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Study on Advanced Super Finishing Processes

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Abstract: *Poor surface quality of engineering products results in various problems during operations, such as malfunctioning, excessive wear, geometric inaccuracy etc.,because Surface quality is one of the most important properties of the precision devices. Advanced super finishing processes are all about latest technology which is useful for super finishing of various materials with very high precision and accuracy. The traditional finishing processes like honing, grinding, lapping polishing and superfinishing etc., are having certain disadvantages especially while working on complex shapes, intricate areas and does not offer a flexible, cost effective option for finishing small precision devices. This reason made researchers to work on alternative methods. Of course, the advanced super finishing processes have got more precisionthan traditional methods. Hence, an attempt is made to study on various super finishing processes such as abrasive flow machining**,** magnetic float polishing, Magnetorheological abrasive honing,magneto rheological abrasive finishing and magneto rheological finishing. The working of above methods are studied and presented in this paper.*
Keywords: *precision, accuracy, super finishing, abrasive*.

I. Introduction

Precision finishing of internal surfaces and complex geometries is always tough task and very difficult to control. there are many advances taking place in the finishing of materials with fine abrasives, including the processes, the abrasives and their bonding, making them capable of obtaining nanometer order surface finish. abrasives with small multiple cutting edges are generally employed to remove unwanted material from work piece to get desired shape, surface finish and geometrical accuracy. the traditional finishing processes such as grinding, lapping and honing works on this mechanism of finishing. but due to the development of new materials which are difficult to machine, intricate areas and complex geometrical shapes of various components, the available traditional finishing processes are alone not capable of producing required surface finish.advanced super finishing processesare developing in the last few decades have attributed to the relaxation of limitations of tool hardness requirement in edm, ecm, usm, ajm etc. many advanced finishing processes have been developed to tackle various issues faced in traditional methods. magnetorheological fluid (mr fluid) assisted finishing processes are one such kind of finishing processes, which has greater flexibility towards process control and one can finish with close tolerances and without damaging surface topography. more number of polishing techniques is evolved using magnetorheological fluid. some of them are magnetorhelogical finishing (mrf), magnetorheological jet finishing (mrjf), magnetorheological abrasive finishing (mraf), and magnetorheological abrasive honing (mrah). this paper provides a comprehensive study onvarious magneto rheological finishing process and abrasive flow machining.

II. The Traditional Finishing Processes

The surface finish has a vital role in influencing functional characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction. Unfortunately, normal machining methods like turning, milling or even classical grinding cannot meet this stringent requirement.

1. Lapping

Lapping is regarded as the oldest method of obtaining a fine finish. Lapping is basically an abrasive process in which loose abrasives function as cutting points finding momentary support from the laps. Figure 1 schematically represents the lapping process. Material removal in lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1mm in certain cases.

Characteristics of lapping process:

- Use of loose abrasive between lap and the workpiece
- Usually lap and workpiece are not positively driven but are guided in contact with each other
- Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the workpiece.

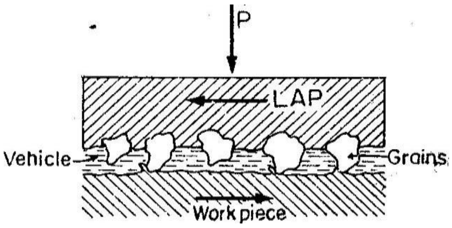

Fig.1 Scheme of lapping process

Cast iron is the mostly used lap material. However, soft steel, copper, brass, hardwood as well as hardened steel and glass are also used.

Abrasives of lapping:
- Al_2O_3 and SiC, grain size 5~100µm
- Cr_2O_3, grain size 1~2 µm
- B_4C_3, grain size 5-60 µm
- Diamond, grain size 0.5~5 V

Vehicle materials for lapping
- Machine oil
- Rape oil
- grease

Technical parameters affecting lapping processes are:
- unit pressure
- the grain size of abrasive
- concentration of abrasive in the vehicle
- lapping speed

2. Honing

Honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the workpiece does not perform any working motion. Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. The honing stones are held against the workpiece with controlled light pressure. The honing head is not guided externally but, instead, floats in the hole, being guided by the work surface (Fig.2). It is desired that
1. honing stones should not leave the work surface
2. stroke length must cover the entire work length.

