

=12.20gm

Weight CIP HS grade= .015*10*7.87

gm =1.1805gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.58*10*.812gm

=4.71gm

RUN-13: concentration of this run is – 15.5 vol % CIP CS grade

4.5 vol% CIP HS grade

25 vol% SiC (800 mesh size)

55 vol% base

fluid Weight of CIP CS grade= .155*10*7.87gm

=12.20gm

Weight CIP HS grade= .045*10*7.87 gm

=3.54gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.55*10*.812gm

=4.47gm

RUN-17: concentration of this run is – 14 vol % CIP CS grade

3 vol% CIP HS grade

25 vol% SiC (800 mesh size)

58 vol% base

fluid Weight of CIP CS grade= .14*10*7.87gm

=11.02gm

Weight CIP HS grade= .03*10*7.87 gm

=2.26gm

Weight of SiC 25 vol% = .25*10*3.22 gm= 8.05gm

Weight of Base fluid=.58*10*.812gm

=4.71gm

STEP-2: Mixing the powder of CIP (CS grade), CIP (HS grade), and abrasive powder (SiC) in calculated amount for each sample uniformly in the ball mill for 15min duration.

STEP-3: Put some amount of the uniformly mixed powder in the base fluid which is (paraffin oil +AP3 grease) and stir with the help of stirrer so that the material powder mixed uniformly with base fluid.

STEP-4: Put small quantity of powder in between the stirring and stir the complete sample mixture for 2 hrs so that all powder mixed uniformly with the base fluid. Repeat the above steps for preparation all the nine samples.

Fig.3.5 stirring of sample with the help of Stirrer

3.7 STATISTICAL ANALYSIS

RSM is the collection of mathematical and statistical techniques that are used for the modelling and analysis the problems in which a response of interest is influenced by several parameters, and the aim is to optimize their response. Using RSM, 3 independent parameters or responses are chosen viz. CIP CS grade, CIP HS grade, current, and their selected levels are shown in Table-3.1. Base fluid (paraffin oil+ AP3 grease) is added for making total volume of fluid to 100%. Experimental plan is shown in table 3.2, compositions in % volume of each fluid sample, and responses summary of yield stress based upon Herschel– Bulkley model. Response surface analysis is applied to obtain the effect of every individual parameter and their interactions on response parameters using Stat-Ease Design Expert software. Put the value of Sequential model sum of square in the inserted table 3.4.

Table-3.4: Sequential model sum of square

Source	**Sum of square**	**df**	**Mean square**	**F value**	**P-value Prob >f**
Mean vs Total	1.594E+008	1	1.594E+008		
Linear vs mean	5.351E+007	3	1.784E+007	22.76	<.0001
2FI vs linear	2.661E+006	3	8.869E+005	1.17	.3598
Quadratic vs 2	9.869E+006	3	3.296E+006	4363.05	<.0001
Cubic vs Quadratic	6211.03	4	1552.76	7.01	.0190
Residual	1329.02	6	221.50		

Table 3.5: Model summary statistics

Source	Std. Deviation	R-square	Adjusted R-square	Predicted R-square	PRESS
Linear	1.254E+007	11	1.140E+006	1330E+005	<.0001
2F1	9.877E+006	8	1.235E+006	1441E+005	<.0001
Quadratic	7477.22	5	1499.44	175.03	<.0001
Cubic	1286.19	1	1286.19	150.14	<.0001
Pure error	42.8	5	8.57		

Table 3.6: ANOVA for response surface quadratic model

Source	Sum of square	df	Mean square	F-value	P-value Prob>F
Model	6.604E+007	9	7.338E+006	9731.56	<.001
A-CS	9.409E+006	1	9.409E+006	12478.26	<.001
B-HS	4.306E+006	1	4.306E+006	5710.57	<.001
C-I	3.979E+007	1	3.979E+007	52777.28	<.001
AB	2.731E+005	1	2.731E+005	362.15	<.001
AC	1.565E+006	1	1.565E+006	2075.16	<.001
BC	8.230E+005	1	8.230E+005	1091.56	<.001
A2	2.133E+006	1	2.133E+006	2828.86	<.001
B2	1.059E+006	1	1.059E+006	1404.19	<.001
C2	8.048E+006	1	8.048E+006	10673.39	<.001
Residual	7540.06	10	754.06		
Lack of fit	7497.22	5	1499.44	175.03	<.001
Pure error	42.83	5	8.57		

The model terms are significant when the prob>F is smaller than <0.0001. All the terms in the above are significant. The final equation in term of coded factor is

$$R1=1865.18536+830.02085*A+561.50265*B+1707.00757*C+184.75000*A*B+442.25000*A*C+320.75000*B*C+384.71720*A^2+271.04978*B^2+747.28620*C^2$$

The final equation in terms of actual factor values is given as

$$\text{Yield shear stress} =1865.18536 + 830.02085*CS + 561.50265*HS + 1707.00757*I + 184.75000*CS*HS + 442.25000*CS*I + 320.75000*HS*I + 384.71720*CS^2 + 271.04978*HS^2 + 747.28620*I^2$$

Chapter 4 Result and discussion

Analysis of different parameter is discussed in this chapter which is obtained by using RSM. The independent parameters taken are carbonyl iron powder of CS grade, carbonyl iron powder of HS grade and current. By varying the concentration of all three parameters and prepare samples and perform rheology on all these samples that obtained by using DOE. Now discussing the result obtain from the rheological characterisation and their effects on yield shear stress and max viscosity.

