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EFFECT OF MAGNETIC FIELD IN MAGNETORHEOLOGICAL FLUID FINISHING PROCESS A REVIEW

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ABSTRACT

Magnetorheological (MR) fluid is a smart material whose flow behavior can be altered with the application of magnetic field. The MRF technology has ability to transmit force in a controllable manner by application of magnetic field, thus improving performance especially in areas where controlled fluid motion is required. This rheological property of MR fluid gives solutions to many engineering challenges. Applications of MRF technology are in brakes, dampers, journal bearings, finishing, pneumatic artificial muscles, fluid clutches, aerospace etc. where by giving electrical inputs, comparatively faster mechanical output in a controlled manner is achieved. Magnetorheological fluid finishing (MRFF) is one of such application in which the controllability of MRF is used to finish the material surface. MRFF process is an ultra-finishing process that has been applicable to a large variety of materials, ranging from brittle material such as optical glasses to ductile material such as aluminium. When magnetic field is applied to MR fluid the non-magnetic abrasive particles aligned with the carbonyl iron particles (CIPs) chain and remove material from the surface being finished. The quality of the final finished surface generally depends on the constituents (iron particles, abrasive particles, carrier medium etc.) of MR fluid and applied magnetic field strength. Rheological properties such as yield stress and viscosity of MR fluid significantly affect the quality of the finished surface. It is also very important to have the knowledge of forces acting on the workpiece to understand the mechanism of material removal. In this study, the mechanism of MRFF is studied, which is responsible for the material removal in MRFF process. This is a review paper covering the principles of MRFF process and effect of magnetic field in MRFF process.

Keywords*: *Precision Finishing, Magneto Rheological Fluid, Magnetorheological Finishing Processes, Magnetic Field

I. INTRODUCTION

Rheology is defined as the study of the deformation and flow of matter (typically materials such as rubber, molten plastics, blood, paint, electro-rheological fluids, MR fluids etc.) under the influence of an applied stress. The rheological properties of a liquid are the governing features that can be quantified to characterise its behaviour. The properties that can be affected are plasticity, elasticity and viscosity. Magneto rheology is a branch of rheology which deals with the flow behaviour and the deformation of the materials under the influence of applied magnetic field. An MR fluid is synthesised by suspending ferromagnetic particles in a carrier fluid [1]. The carrier fluid forms the continuous phase of the MR fluids. MR fluids exhibit a change in rheological properties when being exposed to a magnetic field (this is known as the on-state). In the on-state, ferromagnetic particles are magnetically induced and aggregate to form chain-like or column-like structures parallel to the applied field. Due to this, MR fluids have the ability to reversibly change from viscous liquids to semi-solids in milliseconds when being exposed to a magnetic field. This feature enables a rapid response interface between mechanical systems and electronic controls, making MRF technologies attractive for many applications (e.g. dampers, brakes, journal bearings, finishing, pneumatic artificial muscles, fluid clutches, aerospace etc.). A typical MR fluid contains between 20 – 45 % by volume of suspended particles. Normally, soft iron particles are used (e.g. pure iron particles and carbonyl iron), because these particles provide a good trade-off between cost and fluid strength (i.e. large saturation magnetisation). Other than carbonyl iron particles, powder iron, iron oxides, iron nitride, iron carbide, nickel and cobalt are also used as magnetizable particles. These days one of the major application of MRF technology is in finishing known as Magnetorheological Fluid Finishing (MRFF) process. This process is used for finishing of hard and brittle material like glass as well as soft and ductile material like aluminium. MRFF process is based on the mechanism of mechanical abrasion in which the material removal is done by the non-magnetic abrasives particles and some time by suspended iron particles of MR fluid itself but with better flexibility towards process control as compare to classical finishing processes. A proper composition of MR fluid and abrasive particles (if required) can be successfully employed for achieving micro to nano-level surface finishing or polishing a variety of materials from hard crystals to optical glasses.

In the past two decades, different finishing processes have been developed which can control the abrading forces more accurately. Some of these processes which use magnetic field as a controlling force are magnetic float polishing [2], magnetorheological finishing [3], magnetic abrasive finishing [4], magnetorheological jet finishing [5] etc.