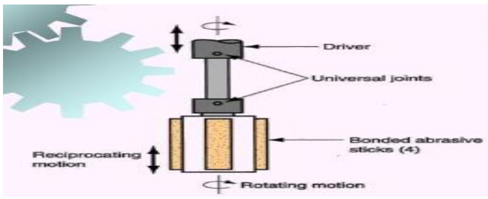

Fig 2: Honing

The honing stones are given a complex motion so as to prevent every single grit from repeating its path over the work surface. The critical process parameters are:
1. rotation speed
2. oscillation speed
3. length and position of the stroke
4. honing stick pressure

3. Super finishing

Figure 3 illustrates superfinishing end-face of a cylindrical workpiecein radial mode. In this both feeding and oscillation of the superfinishing stone is given in the radial direction.

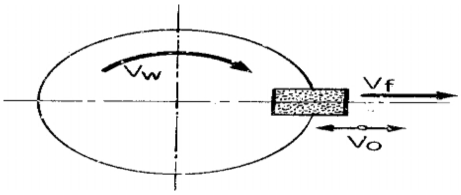

Fig 3

Figure 4 shows the superfinishing operation in plunge mode. In this case the abrasive stone covers the section of the workpiece requiring superfinish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction.

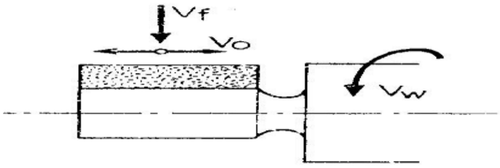

Fig 4

4. Grinding

Grinding is a metal cutting operation performed by means of abrasive particles rigidly mounted on a rotating wheel. Each of the abrasive particles act as a single point cutting tool and grinding wheel acts as a multipoint cutting tool. The grinding operation is used to finish the workpieces with extremely high quality of surface finish and accuracy of shape and dimension. Grinding is one of the widely accepted finishing operationsbecause it removes material in very small size of chips 0.25 to 0.50 mm. It provides accuracy of the order of 0.000025 mm. grinding of very hard material is also possible.

The Indian Standard Coding system of grinding wheel is IS : 551-1954. It provides uniform system of coding of grinding wheels to designate their various characteristics. It gives a general indication of the hardness and grit size of any wheel as compared with another. Coding of a grinding wheel consists of six symbols as described below.

W : Symbol for Manufacturer’s Abrasive Type (Prefixed)
C : Name of Abrasive
30 : Grain Size
L : Grade
5 : Structure Type
R : Bond Type
17 : Manufacturer Symbol for Record (Suffix)

The sequence of codes of a grinding should be followed in the same sequence as described above. There are six symbols and first one which is seventh, is optional.

III. Advanced Super Finishing Processes

1. Abrasive Flow Machining (Afm) Or Abrasive Flow Deburr Or Extruder Honing.

This process was developed basically to deburr, polish and radius difficult to reach surfaces and edges by flowing abrasive laden polymer over the work piece surface.

It uses two vertically opposed cylinders, hydraulic ram fixture, clamping system and the medium(mixture of viscoelastic material and abrasive particles).

Abrasive fluid flows through workpiece by hydraulic ram.The key components of AFM are the machine, the tooling, types of abrasives and medium composition. In abrasive flow machining, the abrasive fluid flows through the workpiece, effectively performing erosion. Abrasive particles in the fluid contact raised features on the surface of the work piece and remove them.

Types of AFM are one- way flow process and two-way flow process.

AFM- may be manually operated or automated using CNC. Automated AFM is capable of handling 1000s of parts per day, not typically used for large stock removal operations.Its ability to process multiple parts simultaneously.

Applications of AFM:
Aerospace, aircraft, medical components, electronics, automotive parts, precision dies and moulds manufacturing industries, food processing, semiconductor equipment, pharmaceutical manufacturers and ultra clean or high purity devices.