4.1 Effect of CIP (CS Grade):

As the concentration of CIP CS grade increases by keeping other two parameters value equal to zero, the value of yield shear stress increasing continuously when magnetic field of constant value is applied. This is because the particles of CIP CS grade are aligning themselves in a chain like structure which is difficult to break so more stress is required and it also increases the value of viscosity. The curve behaviour is shown in the graph 4.1.

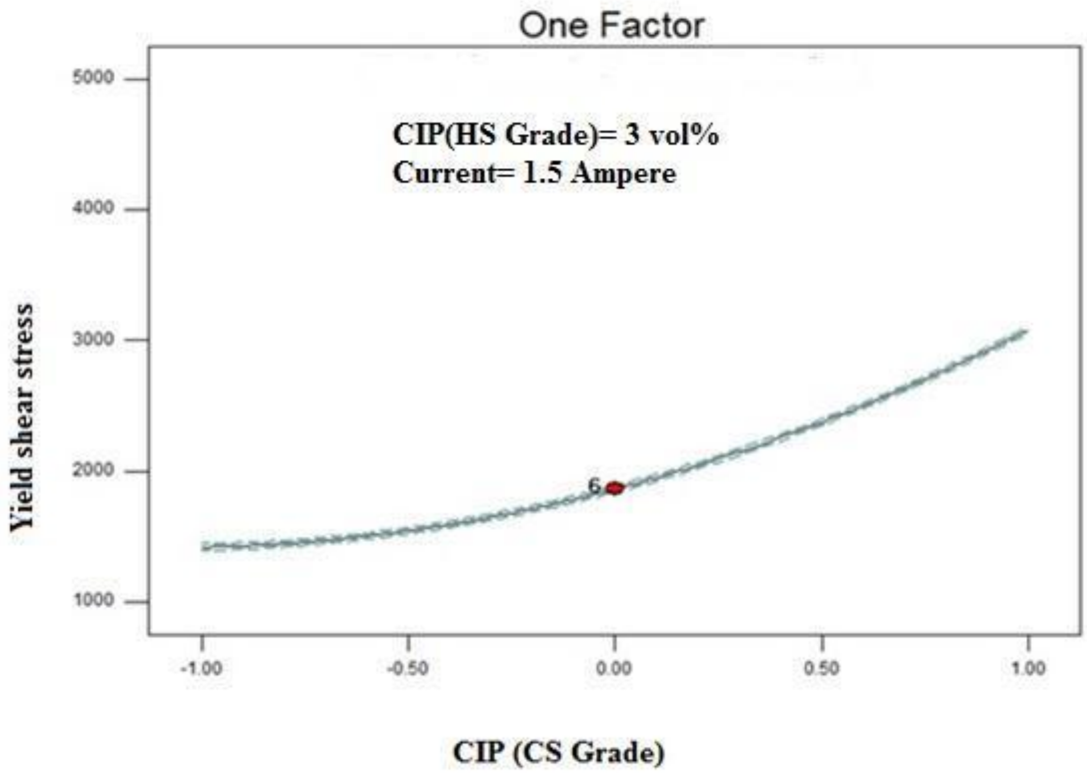


Fig.4.1 Shows effect of CIP (CS grade) on yield shear stress

4.2 Effect of CIP (HS Grade):

Here also the value of yield shear stress increases as the concentration of HS grade of CIP increases but the rate of increasing the value of yield shear stress in CIP CS grade is more than that of CIP HS grade.

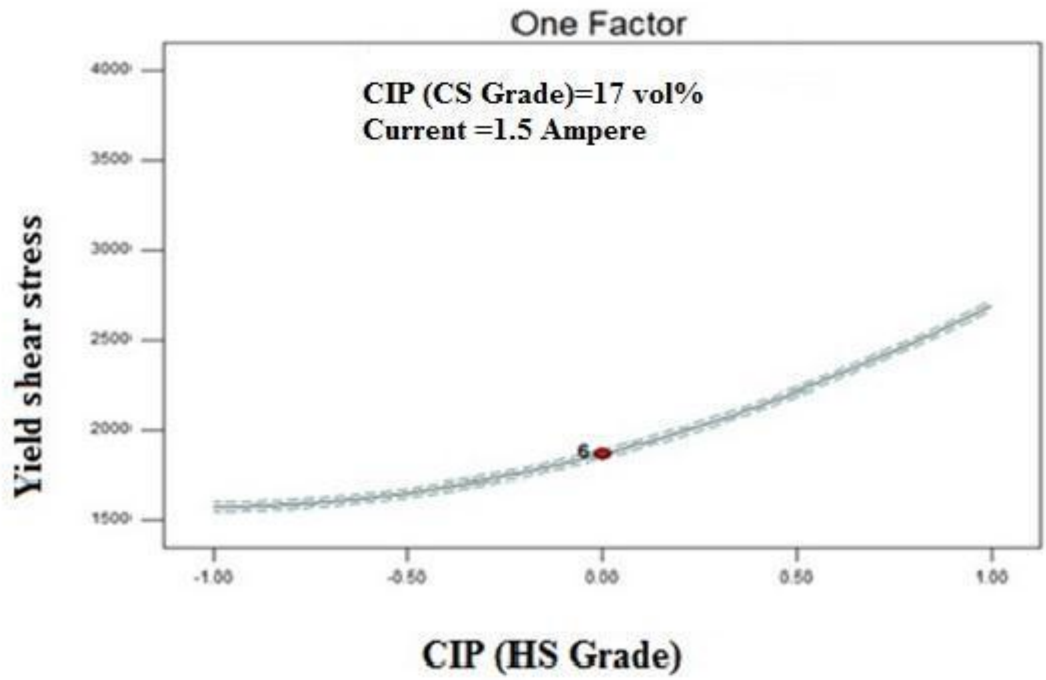


Fig.4.2 Shows effect of CIP HS grade on yield shear stress

4.3 Effect of current:

As the value of current increases the value of the yield shear stress increases when magnetic field is applied on a given sample.

