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RHEOLOGICAL CHARACTERIZATION OF MRP FLUID : A REVIEW

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ABSTRACT

Magnetorheological finishing (MRF) is a precision material removal process that has been applied to a large variety of brittle materials, from optical glasses to hard crystals. MRF is based on a magnetorheological (MR) fluid that consists of carbonyl iron powder (CIP), silicon carbide (SiC) and base fluid.Detailed studies of MR fluid characterize rheological properties by Magnetorheometer. Three constitutive models viz. Bingham Plastic, Herschel–Buckley, and Casson fluid are used to characterize the rheological behavior of 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 conducted, and contribution of each model term affecting improvement in yield stress and viscosity is calculated. To estimate the saturation magnetization of MR fluid, M-H curve is plotted using vibrating sample magnetometer (VSM), and effect of temperature on yield stress and viscosity is discussed.

Keywords: **MR fluid; Viscosity; Yield stress.**

I. INTRODUCTION

Magnetorheological finishing (MRF) is a precision material removal process that has been applied to a large variety of brittle materials, from optical glasses to hard crystals, such as sapphire [1]. This process utilizes MR fluid and nonmagnetic polishing abrasives in a magnetic field to polish materials. Several researchers have described the evolution of MRF in recent years. The standard MR fluid consists of carbonyl iron (CI) as the magnetic component, abrasive particles, with the balance made up of deionized (DI) water and fluid stabilizers. Figure.1 shows schematic view of MRF process and detail view of finishing region. MR fluid is pumped from the fluid container up to the nozzle, where it is ejected onto the rotating wheel as a ribbon. At the initial point of contact, the MR fluid is a viscous fluid with the approximate consistency of honey. The rotation of the wheel drags the fluid under the workpiece in the region where it is acted upon by the magnetic field. The MR fluid ribbon flows through the converging gap between the workpiece and the wheel. The magnetic field stiffens the ribbon in this region giving it the approximate consistency of clay depending upon the field strength. Significant shear forces are created by the interaction among the wheel, MR fluid, and workpiece surface, because the MR fluid ribbon flows through a converging gap. Rotation of the wheel continues to drag the MR fluid from delivery region to region, where it is removed from the wheel through suction. Here the magnetic field does not act on

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the MR fluid so it again has the consistency of honey. The MR fluid is pumped back to the fluid container, where it is cooled to a set point temperature. The fringing field in the gap between the pole pieces has a strong vertical gradient. The field is higher at the wheel surface than it is at the workpiece surface, which causes the carbonyl iron particles (CIPs) to be pressed against the wheel surface and the nonmagnetic abrasive to move towards the workpiece surface due to magnetic levitation force [2]. Magnetic levitation is defined as a force exerted on nonmagnetic bodies by a magnetic fluid. In the finishing process the nonmagnetic bodies are the abrasives. Therefore, the levitation force pushes the abrasives into the specimen surface. The indented abrasives are intact with the MR fluid ribbon which is rotating along the wheel. The forces acting on an abrasive particle when it is approaching a roughness peak are magnetic levitation force (F_{ml}) transferred by the surrounding CIPs, which helps in indenting the abrasive particle into the workpiece surface. The shear force (F_s) is due to rotation applied by the carrier wheel which helps in cutting the roughness peak (Fig. 1(b)). Some of the researchers [3] have designed MR rheometer for characterizing MR finishing fluid. This MR rheometer can measure the yield stress that depends on the mutual orientation of the magnetic field and the direction of deformation. They modeled MR fluids as Bingham fluids with a yield stress (10 kPa) and small plastic viscosity (0.5 Pa.s). To understand and model this process correctly it is important to study the rheological properties (yield stress and viscosity) of the fluid under the influence of the magnetic field. In this article, an attempt has been made to characterize the rheological properties of MR fluid by varying fluid compositions at different magnetic fields. Effect of temperature change on rheological properties of MR fluid is also studied.

II. MR flUID

MR fluids [4] are the magnetic field-controllable fluid whose rheological behavior which depends on the strength of the magnetic field.

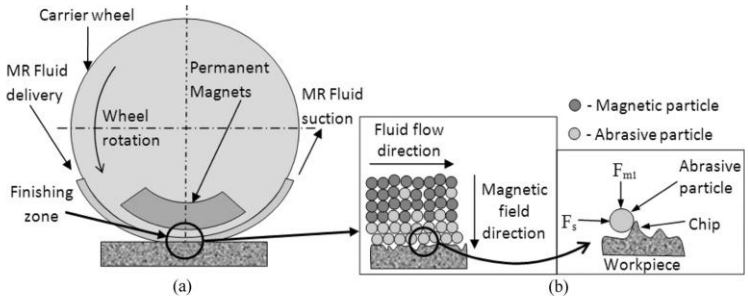

Figure 1.—(a) Schematic view of the MRF process and (b) magnified views of finishing zone[4]

Normally, the rheological properties like viscosity and shear stress change with other physical properties, such as chemical composition and temperature.