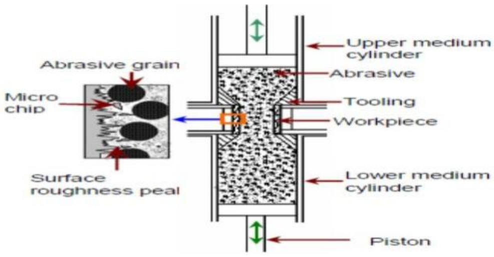

Fig.5 Abrasive flow machining

2. MAGNETIC FLOAT POLISHING (MFP)

Magnetic float polishing is a new technique developed for efficient finishing of very hard materials like ceramics.Because, they may develops defects during grinding leading to fatigue failure.

The process involves the use of magnetic field to support abrasive slurries in finishing ceramic balls and bearing rollers. This technique is based on the ferro-hydrodynamic behavior of a magnetic fluid.
The setup includes magnetic fluid containing fine abrasive grains and extremely fine ferromagnetic particles in a carrier fluid (water or kerosene) and work piece.

The ferro fluid is attracted downward towards the area of higher magnetic field and the abrasive grains, the ceramics ball, and the acrylic float inside the chamber. The drive shaft is fed down to contact the balls and to press them down to reach the desired force level and the balls are polished by the relative motion between the balls and the abrasives. Applications are for balls used in bearings.

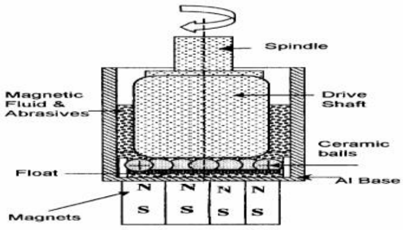

Fig.6 Magnetic Float polishing.

3. MAGNETORHEOLOGICAL ABRASIVE HONING (MRAH)

Sadiq and Shunmugam in 2009 [1,2] developed a finishing process which is similar to the conventional honing except the workpiece is given rotation while in conventional the stone rotates. The workpiece is rotated within the medium and at the same time a reciprocating motion is provided to the medium. Experiments were performed on stainless steel and Aluminium workpiece. From the experiments, the researchers are concluded that surface finish was improved by increasing the magnetic field density as the fluid develops greater yield strength to remove the surface irregularities. And also they found improvement in surface finish at higher rotation speed of the workpiece. Finite element analysis was also performedto understand the nature of magnetic field likely to be produced to calculate the axial stress due to the flow of MR fluid, and to predict final surface roughness value. The comparison of results reveals just satisfactory agreement. However, this analysis did not consider radial stresses developed in the medium.

4. MAGNETORHEOLOGICAL ABRASIVE FINISHING (MRAF)

This process depends on extrusion of a magnetically stiffened slug of fluid across the passage formed by workpiece surface and fixture byJha and Jain [3]. And the working process is similar to the Abrasive flow finishing(AFM) process. In AFM Process, the abrading forces are mainly depends on putty (polymeric medium) rheological behaviour, which has least control by the external forces. To overcome this controllability of the rheological properties of the abrasive medium, a new hybrid process “Magnetorheological abrasive flow finishing process was developed.

Jha and Jain [4] were carried out experiments to study the effect of Extrusion pressure, magnetic flux density, and number of finishing cycles on the change in surface roughness. They concluded that magnetic flux density was the main contributor in improving surface finish. As the magnetic flux density increases, CIP chains hold abrasives more firmly and result in faster finishing action. But surface roughness value progressively decreases with increase in finishing cycles.

The process MRAF is capable of super finishing hard materials such as silicon nitride (Si3N4) using boron carbide, silicon carbide, and diamond abrasivesJha and Jain [5]. In this process, magnetic field is applied to the cylindrical fixture with two cores of an electromagnet which are placed opposite to each other. Least magnetic field is observed on the cylindrical fixture. The workpiece kept in this zone, comparatively less finished than the one kept in the zone in front of the core material. To enhance the process performance and to optimize the polishing conditions, researchers Das, Jain et al. [6] have modified the existing MRAF setup as shown in fig.7 and achieved a higher relative velocity and higher finish rate.