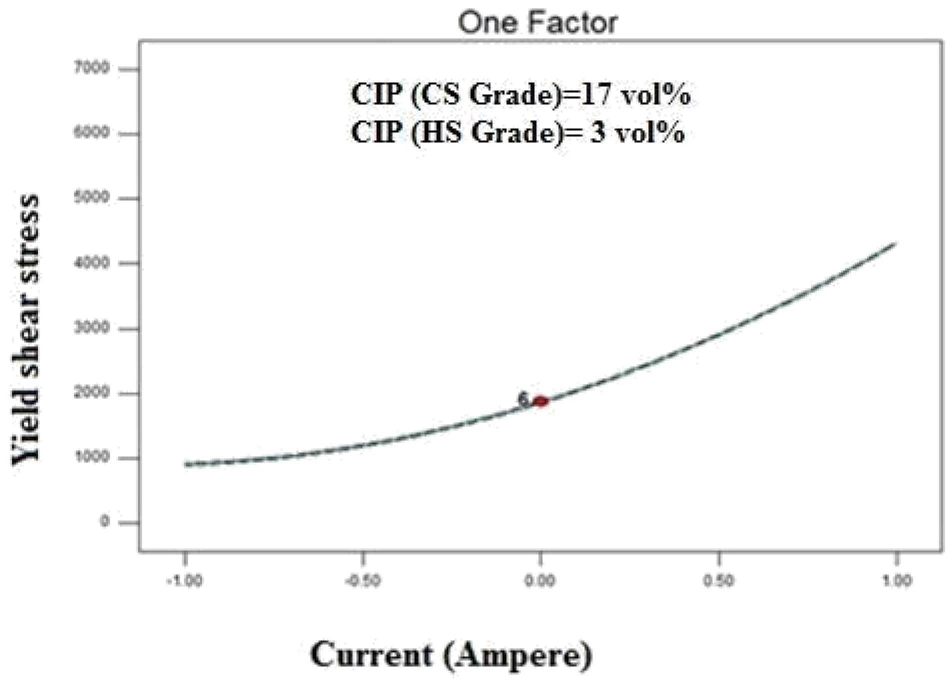


Fig.4.3 Shows effect of current on yield shear stress

The above curve shows their effect individually on the value of yield stress and viscosity. Now discuss the effect on variation of 2 parameters keeping third constant on the values of yield shear stress.

4.4 Effect on yield shear stress by changing two parameters:

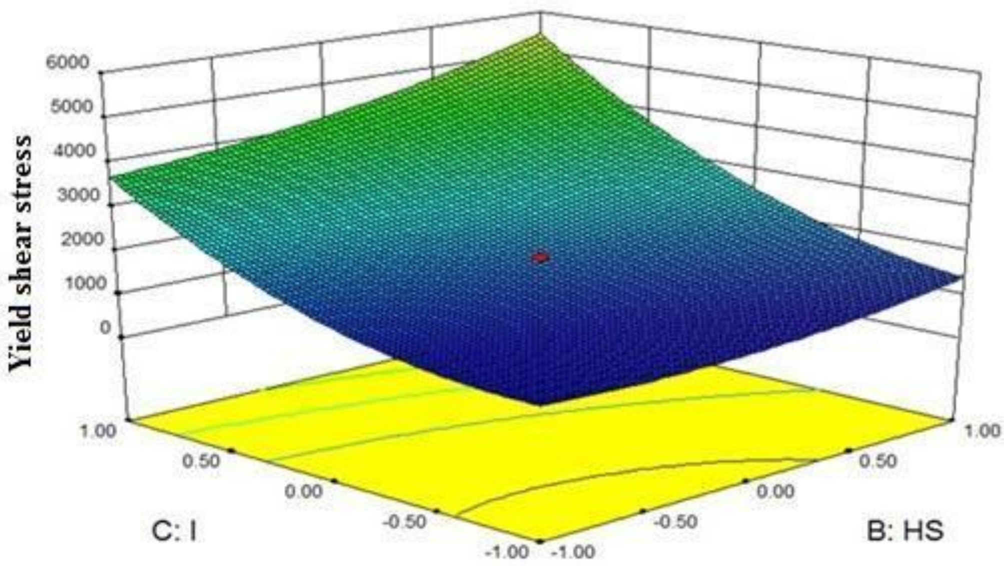


Fig. 4.4 shows the effect of current and CIP (HS grade) on yield shear stress keeping CIP (CS grade) 17 vol %

The quadratic surface above shows the effect of any two parameters out of three on the yield shear stress keeping value of third one equal to 17 vol%.

