A REVIEW ON RECENT DEVELOPMENTS IN MAGNETORHEOLOGICAL FLUID BASED FINISHING PROCESSES

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ABSTRACT-The recent engineering applications demand the use of tough, high intensity and high temperature resistant materials in technology, which evolved the need for newer and better finishing techniques. The conventional machining or finishing methods are not workable for the hard materials like carbides; ceramics, die steel. Magnetorheological fluid assisted finishing process is a new technique under development and becoming popular in this epoch. With the use of external magnetic field, the rheological properties of the MR fluid can be controlled for polishing the surfaces of components. An extended survey of the material removal mechanism and subsequent evolution of analytical MR models are necessary for raising the finishing operation of the MR fluid process. Understanding the influence of various process parameters on the process performance measures such as surface finish and material removal rate. The objective of this study is to do a comprehensive, critical and extensive review of various material removal models based on MR fluid in terms of experimental mechanism, finding the effects of process parameters, characterization and rheological properties of MR fluid. This paper deals with various advancements in MR fluid based process and its allied processes have been discussed in the making the developments in the future in these processes.

KEYWORDS: **Magnetorheological fluid (MR fluid), Process parameter, Surface roughness, Material removal rate**

1. INTRODUCTION

The modern engineering applications have necessitated high precision manufacturing. For most engineering components the surface roughness plays a vital role in their service life. It influences the fatigue life since irregular and rough surfaces are generally subjected to fatigue stresses as a result of which premature failure of the component occurs [1]. As surface roughness increases, many problems are experienced such as resistance to flow, friction, wear and tear, etc. leading to a lower efficiency of the component. Hence, in some applications, a surface polishing operation is required during or after manufacturing process to make them suitable for achieving the desired function. The conventional finishing processes such as grinding, lapping, etc. are unable to produce the surface roughness of the order of nanometer as the complexity of the surface increases and control over the process is not achieved beyond a limit [2]. Therefore, advanced finishing processes are of significant importance for components high precision.

2. CONVENTIONAL FINISHING PROCESSES

Before continuing discussion of advanced fine precision finishing processes, it is essential to understand the underlying basic concept of conventional finishing processes viz. Grinding, lapping and honing. All these processes apply the use of multipoint cutting edge in the form of abrasives, which may or may not be bonded, to perform cutting action [3]. These processes have been in use for many decades because of their simplicity and capability to finish the surfaces at very close tolerances. It has been predicted that the machining accuracies obtained through conventional processes would be as narrow as 1 μm, while in precision and ultra-precision machining would be 0.01μm (10nm) and 0.001μm (1nm) respectively [4]. These accuracy objectives for recent ultra precision machining can't be accomplished by simple extension of conventional machining methods and techniques. New advanced finishing processes were evolved in the last few decades to vanquish the limitations of conventional finishing processes in terms of harder tool requirement and precise control of abrading forces during operation

3. ADVANCED FINISHING PROCESSES (AFP)

One of the important features of any finishing process is the precise control of abrading forces to obtain components with close tolerances and maintain the surface topography. Hence, the processor model that can control the forces in real time is the most suitable processes for finishing different types of materials to the surface roughness value of a nanometer. There are many developments taking place in the polishing of materials with fine abrasive particles, for obtaining the surface finish in the order of nanometer. Finishing operations are the most significant, costly, and labor intensive areas in the overall production process. Abrasive processes are extensively used for finishing operations as they provide a high degree of surface finish and close tolerances [5]. Some advanced finishing processes like abrasive flow finishing (AFF) [6], and some magnetic field assisted finishing processes such as magnetic float polishing (MFP) [7], magnetic abrasive finishing (MAF) [8] have evolved in the last few decades.

4. MAGNETORHEOLOGICAL FINISHING (MRF)

Finishing high precision surfaces are really expensive and labor intensive as they are traditional. Center for Optics Manufacturing has developed a technology to automate the lens finishing process using magnetorheological fluid finishing (MRF) technique to overcome the difficulties associated with conventional method. MR-Fluids are suspensions are prepared with micron sized magnetizable particles such as carbonyl iron, dispersed in a non-magnetic carrier medium like silicone oil, mineral oil or water. Newtonian behavior is exhibited by an ideal MR fluid in the absence of magnetic field. After the application of an external magnetic field, then the CIPs form the chain and embed the particles among them for performing the finishing action [9,10].