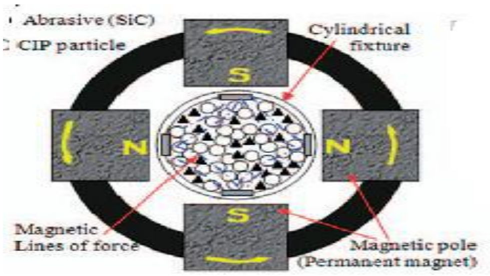

Fig.7 Mechanism of R-MRAF

5. MAGNETORHEOLOGICAL FINISHING(MRF)

MRF is a magnetic field assisted precision finishing process developed and commercialised by QED Technologies Inc.Kordonski and Jacobs 1996 [7] andJacobs, S. D., W. Kordonski, et al [8]. This is a precision technology that may produce surface accuracy on the order of 30nm peak to valley and surface micro-roughness less than 10Å rms. MRF was initiated in Minsk, Belarus by Kordonski and Gorodkin [9]. In 1999, MRF was fully commercialised by QED Technologies. The magnetically stiffened MR fluid generates a unique pressure distribution in the gap that is associated with an unsheared fluid, which is attached to the moving wall as shown in fig.8. A quasi –solid moving boundary is effectively formed very close to the surface of the workpiece resulting in the high shear stress in the contact zone and material removal over a portion of the workpiece surface. The material removal is enhanced by nonmagnetic abrasive particles, which are constitutes of the slurry and forced out to the polishing interface by a magnetic field gradient. When the MR fluid mixed with abrasives flows over specimen surface, the shear stress of the fluid generates a drag force to move the abrasives, which results in material removalKordonski and Golini [10] and Shorey, Jacobs et al. [11]

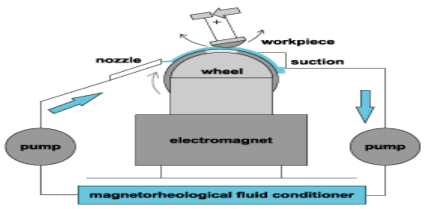

Fig 8. Magnetorheological Finishing Machine

QED technologies developed wheel kind of MR Finishing tool. In this the magnetorheological polishing fluid circulated continuously during the MRF process, the fluid adheres the periphery of the wheel. The shape of the fluid is determined by wheel speed, the magnetic field strength, gap between the workpiece and wheel, and fluid flow rateSchinhaerl, Smith et al. [12]. Cheng et al [13] were introduced a novel design of polishing tool comprising of a self-rotating wheel and brass wire coils aligned to the direction of its rotating axis as shown in Fig 9. They presented an experimental study to determine the magnetic fluid viscosity as a function of the applied electric voltage through generation of magnetic field. They observed that viscosity would increase with the driving voltage and Surface accuracy is improved over three times with abrasives in the fluid compared to the without abrasives.

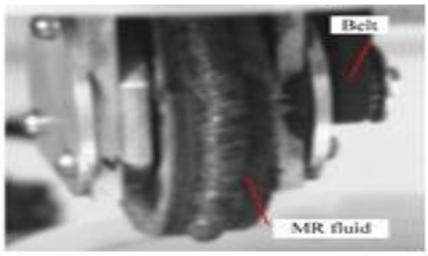

Fig. 9 The MRF under the action of the magnetic field

Cheng, Feng et al [14] are conducted experimental study on the reaction- bonded SiC components using Magnetorheological finishing. In this case they used MR fluid composition as Carrier fluid (water-55%), Magnetic particles (CI particles-36%) and abrasive particles (cerium oxide, alumina and diamond-6%) and stabilizer (silicon oil-3%) in Vol%. They observed that Diamond particles are giving higher material removal rate compared to CeO2 and Alumina. Additionally by adding small amount of CeO2 to the diamond based MR fluid, they observed significant change in surface finish. Miao, C., S. N. Shafrir [15] carried out experiment to measure the drag and normal forces in MRF using spot taking machine. Their approach experimentally addresses the mechanisms governing material removal in MRF for optical glasses in terms of the hydrodynamic pressure and shear stress. Their work reveals that the volumetric removal rate shows a positive linear dependence on shear stress that depends upon Young’s modulus, fracture toughness, and hardness.