Similarly many MRFF processes have also been developed for finishing of different shapes and sizes of components. Some of these processes includes Magnetorheological abrasive flow finishing (MRAFF) which is developed for finishing of internal surfaces of cylindrical workpieces [6]. In progress to MAFF process a new process called Rotational-MRAFF is developed in which the total finishing time is reduced, uniformity in surface finish improved, and cross-hatch patterns created on the internal surfaces [7]. Requirement of complicated fixtures for finishing of external surfaces, restrict the application area in these processes. Some other MRFF processes use a wheel-based finishing tool, which are mainly used for finishing of different shapes and sizes of external surface [8-10]. However, with wheel based finishing tool it is not possible to finish internal surfaces like internal cylindrical surface, holes, etc. because of the shape of the finishing tool. Shimada et al. [11] developed a magnetic compound fluid (MCF), having magnetite particles of 10 nm average diameter, abrasive particles, CIPs, kerosene and water. This process is validated on three soft materials of 8mm diameter.

II. BASICS OF MAGNETORHEOLOGICAL FINISHING PROCESS

In the off-state condition i.e. without application of magnetic field, the behavior of MR fluid is just like a Newtonian fluid (viscosity 0.1–1 Pa s) but when magnetic field is applied to MR fluid i.e. in on-state condition the iron particles form chain like columnar structure and the fluid gets stiffened (viscosity 10–20 Pa s) depending upon the magnetic field strength and behaves as a viscoplastic fluid having sufficient strength to remove the material from any surface. In case of hard materials abrasive particles are added in the fluid, these particles embedded in between the iron particles' chain like columnar structure and the finishing operation on the workpiece surface is performed by these particles (Fig. 1).

In on-state condition the iron particles aligned in the direction of magnetic lines of forces [6]. Relative motion between the iron particles chains and the workpiece surface causes wear on the surface. Rubbing of particles' chain with the workpiece surface produces high stress concentration at the tips of surface asperities cause plastic deformation of asperities and finally abrading of the asperities. The strength of the iron particles' chains plays an important role in removing the material from workpiece surface which is governed by the yield stress of MR fluid. The characteristics of polished surface such as material removal rate, surface finish, etc. depend on the yield stress of MR fluid under the application of magnetic field.

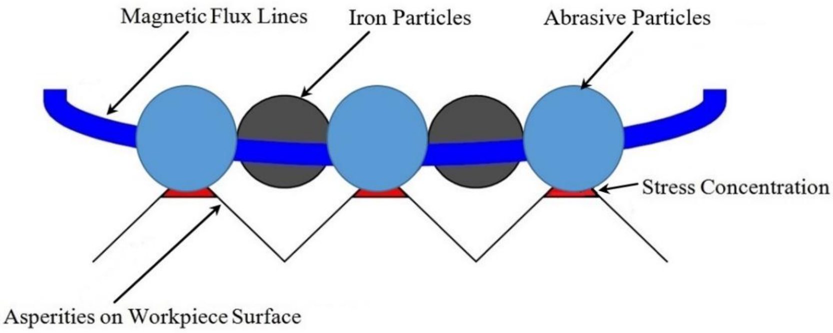

Fig. 1 Plausible Mechanism of Wearing of Asperities in Magneto Rheological Finishing Process

III. ABRASIVE PARTICLES USED IN MRFF PROCESS

In MRFF process, the nonmagnetic bodies are abrasive particles. Therefore, the levitation force pushes the abrasive particles towards the workpiece surface. Many abrasive particles are embedded and supported by CIPs chains and they perform finishing on the workpiece surface. The strength of the CIPs chains plays a significant role in the finishing mechanism and it is governed by the yield stress of MR fluid. Hence, the stiffness of MR fluid depends on the rheological properties such as yield stress and viscosity. The polishing characteristics such as surface finish, material removal rate, etc. depend on the stiffness (yield stress) of MR fluid under the effect of magnetic field.