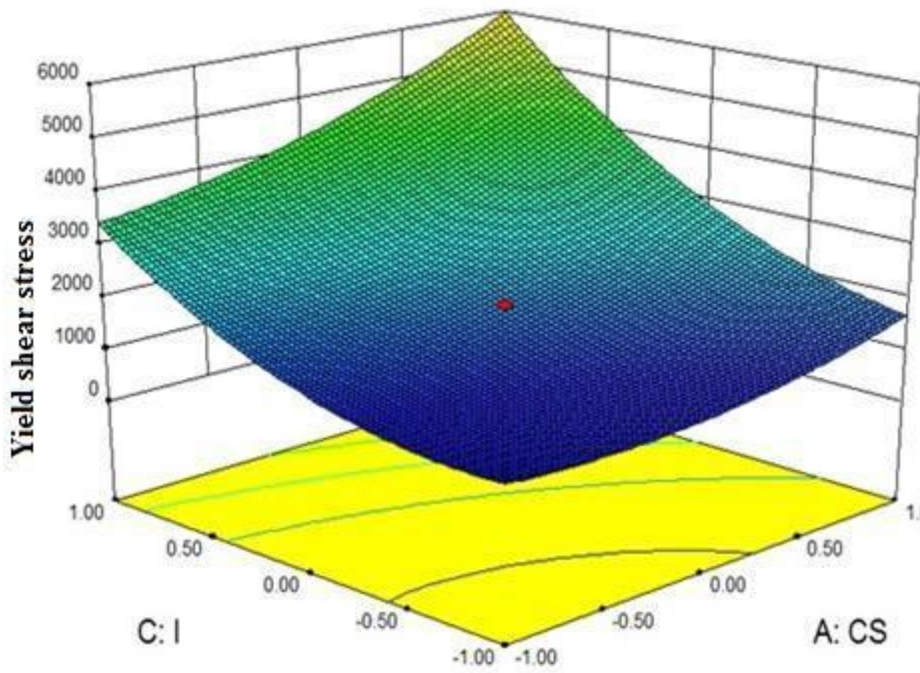


Fig. 4.5 shows effect of current and CIP (CS grade) on yield shear stress keeping CIP (HS grade 3 vol%

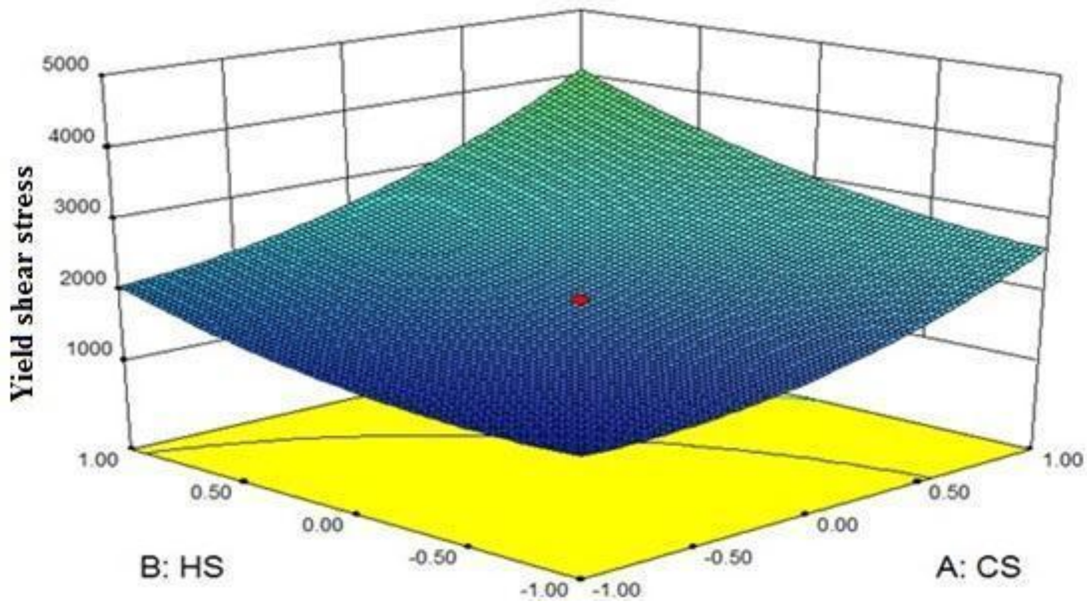


Fig. 4.6 shows effect of CIP (CS grade) and CIP (HS grade) on yield shear stress keeping current 1.5 Ampere

Chapter 5 Conclusion and future scope

The present study of rheological characterisation and statistical analysis of bimodal magnetorheological polishing fluid shows the effect of various parameters on the response yield shear stress which is given below.

(1) It has been observed that as the concentration of CIP of CS grade increases, keeping CIP of HS grade and current level constant, the yield shear stress increases. It is due increase of chain strength of MRP fluid on increase of CIP of CS grade concentration. Since CIP of CS grade shows more magnetization (saturation magnetization of CIP CS grade is 210 emu/gm at 2 tesla magnetic field).

(2) The results show that as the concentration of CIP of HS grade increases, keeping CIP of CS grade and current level constant, the yield shear stress increases. It is due increase of chain strength of MRP fluid on increase of CIP of HS grade concentration. Since CIP of HS grade shows lower magnetization (saturation magnetization of CIP HS grade is 139 emu/gm at 2 tesla magnetic field). Hence, it shows less increase in yield shear stress as compared to yield shear stress obtained with CIP of CS grades.

(3) The yield shear stress has been found increased continuously on increase of current. It is due to the reason that the chain strength of MRP fluid increased on increasing the current. It shows that the particles in the MRP fluid hold to each other more firmly on increase on current.