5. MECHANISM OF MR FLUID BASED PROCESSES

Cheng et al [11,12] developed the self rotating wheel and brass wire coils aligned to the direction of the axis type mechanism for analyzing the magnetic field strength, the frame of the fluid along the periphery of wheel, fluid flow rate. In another study, an observational study was carried with and without using abrasive particles in the fluid to ensure the result of surface roughness. Mali et al [13] designed and developed a two way AFM set up for finishing the internal passage. Li et al [14] developed a set up for finishing the peculiar parts for which they simulated the AFM process for its speed and pressure distribution using CFD software. Jha et al [15] designed and fabricated a magnetorheological abrasive flow finishing process for polishing the internal geometries of the stainless steel workpieces. The MRAFF process depends on extrusion of a magnetically stiffened slug of magnetorheological polishing (MRP) fluid backward and forward through or across the passage formed by work piece surface and fixture. The abrasive particles embedded between CIP chains under axial extrusion pressure perform the finishing action. The rheological behavior of polishing fluid changes from nearly Newtonian to Bingham plastic and vice versa upon entering and exiting the finishing zone respectively [16]. It is observed that magnetic field, concentration of CIPs as well as abrasive particles significantly influence the yield stress and viscosity [17]. It is also observed that MR fluid exhibits shear thinning phenomenon. The viscosity of smart magnetorheological polishing fluid (MRPF) is a function of applied magnetic field strength, and This can be varied according to the desired finishing characteristics. The shearing of the Bingham plastic polishing fluid near the workpiece surface contributes to the material removal and consequently to the finishing process [18]

6. PARAMETRIC REVIEW OF MR FLUID PROCESSES

R. Turczyn et al [19] have developed the model magnetorheological (MR) fluids for preparing the MR by using three types of carriers that is silicone oil OKS 1050, synthetic oil OKS 352 and Mineral oil OKS 600.This oil mixed with carbonyl iron powder CI HQ also, added stabilizers Aerosil 200 and 972, Arsil 1100 and Arabic gum. Stabilizers reduce the sedimentation. Due to sedimentation, incomplete chain formation so the MR fluid response to the magnetic field is restricted and in an extreme situation MR fluid containing device can fail. So, in order to avoid the failure of device, it is essential to use stabilizers in the MR fluid. Stabilizers maintain good stability. M.Kciuk et al [20] conducted experimentation on model MR fluid prepared using silicone oil OKS 1050 mixed with carbonyl iron powder CI and Aerosil 200 was added as stabilizers. It was confirmed on the basis of conduct investigations that the enlargement of the concentration of magnetic particles (CI) increases the dynamic viscosity of MR fluid. Addition of silica prevents concentrating of the CI particles and it results in the gel mesh formation. Jain et al [21] have studied the MAF process on non-magnetic stainless steel work piece with loosely bonded magnetic abrasives. He reasoned out that the working gap and circumferential speed are the parameters which significantly influence the surface roughness value (Ra). D. Singh et al [22] have investigated the important parameters such as voltage, rotational speed of the magnet, working gap, and abrasive size influencing the surface quality generated during the MAF. They too reported that the magnetic force and tangential cutting force increase with an increase in voltage and decrease in working gap. A. Wani [23] focuses on the modeling and simulation for the prediction of surface pitting on the brass workpiece surface finished with MAFF process. Shai N. Shafrir et al [24] have focused on five nonmagnetic tungsten carbide (WC-Ni) materials, including one binder less material. It was found that the peak-to-valley (p–v) micro roughness of the surface after micro grinding with rough or medium abrasive size tools gives a measure of the deformed layer depth. Manas Das, V. K. Jain [25] has developed magnetorheological abrasive flow finishing technique for nano finishing of components. They contemplated the effect of current to the electromagnet or magnetic flux density and number of cycles on the surface finish of the stainless steel work piece. It is noted that reduction in surface roughness value by increasing the number of cycles when the current increased from 1 to 6A of an electromagnet. As a consequence, the probability of rotation of abrasive particles responsible for removal of material is really less. Jung et al [26] used effective abrasives, namely magnetizable abrasives containing iron powders which are sintered with nano-pipes made of carbon for finishing aluminum oxide and titanium carbide materials. Ajay Sidpara, et al [27] conducted the experiments on silicon work piece with different cases of MR fluid and examined how the abrasives (CeO_2 and Al_2O_3) and carrier (paraffin oil and water) interact chemically and how it affects the nanopolishing of single silicon crystal by finishing process. It is brought out from the experiment that MR fluids with oil as carrier fluid have low yield stress compared to MR fluid with water as the carrier fluid when a magnetic field is same. For greater polishing and high MRR, high yield stress is essential.