2.1. COMPOSITION OF MR FLUID

The MR fluid is a suspension of micron-sized magnetizable particles such as carbonyl iron particles (CIPs) and non-magnetic abrasive particles dispersed in either an aqueous or non-aqueous carrier fluid. The magnetic particles are usually CIP, highly pure iron or iron/cobalt alloy particles to achieve a high magnetic saturation. Since oxidation stability of CIPs is higher compared to others, it is widely used in MR fluid applications. To obtain good rheological properties, high magnetic saturation and lower magnetic coercivity are necessary for a strong MR fluid. The magnetic particles used in the present work to prepare MR fluids, which are subsequently

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used in the MRF process, are CIPs of HS grade. In MR fluids, critical factors such as the stability against sedimentation, as well as the large magnetic field- induced yield stress and low viscosity in the absence of magnetic field, should be taken into account for their better applicability [5]. To improve these contradictory requirements simultaneously, researchers have added submicron-sized particles (fumed silica, FS) into CI-based MR fluid. This spherical particle not only reduced sedimentation but also improved flocculation stability of the CI-based MR fluid without any noticeable change in the MR behavior [6]. Colloidal silica can be used to polish most metals, alloys, minerals, ceramics, and composites. Colloidal silica, also referred to as a sol, contains very fine particles (1–300 nm in diameter) that remain in suspension over a long period of time (several years) [7]. Many MR fluids are known in the literature, including both oil-based and water based fluids. Now here, off-state viscosity is equally important to circulate the MR fluid easily in the fluid circuit. Oil-based MR fluid has high off state viscosity compared to water-based. Another drawback of the oil-based MR fluid is cleaning of fluid circulatory system after experimentation due to stickiness to the internal surfaces of the components in the fluid delivery system. So the present application contemplates use of an MR fluid that is preferably based on an aqueous carrier fluid (deionized water) for most applications. The additives include stabilizers and surfactants. Additives are suspending agents and anti-corrosion/antiwear components [8]. Highly viscous materials such as grease or other thixotropic additives are used to improve settling stability. Additives are required to control the viscosity of the liquid, the settling rate of the particles [9], and the friction between the particles. The present MR fluid contains a stabilizer such as glycerol to add viscosity to the MR fluid and to create conditions that help to keep the magnetic particles and abrasive particles in suspension [10].Researchers [11] have developed a model for material removal rate MRR peak of glass polishing by MRF process which accounts the effect of size and concentration of abrasive as well as CIP.

2.2 RHEOLOGICAL CHARACTERIZATION

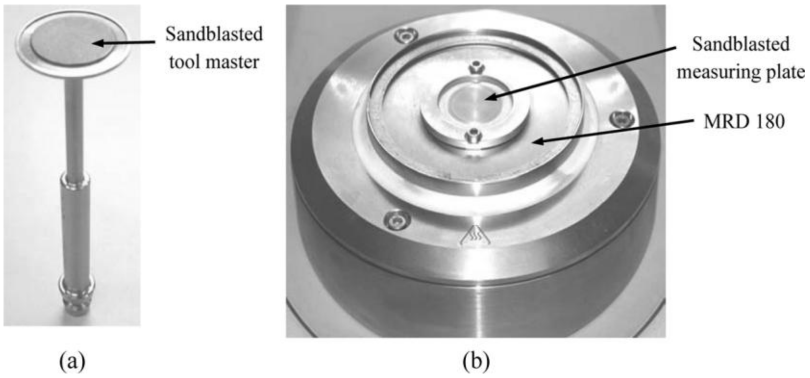

Figure 2.—Sandblasted (a) tool master and (b) measuring plate with magnetorheological device (MRD 180).

III. MODELING OF MR flUID

A key aspect of application of MR fluids is the characterization of rheological properties such as shear yield stress and viscosity. Three commonly used models for viscoplastic fluids are Bingham Plastic, Herschel–Bulkley, and Casson fluid. Using the shear stress and shear rate data obtained from a rheometer, these constitutive models are utilized to characterize the data.

VI. DESIGN OF EXPERIMENTS

RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables, and the objective is to optimize this response [12]. Using RSM, 4 independent parameters are chosen viz. CIP (C), abrasive (A), deionized water (D), and magnetic field (M), and their selected levels are shown in Table 1.

Table 1.—Coded levels and corresponding actual values of process parameters.

Sr. No.	Levels	CIP (C)	Abrasive (A)	Deionized water (D)	field (M)
1	−2	28	1 5	48	0 05
2	-1	32	4	51	0 1
3	0	35	6 5	54	0 35
4	1	38	9	57	0 6
5	2	41	11 5	60	0 85

Glycerol is added for making total volume of fluid to 100%. Response surface regression analysis is done to evaluate the effect of individual parameter and their interactions on response parameters using Stat-Ease Design Expert software.

V. CONCLUSIONS

Based on the comparison of R^2 values of all 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 modeling the MR fluid in fluid flow analysis and simulation.From the ANOVA analysis, 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 0.6 T 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.

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