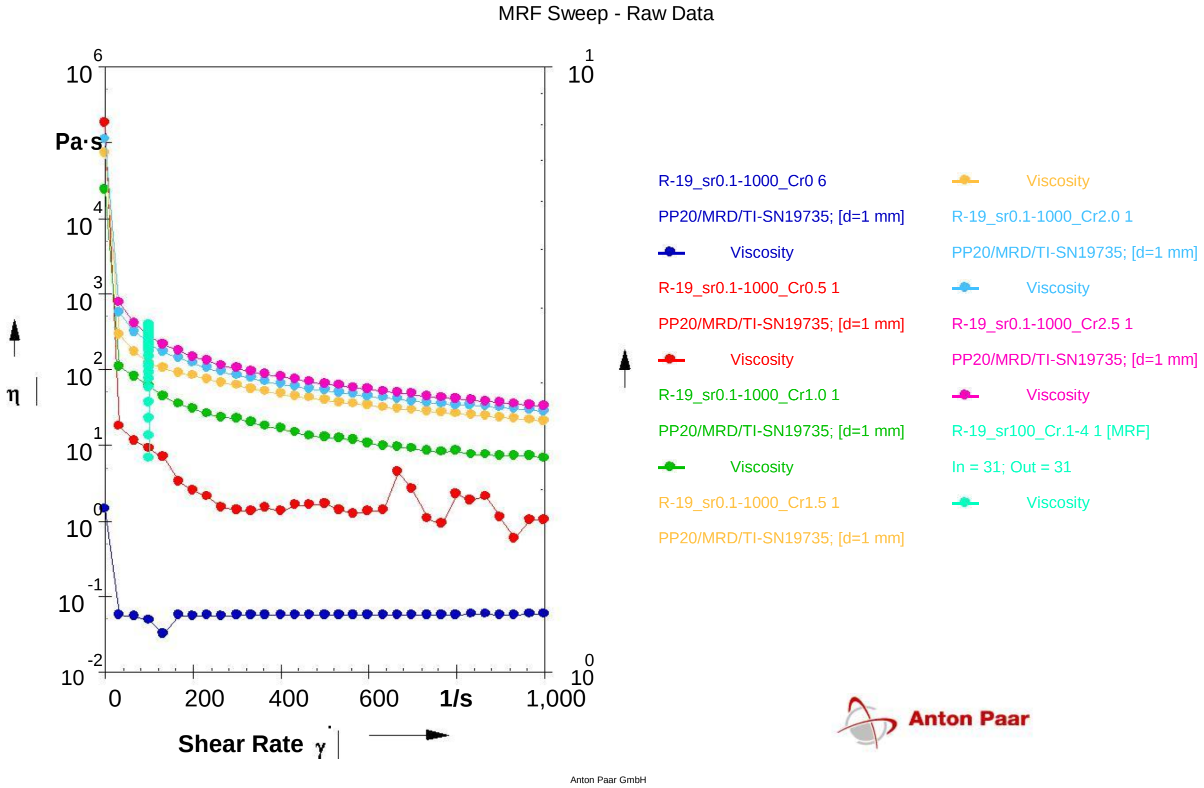
(4) The values of optimum process parameters have been found as CIP of CS grade is 20 vol%, CIP of HS grade is 6 vol% and current 2.5 ampere in the given experimental range of variables. The optimum value of yield shear stress has been found as 13705.62 Pa. It shows that 6 vol% of CIP (HS grade) is sufficient to fill the structural micro cavities form due to association of larges particles and improve the yield shear stress of MRP fluid.

Future Scope:

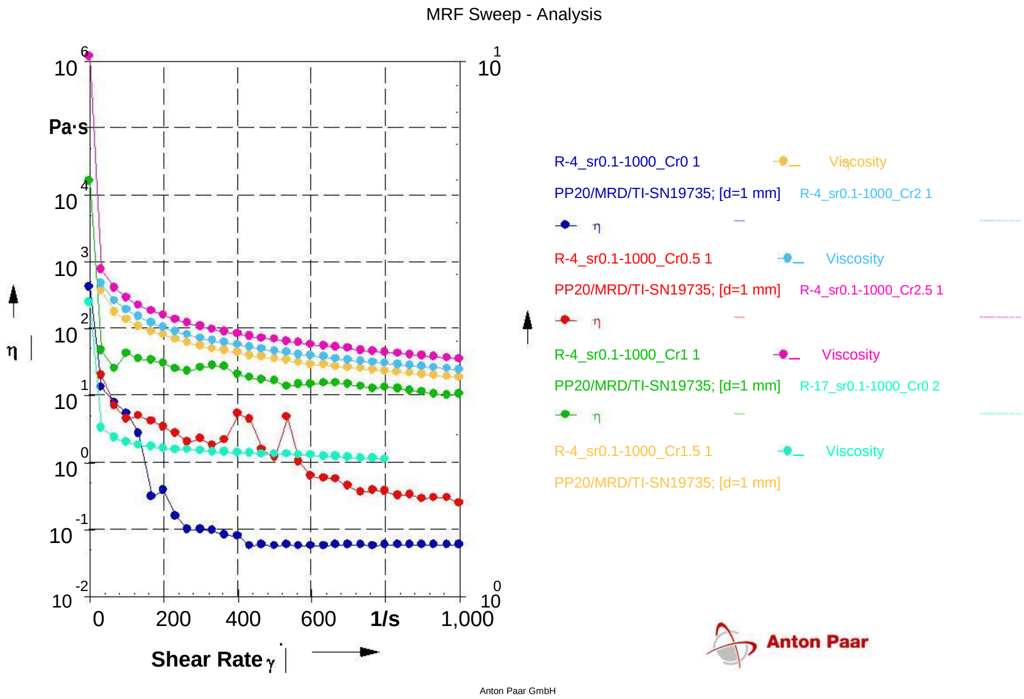
The present study reveals that BMRP fluids are used to obtain very high level surface finish for variety of materials. These fluids can be used for surface finish of variety of actuation systems including optics finishing, fluid clutches, aerospace, sealing, automotive and civil damping application. These fluids can also be used for material removal process for variety of brittle materials like hard crystals (sapphire). The bimodal MRP fluid can also be used for finishing of composite materials. The shear strength of bimodal MRP fluid can be further improved with the addition of nano magnetic particles which are having high magnetic saturation.