6. MAGNETORHEOLOGICAL FLUID [MR FLUID]

All magnetorheological finishing processes relies for its performance on magnetorheological effect exhibited by carbonyl iron particles along with abrasive particles in non-magnetic carrier medium. The magnetorheological fluid and its composition are crucial in MRF processes, these are smart fluids discovered by Rabinow in 1948 [16], that responds to an applied magnetic field in their rheological behaviour. MR fluids are suspensions of micron sized magnetic particles in a viscoelastic base medium such as water, glycerol, silicone oil, paraffin oil with some additives. In the absence of magnetic field, these fluids exhibit non Newtonian behavior. On the application of magnetic field, these fluids become stiffer and large shear force is required to make the fluid flow. Its ultimate strength is limited by magnetic saturation.

Ginder, J [17] The selection of the carrier liquid determines the temperature ranges in which the MR fluid can be utilized. Even though silicone oil is the most frequently used carrier liquid, hydrocarbon oil has some advantages due to its low viscosity, better lubrication properties and suitability for high shear-rate applications. Moreover, a hydrocarbon oil-based MR fluid has lower zero field viscosity, which is about 0.6 times less than the silicone oil-based MR fluid. On the other hand, a water-based MR fluid can minimize waste disposal problems and allows the particles to be easily recycled from the materialPhulé, P [18]. In order to reduce particle aggregation and settling, different procedures have been proposed: (1) adding thixotropic agents (ex. Carbon fibers, silica nanoparticles)Bossis, Volkova et al. [19] and(2) De Vicente, López-López et al. [20] added surfactants(ex: Oleic or stearic acid)(3) adding magnetic nanoparticles, Chin, Park et al. [21] (4) the use of viscoplastic media as a continuous phase, Rankin, Horvath et al. [22] and (5) water-in-oil emulsions as carrier liquids, Park, Chin et al. [23]. Glycerol and surfactants are used in water based fluid as stabilizers.
The following table represents Comparison of surface finish obtained by different advanced finishing processes:

Sr.No.	Process	Size in (μm or nm)
1	Grinding	0.90-5.00 μm
2	Honing	0.13-1.25 μm
3	Lapping	0.08-0.25 μm
4	Super finishing	0.01-0.25 μm
5	Abrasive flow machining (AFM) with SiC abrasives	50 nm
6	Magnetic float polishing (MEP) with Cr2O3 abrasives Ceo abrasives	 9.1 nm 4.0 nm
7	Magnetic Abrasive Finishing (MAF) with diamond abrasives	 40 nm 7.6 nm

Table 1: Comparison of surface finish obtained by different advanced finishing processes

IV. Conclusions

The study on Magneto rhelogical finishing (MRF), Magneto rheological jet finishing (MRJF), Magneto rheological abrasive finishing (MRAF), and Magneto rheological abrasive honing (MRAH) presented in this paper. Following conclusions can be drawn from the presented discussion.

It has been observed that the precise control of forces on abrasive particles using non-traditional methods are useful for fine finishing and high precision finishing. The surface finishing occurs fully or partially with the use of abrasive particles in most of the advanced super finishing processes. Fine finishing of brittle materials can be easily done in nanometer range.The MRF is an effective super finishing process for optical materials with variety shapes such as flat, spherical, Concave, and convex Surface finish up to nanometer level is achieved without sub surface damage. MRAF process has been developed as a new deterministic finishing process, also possesses the ability to correct roundness error of hard cylindrical stainless tubes. This process is still under development stage, and it can be further improved after overcoming its existing limitations. The smart behavior of MR polishing fluid is utilized to precisely control the finishing forces, hence final surface finish.

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