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A REVIEW ON THE USE OF MR FLUID ASSISTED FINISHING PROCESSES

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ABSTRACT

Magnetorheological (MR) fluid comes in the category of smart materials because of their unique characteristics. Rheological behaviour of MR fluids changes with the help of magnetic field. This characteristics of MR fluid is very helpful for regulation of finishing forces in finishing processes. A mixture of MR fluid with abrasives are used in finishing processes. Finishing of a component involves a very important and final step in manufacturing industries. Present paper deals with a review on MR fluid assisted finishing processes.

Keywords*: *Magnetorheological (MR) fluid, Abrasives, Finishing processes

I. INTRODUCTION

Precise finishing is desired in industries for various types of components. A number of conventional finishing processes are in use from long times for finishing of simple shapes components. Invention of more and more hard material takes place with the advancement of technology and need. Also shape complexity of components or parts increases simultaneously. All this led to the involvement of advanced finishing processes for precise finishing of various complex shapes component made of different materials[1]. Various types of advanced finishing practices have been developed and hybridised in last few decades which includes Abrasive flow machining (AFM) process and its variants like Magneto-abrasive flow machining (MAFM) process, Centrifugal force assisted AFM (CFAAFM) process , Electrochemical aided AFM (ECAFM) process, Drill bit guided AFM (DBG-AFM) process, Magnetic abrasive finishing (MAF) process, Chemo mechanical polishing (CMP) process. All conventional as well as advanced finishing processes makes use of abrasive particles in different bonded and unbonded form. But, these conventional as well as advanced finishing processes are unable to control finishing forces acts on work surface during finishing operation. Control of finishing forces is very necessary to obtain precise finishing[2]. Also different kinds of work material surfaces needs different magnitude of finishing forces. To overcome this, a magnetorheological fluid assisted finishing process was developed by Center for optics manufacturing (COM) in Rochester, N.Y. The developed process named as magnetorheological finishing (MRF) and has the ability to externally control the finishing forces. Since then, a number of finishing setup are evolved which makes use of magnetorheological (MR) fluid. The present paper gives a review on magnetorheological (MR) fluid assisted finishing and its expansion.

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II. MR FLUID ASSISTED FINISHING PROCESSES

A number of MR fluid assisted finishing processes have been developed by various researchers. A classification of these processes is given in Fig. 1.