Appendix

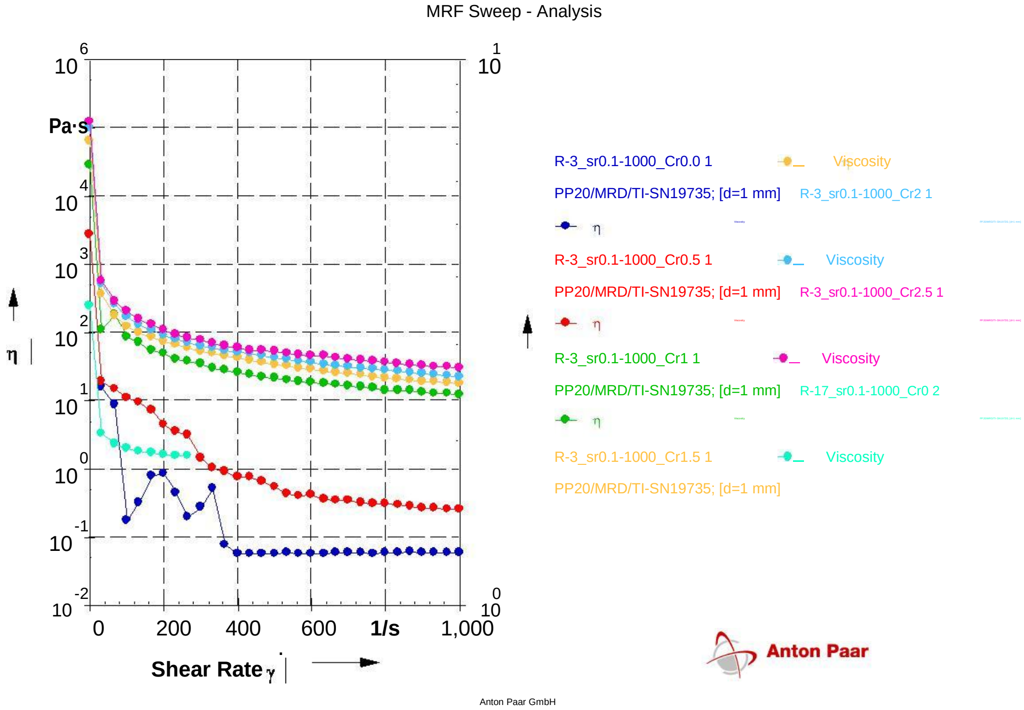
A-1 RUN 1 rheology graph (20 vol% CIP CS grade, 3 vol% CIP HS grade)



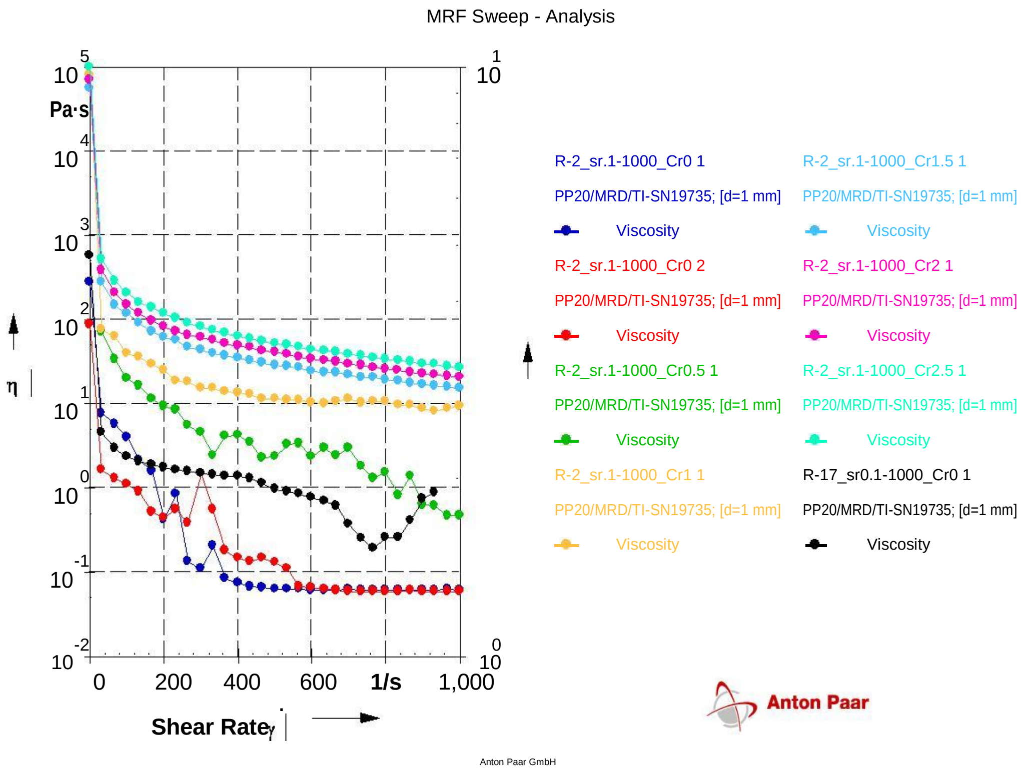
A-2 RUN 3 rheology graph (17 vol% CIP CS grade, 3 vol % CIP HS grade)