In order to get good surface finish, it is essential to know the characteristic efficiency of the finishing fluid. Keeping in view this, Wan Li Song et al [28] investigated the finishing efficiency of magnetorheological fluid using a pin-on-disc tester on steel specimen surfaces under magnetic field. The experimental results verified by multiple regression model. The highest concentration of MR fluid is better finishing ability to reduce surface roughness. Ajay Sidpara, et al [29-30] has investigated experimentally and theoretically the forces acting on the work piece during the MRF finishing process. They summarized that there is an increase in normal and tangential forces with an increase in CIPs concentration; however, there is a decrease in forces with an increase in the gap and abrasive's concentration. Ajay Sidpara, et al [31, 32] has used a single crystal blank of silicon by varying particle size of CIP and the concentration of CeO2 and diamond particles in MR fluid. They reported that increasing the CIPs size ranging from 1.1 μm to 2 μm then enhances the material removal rate and reduction in surface roughness. However, if the carbonyl iron powder size is further increased from 5µm and 9 µm, decreases the surface finishes. This is due to deeper penetration and non-uniform nature of the strength of the MR fluid. If the difference between Carbonyl Iron Powder and abrasive particles is minimized, then better finishing results are achieved. High yield stress of MR fluid results in increased MRR but simultaneously it increases surface roughness. R. Singh1 et al [33] devised a new abrasive flow finishing process which is assisted by hybrid magnetic force. The influences of the different process parameters investigated such as magnetic flux around 0.2-0.7 T, abrasive particle size in the range of 60-65 µm, polymer to gel ratio was 1:1 % by weight and aluminum oxide to iron powder was 3:2 % by weight, temperature of the medium was around 32 ± 2 °C, and the initial surface roughness of the specimen was kept 0.6-1.1 µm. Kanthale et al [34, 35] studied the different configuration of electromagnets for verifying the magnetic field strength as well as different shape of finishing tools to characterize the surface roughness of the mild steel specimens. They assessed the parameters processing time, voltage, rotating speed of the tool, and ratio of iron filings and aluminum oxide particles. It was reported that the processing time, and iron filings and abrasive particles plays an significant role for finishing the mild steel surfaces. A.K Singh [36-38] Ball end MR finishing tool is designed and fabricated for finishing of 3D surfaces of ferromagnetic and non ferromagnetic work pieces. They reported that the working gap, finishing time and strength of the magnetic field around tool was an effective parameter for obtaining better surface finishes.

7. CONCLUSION

MR fluid based finishing processes are capable of finishing complex geometries in a broad assortment of material of workpieces. It has been observed from the substantial study of literature:

1) The MR fluid based process is having a great capability, less affected surface integrity of processed parts, but the low material removal rate compared to other advanced finishing process.
2) The CIP and abrasives are prime components of the operation. Stiffness of MR fluid is dependent on magnetic field strength and size of CIPs. Size of abrasives and its type influence material removal rate and time of cycle.
3) Magnetizing force of CIPs, Normal force and tangential cutting force plays a vital role during the finishing process.
4) Optimization of process is essential for economic and efficient use of process. When analytical methods are absent, optimization of process is difficult and time consuming.
5) This study would also provide a base for developing an effective, economic, and efficient strategy for optimization and control of the process.

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