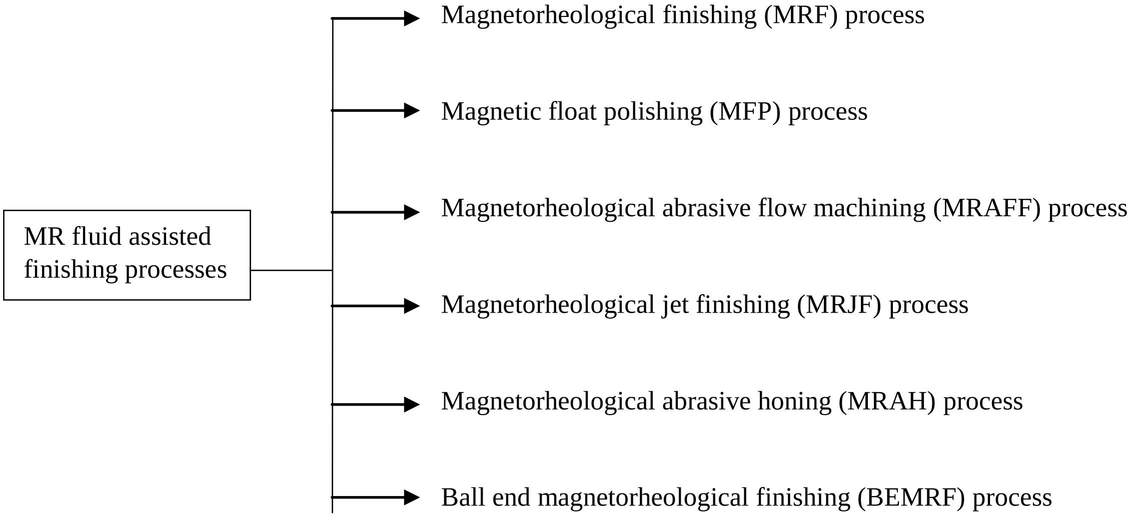

Fig1: A Classification of MR fluid assisted finishing processes

III. MAGNETORHEOLOGICAL FINISHING (MRF) PROCESS

Magnetorheologicalfinishing is a magnetic and MR fluid based finishing process which was initially introduced in Minsk, Belarus and after that it was fully developed and commercialised by QED Technologies[3]. In magnetorheological finishing (MRF), the MRP fluid is supplied to the circumferential edge of a rotating wheel. The rotating wheel is positioned on work surface in such a way that a converging gap takes place. A schematic diagram of magnetorheological finishing (MRF) is shown in Fig. 2. When a magnetic field is applied, rheological property of MRP fluid changes and it gets stiffened. The stiffened MRP fluid on periphery of rotating wheel tool helps to remove peaks from the surface of work material. The shape of MRP fluid on periphery of rotating wheel is determined by magnetic field strength, MRP fluid flow rate, rotating tool speed and the gap between work surface and rotating wheel tool[4].Cheng et al. [5] were introduced a self-rotating wheel for finishing of K9 glass. Experimental study was conducted by with and without use of abrasive particles in MR fluid and they observed that surface finish increased three times with the use of abrasive in MR fluid. In another work, effect of different types of abrasives was investigated by Cheng et al. [6]. They found higher material removal with the use of diamond particles. A number of researchers have used MRF for polishing of silicon wafers silicon micro channels [7][8][9]. A new method for fine finishing of cylindrical workpiece was presented by Gheisari et al. [10]. A standard composition of MRP fluid comprising of carbonyl iron particles and cerium oxide abrasives mixed in deionised water with some additives have been used for polishing of various types of optical glasses. Effect of a different composition of MRP fluid was investigated by Jacobs et al. [11] for polishing of IR materials. A different variant of MRF was presented by Pattanaik and Agarwal [12] for finishing of free form surface of copper material. Process parameters effect on final surface finish of free form copper workpiece was investigated by authors. Effect of various process parameters on material removal of BK7

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borosilicate glass was also investigated by Miao et al. [13]. Chen et al. [14]in their published work presented some improvements with magnetorheologicalfinishing of KDP crystals. Sidpara and Jain [15] presented an experimental investigation with the use of different kinds of abrasives and base fluid. Chemical interaction on silicon surface was observed with the use of different MRP fluid samples. Effect of magnetic as well as nonmagnetic particle concentration, size and type was investigated on surface of single crystal silicon [16]. Nano level finishing of synchrotron beam line mirrors and freeform surfaces of knee joint implant was also carried out with the use magnetorheological finishing process [17][18].

IV. MAGNETIC FLOAT POLISHING (MFP) PROCESS

Magnetic float polishing process wasinvented for efficient finishing of very hard materials like ceramics. Hard ceramics possess certain defects during conventional grinding process and sometimes it leads to fatigue failure [19]. MFP process makes use of magnetic slurries in finishing of ceramic balls and bearing rollers. This technique is based on the ferro-hydrodynamic behavior of a magnetic fluid where effect of magnetic field is utilised to levitate non-magnetic suspensions. The levitation force applied on nonmagnetic bodies is proportional to the field gradient and is highly controllable. A schematic diagram of magnetic float polishing is shown in Fig. 3. Chemistry of abrasive particle type with the workpiece surface is also important to know. In a study Komanduri et al. [20] investigated for the effect of chemical interaction of different types of abrasives with the work surface of silicon nitride. Effect of various process parameters on final surface roughness of silicon nitride balls was investigated by Jiang and Komanduri[21]. Effect of polishing force was found most significant for final surface roughness.

V. MAGNETORHEOLOGICAL ABRASIVE FLOW FINISHING (MRAFF) PROCESS

Magnetorheological abrasive flow finishing process is similar to abrasive flow machining (AFM) process. Actually MRAFF is an hybrid version of AFM process that involves an inclusion of magnetic field assisted MRP fluid which is extruded back and forth through the restricted passage formed by work surface and tooling fixture [22]. The newly developed process possess determinism and controllability of finishing forces during finishing practice. Effect of process parameters on final surface roughness is very important. In a study, Jha and Jain [23] investigated the effect of extrusion pressure and number of finishing cycles on final surface roughness of stainless steel work surface. Finishing capability of MRAFF process on brittle and hard silicon nitride work surface was carried out by Jha and Jain [24]. Effect of different types of abrasive based MRP fluid samples was investigated for final surface roughness. Author’s Jha and Jain [25] reported that magnetic flux density is most significant parameter in MRAFF process. It was also reported that a best surface finish of 30 nm surface roughness achieved on stainless steel workpiece. In another study force analysis on abrasive particle was carried out by Jha and Jain [26]. An upgraded variant of MRAFF termed as Rotational Magnetorheological abrasive flow finishing (R-MRAFF) was introduced to improve process performance of MRAFF. The polishing medium was rotated around the axis of medium cylinder by imparting a rotational arrangement of permanent magnets around the workpiece fixture [27]. A schematic diagram of both MRAFF and R-MRAFF process shown in Fig. 4. (a.) and (b.). Experiment were conducted on different work materials to study the effect of various process

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parameters on final surface roughness. It was found that rotational speed has the highest impact for the percentage change in surface roughness.