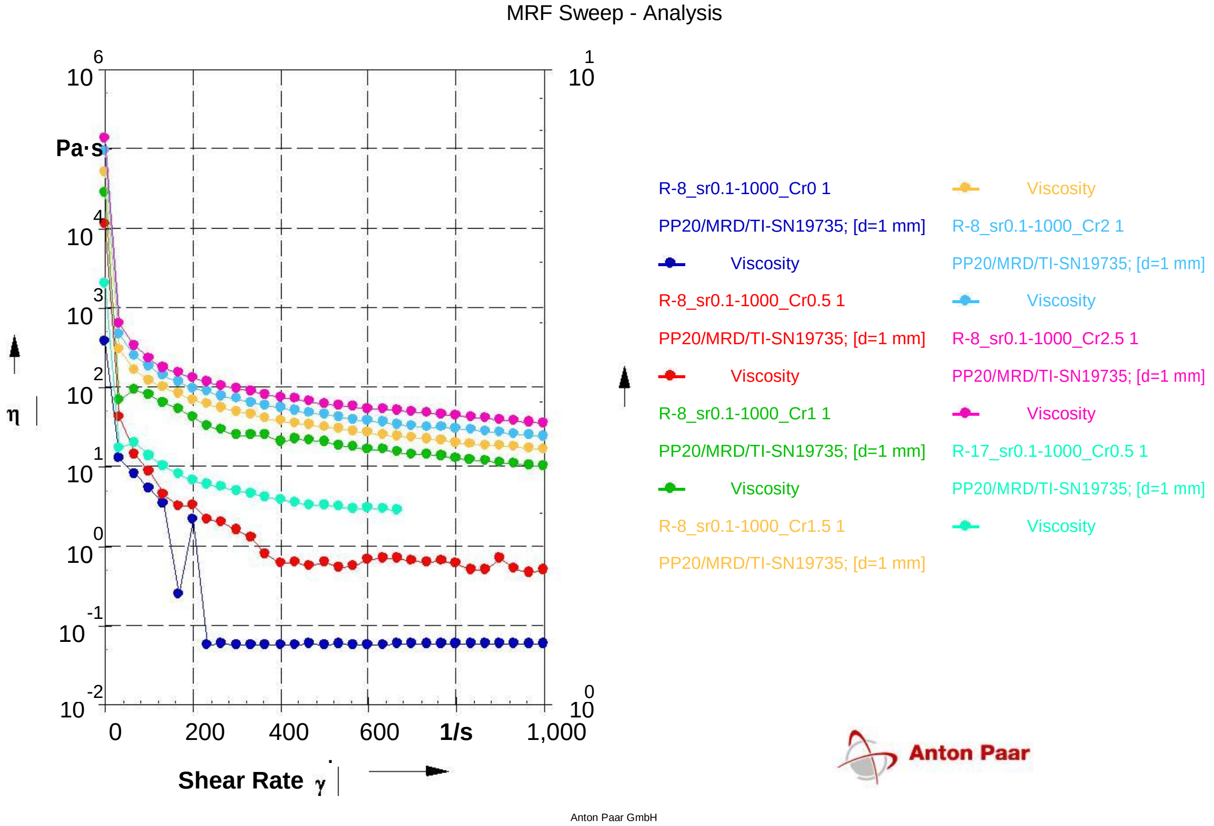
A-3 RUN 8 (18 vol % of CIP CS grade, 1.5 vol % of CIP HS grade) rheology graph