Many abrasive particles are used for finishing such as silicon carbide, aluminium oxide, cerium oxide, diamond powder, colloidal silica, etc. However, cerium oxide is the most appropriate for finishing glasses and silicon-based materials [12] because it is chemically active with these materials which results in high MRR. L.M. Cook [20] observed that CeO_2 has a chemical tooth that promotes bonding of the abrasive particles with the silica, which increases material removal from the silica network and inhibits re-deposition of material back onto the surface. Shorey et al. [8] and Kim et al. [9] also used CeO_2 abrasives for finishing of glasses and silicon micro channels, respectively in MRFF process. Sunil Jha and V.K. Jain [6] used 20 vol% silicon carbide (*SiC*) abrasive particles of 400 mesh size for finishing of internal surface of stainless steel workpiece using Magneto-Rheological Abrasive Flow Finishing (MFAFF), a hybrid nano-finishing machining process. Sunil Jha, and V.K. Jain [19] used three different mesh sizes of Silicon Carbide (*SiC*) abrasive particles 800, 1200 and 2000; 20 vol.% on a stainless steel workpiece to study the effect of particle size on the finishing process. Dong Woo Kim et al. [13] used alumina abrasive particles on *BK7* glass workpiece to study material removal mechanism under various slurry conditions for MR Polishing. B Jung et al. [14] used sintered iron-carbon nanotube (I-CNT) abrasives 0-20% Vol. and mean size 15 µm on a hard disk slider surfaces made of Al_2O-TiC to study the effects of the weighting loss and severity factors, along with their significance and relative importance in optimizing the finishing process and observed that increase in the volume fraction of I-CNT abrasives in the MR fluid increases the averaged mechanical strength of the finishing tool, which improves both the MRR and R_a in the regions of interest. Ajay Sidpara and V.K. Jain [15] used CeO_2 and Diamond particles of size 1.8 µm and 4.5 µm respectively to study the effect of size, concentration and type of abrasive particles as well as the size of magnetic particles on material removal rate and percentage change in surface roughness on a single crystal silicon workpiece. R. Gheisari et al. [16] used diamond particles of size 10-20µm for finishing of aluminium workpiece in their experimental study.

IV. INFLUENCE OF MAGNETIC FIELD IN MRFF PROCESS

The main component in MRFF process is MR fluid, which consists of carrier fluid, magnetic iron particles, additives and nonmagnetic abrasive particles. The quality of the final machined surface in MRFF process basically depends on the concentration of constituents in MR fluid i.e. carrier oil, magnetizable iron particles, additives, abrasive particles and the on-state and off-state rheological properties (yield stress and viscosity respectively) which is a function of applied magnetic field. Literature available on MRFF process clearly shows that magnetic flux density plays a very important role in improving the surface characteristics. A number of researchers investigated the effect of magnetic flux density in MRFF process. Ajay Sidpara and VK Jain [17] investigated the effect of various process parameters in MRFF processes using magnetic ribbon. The effects were correlated with final R_a and material removal rate (MRR) and concluded that the contribution of magnetic flux density is maximum on viscosity (47.58%) and yield stress (44.85%). Sunil Jha and VK Jain [6] conducted experiment on developed MRAFF process with stainless steel workpieces at different values of magnetic field strength to observe its effect on final surface roughness. It was concluded that there was no measurable change in surface roughness observed at zero magnetic field and the finish increases gradually with the increase of magnetic field strength, for the same number of cycles. W. Kordonski and A. Shorey [5] stabilized the round jet of MR fluid by an axial magnetic field as it flows out of the nozzle. It had been experimentally shown that a stable and reproducible material removal function can be achieved at a distance of several tens of centimetres from the nozzle. Ajay Sidpara et al. studied the contribution of various parameters by applying design of experiment in the experimental studies and concluded that magnetic field has the maximum contribution on the viscosity and yield stress of the MR fluid, and it was 49.95% and 92.72% respectively. Dong-Woo Kim et al. [13] investigated the polishing characteristics in MRFF process for BK7 glass by changing process parameters and concluded that material removal rate increases with increase in electric current. Many other researchers used electromagnets at constant magnetic flux density and also permanent magnets which produces a constant magnetic field but still the effect of magnetic field was found a really significant role in finishing process.

V. CONCLUSION

The magnetic field that controls the stiffness of MR fluid during shearing plays the most significant role in finishing of the surface in MRFF. At high magnetic flux density, MR fluid shows high resistance before

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yielding. As magnetic flux density increases, magnetic interaction force between two magnetic particles increases significantly. Hence, the strength of Chains of magnetic particles increases, which in turn increases the stiffness of the MR fluid, i.e., yield stress. But a very high yield stress of MR fluid is also not preferable for finishing of soft materials because it causes the MR fluid to interact rigorously with the workpiece surface and creates deep micro-/nano-scratches. Hence, a moderate yield stress is desirable for achieving low final roughness as well as high MRR. Furthermore, when magnetic flux density is high the yield stress of MR fluid is also high which causes lesser movement of magnetic particles during flow of MR fluid. It also increases the viscosity of MR fluid. Because of the high yield stress and high viscosity, the MR fluid interacts aggressively with workpiece without undergoing yielding which results in high final surface roughness value and high MRR.

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