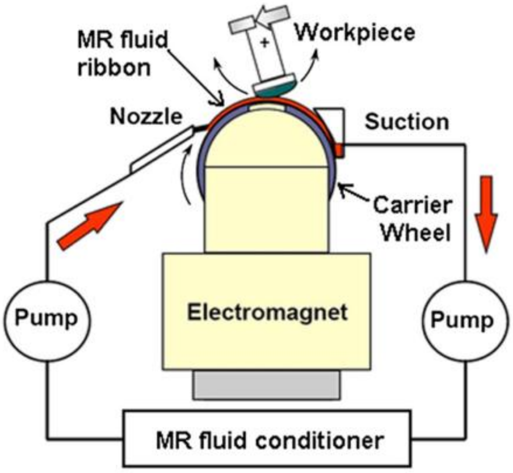

Fig.2. Schematic diagram of magnetorheological finishing (MRF) [28]

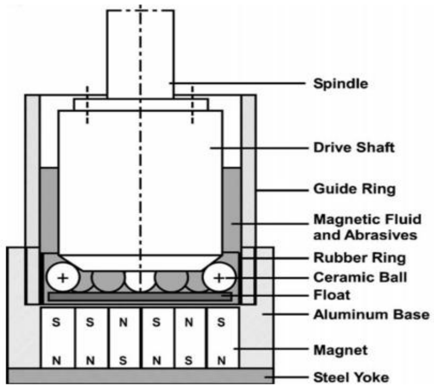

Fig. 3. Schematic diagram of magnetic float polishing [19]

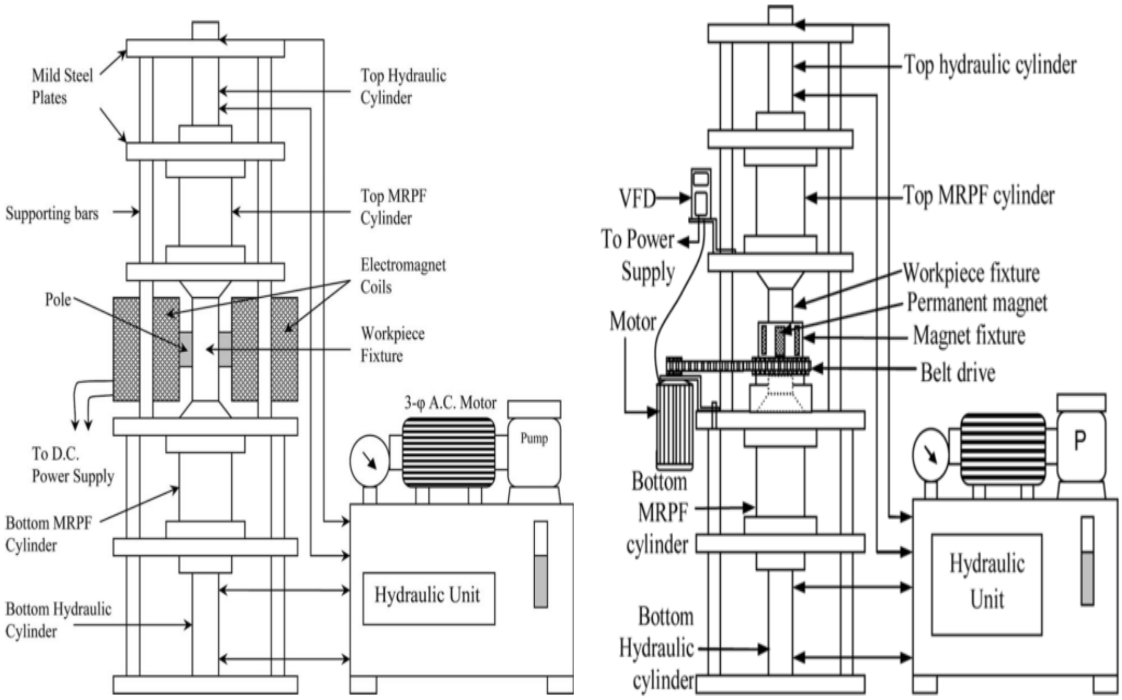

Fig.4. Schematic diagram of (a) MRAFF process[22](b.) R-MRAFF process[29]