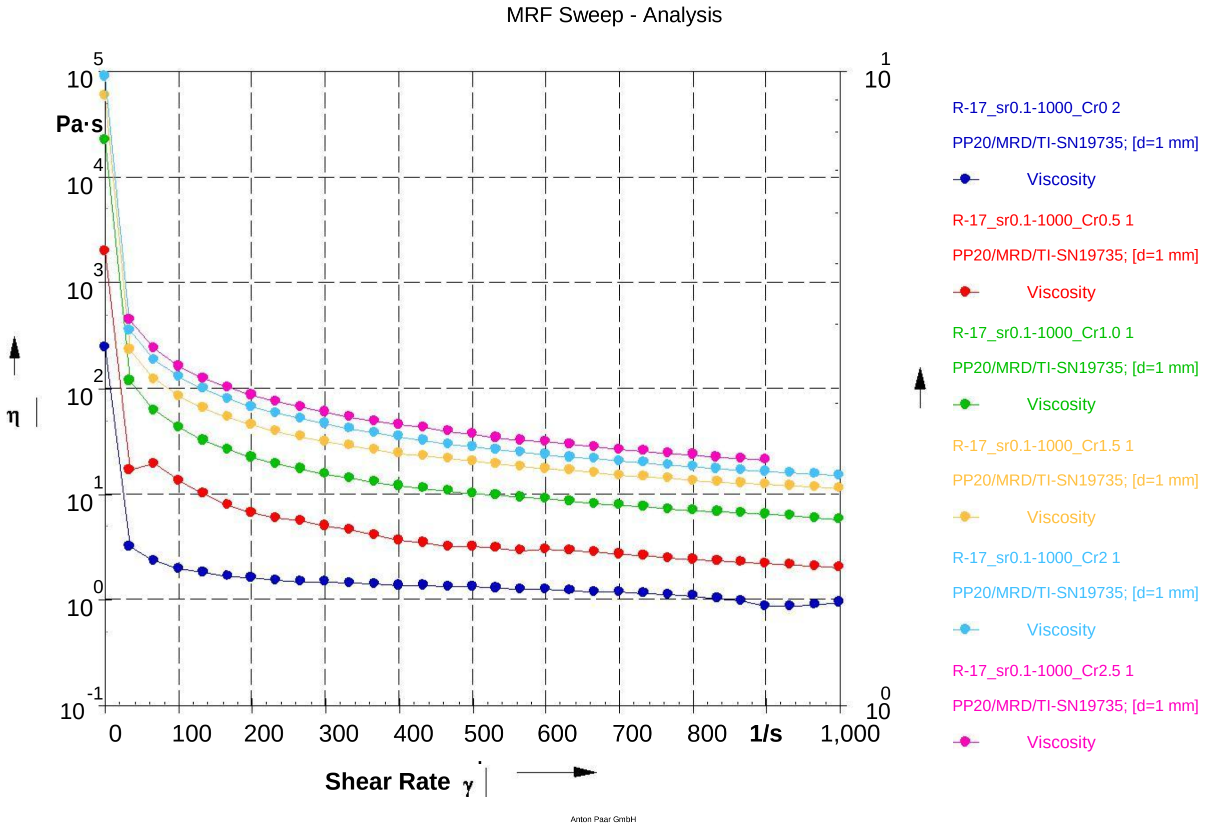
A-4 RUN 10 rheology graph (15.5 vol% of CIP CS grade, 1.5 vol% of CIP HS grade)



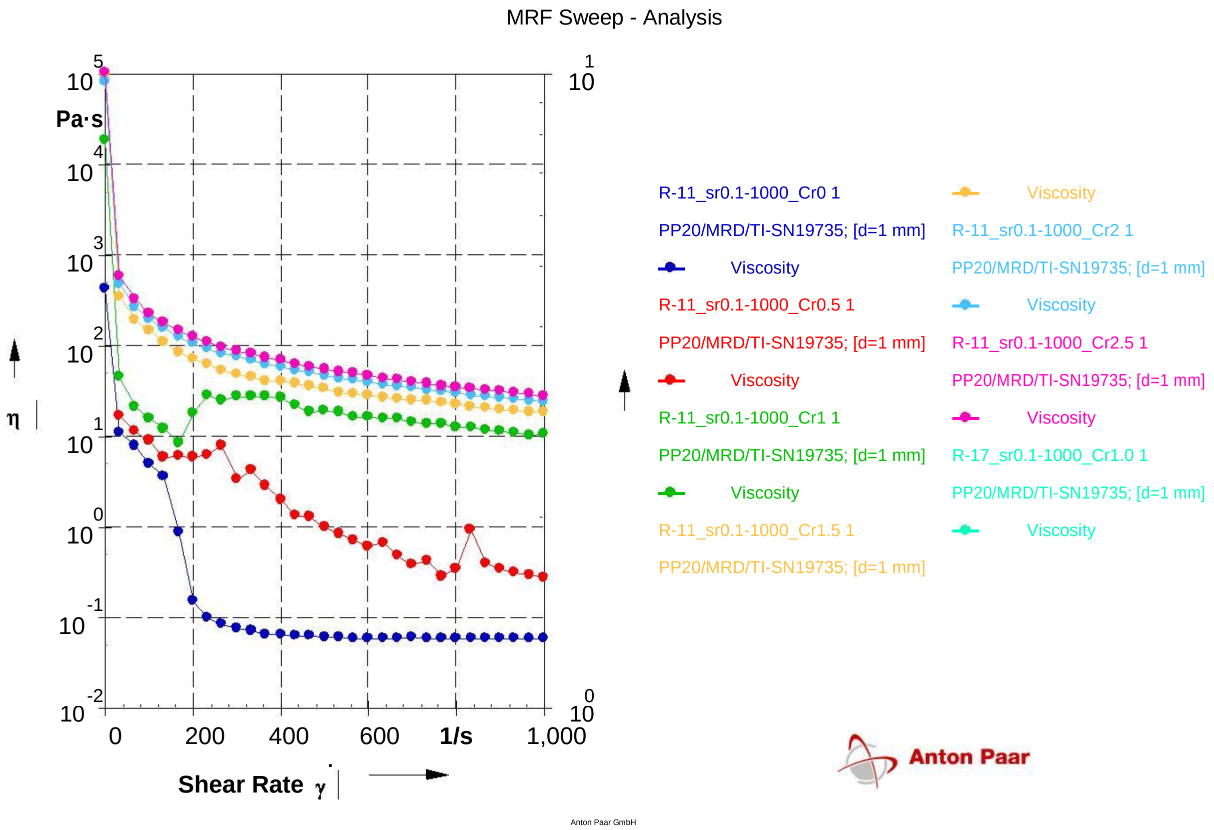
A-5 RUN 13 rheology graph (15.5 vol% of CIP CS grade, 4.5 vol% of CIP HS grade)



A-6 RUN 15 rheology graph(18.5 vol% of CIP CS grade, 1.5 vol% CIP HS grade)



A-7 RUN 17 rheology graph (14 vol% of CIP CS grade,3 vol% of CIP HS grade)



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