VI. MAGNETORHEOLOGICAL JET FINISHING (MRJF) PROCESS

Magnetorheological jet finishing (MRJF)process was developed to finish freeform and steep concave optics which are otherwise challenging to finish using traditionalmethods[30]. In MRJF, a magnetically stabilized jet

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of MRP fluid from nozzle is made to act on worksurface at a distance of several tens of centimetres.A schematic diagram of MRJF process is shown in Fig. 5. Authors Tricard et al. [31]reported for the ability of MRJF process for precise finishing of materials like glasses, single crystals, advanced creamics and metals. The effect of process parameters on material removal of BK7 glass in MRJF process was investigated by authors. They found a significant effect of MR fluid compositions and process duration on material removal.

VII. MAGNETORHEOLOGICAL ABRASIVE HONING (MRAH) PROCESS

A new finishing process termed as magnetorheological abrasive honing (MRAH) was developed by Sadiq and Shunmugam[32]. Magnetorheological abrasive honing (MRAH) is similar to the conventional honing except that the rotational motion is provided to workpiece. In MRAH process, a reciprocating motion is provided to the medium while simultaneously workpiece is made to rotate within the medium. Experiments were performed to understand the effect of various process parameters on final surface roughness of stainless steel and aluminium workpiece. It was concluded that surface finish was improved by increasing the magnetic field density as the fluid develops greater yield strength to remove the surface irregularities. Authors also reported for an increase in surface finish with process duration.In another study, effect of magnetic field on the surface of magnetic and non-magnetic materials was investigated by Sadiq and Shunmugam[33]. A schematic diagram of MRAH process is shown in Fig. 6.

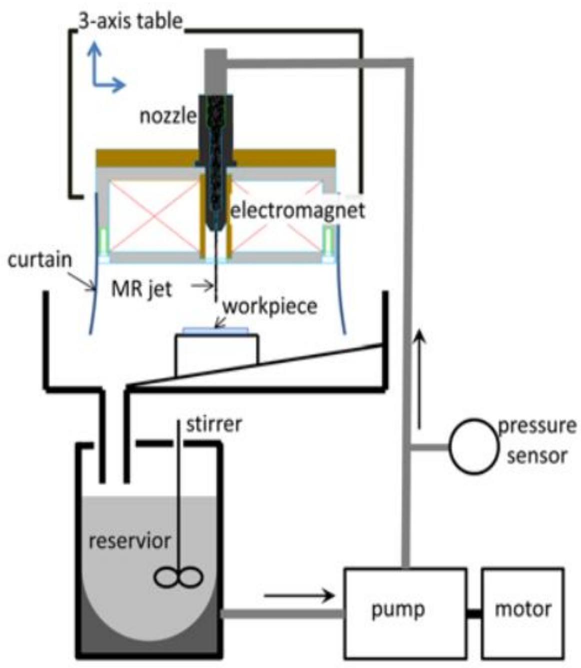

Fig. 5. Schematic diagram of MRJF process [34]

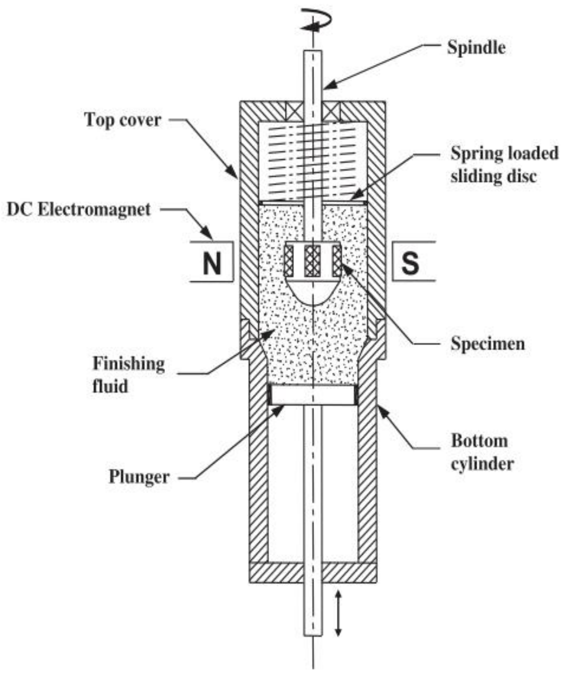

Fig. 6.Schematic diagram of MRAH process [33]

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VIII. BALL END MAGNETORHEOLOGICAL FINISHING (BEMRF)

Ball end Magnetorheological finishing (BEMRF) process was developed for the fine finishing of complex 3D shape components[35]. A schematic diagram of BEMRF process is shown in fig. 7. The pressurized MRP fluid from the reservoir enters to top side of BEMRF tool. BEMRF tool comprise of a central rotating core with a stationary electromagnet around it. The MRP fluid made to flow from top side to the bottom side of BEMRF tool. As soon as MRP fluid comes out from the tool tip, magnetic field concentrates on it with the help of designed electromagnet. Due to magnetic effect, a semi-solid structure of MRP fluid formed at tool tip. Material removal from work surface takes place, when this rotating ball end shape like semi-solid structure comes in contact with the work surface. Researchers Singh et al. [36] investigated the effect of finishing passes on different project faces of a 3D ferromagnetic workpiece. An experimental study to investigate the effect of BEMRF process parameters on final surface roughness of silicon work surface was also carried out. After observations of experimental data, working gap was considered as most effective parameter for final surface finish of silicon [37]. In another study, effect of finishing time was observed for final surface roughness of fused silica glass. It was found that after 90 minutes of finishing time surface roughness of fused silica reduced down to 0.146 nm.

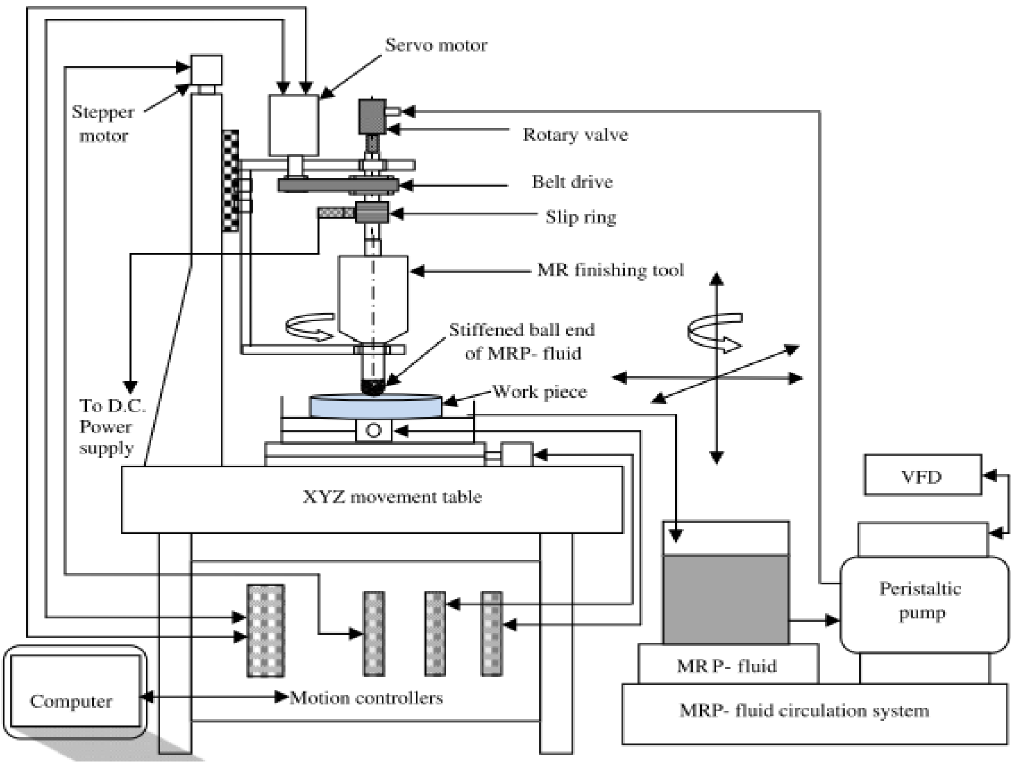

Fig. 7. Schematic diagram of BEMRF process [35]

IX. CONCLUSION

A review on MR fluid assisted finishing processes is presented in this paper. From the above discussion it is concluded that MR fluid possess unique characteristics of its rheological change when subjected to an external magnetic region and because of this unique characteristics, MR fluids are widely used in finishing processes. Various types of MR fluid assisted finishing setup have been developed by researchers for finishing of different shape components. Composition of MR fluid along with abrasives for a specific type of work material is important. Therefore there is a need to further focus on the use of specific types of MR fluid compositions with different types of workpiece materials. There is lot of published work is available on finishing of optical glasses and crystals but the use of MR polishing fluids for finishing of metals need to be explored.

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