An empirical review on Magnetic Abrasive Particle Finishing

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ABSTRACT *As a novel innovative finishing process, magnetic abrasive particle finishing(MAPF) process was invented in the beginning of 20th century, but unfortunately any significant breakthrough and commercial application is not observed till date. This article summarizes major contributions of various researches in the area of MAPF and challenges associated with MAPF for its commercialization. It is considered as novel non-conventional finishing process in which workpiece is kept inside the ring magnet or two split magnets and abrasive particles with magnetic particles kept between magnet and work piece. During the machining process cutting force is controlled by the working gap between these magnets and work piece. The working gap between magnet and work piececan be filled with the loosely bounded abrasive with either iron oxide powder or Magnetorheological fluid. That provides bonding of abrasive particles because of magnetic medium.A Magnetic abrasive surface is formed and acts as a multi-point cutting tool. The magnetic abrasive surface behaves as a grinding wheel and material removal and fine surface finishing operation isdone by controlling working gap. MAPF is used for the finishing of the ferromagnetic materials and non-ferromagnetic cylindrical work piecefor external and internal surface finishing. Major benefit of MAPF process is reduction in cost of dressing grinding wheel, tool compensation and nonproductive time reduction in grinding operation.*

***Keywords**: Magnetic Abrasive Particle Finishing (MAPF) Process, Abrasive powder (Al_2O_3), Ferromagnetic or magnetic powder (Fe_2O_3), Grinding process, Surface finish.*

INRODUCTION

As a novel innovative finishing process, magnetic abrasive particle finishing (MAPF) process was invented in the beginning of 20th century. MAPF process is novel machining process where cutting forces are primarily controlled by the magnetic field. MAPF process can be efficiently used to produce fine surface finish with close tolerance on internal, external or flat surface. In MAPF process primary cutting forcesare controlled by controlling working gap formed between the magnet and the work piece, which in turn provide depth of cut to the machining operation.

The methodology of finishing process in MAPF operation is that a work piece kept inside the ring magnets, and gap between ring magnet and work piece is filled with abrasive powder and magnetic abrasive parti cles. Generally iron powder(Fe_2O_3) are used as Magnetic Abrasive Particlesand alumina oxide Al_2O_3or silicon powder is used as abrasive particles. Magnetic abrasive powder provides bonding of abrasive particles and bonded surface behave as a grinding surface for finishing operation.

Magnetic Abrasive Powderis formed as bounded, loosely bounded or unbounded mixture. Bounded Magnetic Abrasive Powderis a mixture of ferromagnetic powder and abrasive powder, which are sintered at in inert gas atmosphere withvery high pressure and temperature. Loosely bounded Magnetic Abrasive Powderareformed by mechanical mixing of ferromagnetic powder and abrasive powder, where bondingstrength is provided by lubricant. Unbounded Magnetic Abrasive Powderare mechanical mixture of ferromagnetic and abrasive particles without any lubricant. The Magnetic Abrasive Powderbonds each other along the lines of magnetic force and form a grinding surface, which can be considered as flexible magnetic abrasive brush between each magnetic pole and the work piece.This grinding surface behaves like a multipoint cutting tool for finishing operation. A vibrational motion can be given to the magnets to enhance the performance of finishing operation.

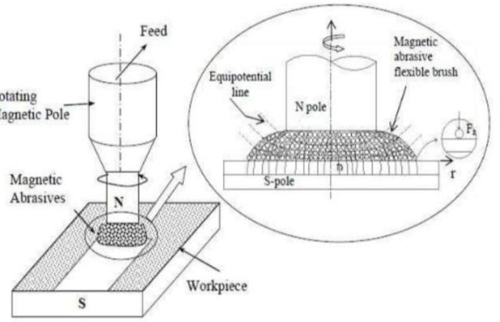

Fig-1 Schematic diagram of the surface MAPF process [10]

Literature Review

Researchers started working on the Magnetic Abrasive Particle finishing process since early 20th century. Significant contribution of researchers is summarized in chronological order in succeeding paragraph.

T Shinmura et al. has concluded that "Internal finishing can be achieved in which the large iron particles and abrasive particles are mixed uniformly when kept between the magnetic poles he decreased the Ra value from 7μm to 0.2μm." [1]

Hitomi Yamaguchi & Takeo Shinmura has observed that "In the abrasive finishing process, the semi-solid mass of the abrasive, which is flexible to change its form and follow the surface irregularities, removes material both the peaks and valleys of the surface. Magnetic abrasive finishing removed more material to obtain a certain surface roughness as compared to magnetic jig finishing because the magnetic jig finishing removes material mostly from the peaks of the surface. As a result, the magnetic abrasive finishing process is useful not for smoothing with when there is a limitation on the material removal limitation but for smoothing a surface with high material removal." [2]

Hitomi Yamaguchi et al. has summarized after experimentation and analysis that "Action of abrasive cutting edges acting against the surface was observed to both cut into the surface and also to displace material, and the resulting finished surface is an accumulation of abrasive cutting marks. Semi solid mass of abrasive tends to remove surface peaks and valley this tends to compare it as pressure copying process. MAPF process removes more material as compared to magnetic jig finishing because magnetic jig removes material only from the peak parts. The magnetic abrasive finishing process is useful not for smoothing with when there is a limitation on the material removal limitation but for smoothing a surface with high material removal."[3]

Hitomi Yamaguchi & Takeo Shinmura has mentioned in his research article regarding magnethic field distribution that "The magnetic field distribution defines the magnetic abrasive configuration and the magnetic force acting on the abrasive, and has a predominant effect on the abrasive behaviour." Authors also added that the abrasive smooth rotary motion improves surface finish quality by the accumulation of the unidirectional scratches of the cutting edges of the abrasive and that the irregular abrasive jumbling enhances the material removal with the accumulation of the deep scratches created by the abrasive dispersed in random directions. [4]

V.K. Jain at el. has developed setup for MAPF and concluded experimentally that "MAPF process on non-magnetic stainless steel with the use of loosely bounded MAPs has been carried out. It was concluded that the working gap and circumferential speed of work piece are the parameters which significantly influence the material removal, change in surface roughness value (Ra), and percent improvement in surface finish".[5]

Geeng-Wei Chang et al. has empirically concluded that "Due to its superior hardness and polyhedron shape, steel grit is better suited to magnetic abrasive finishing. If the FP particle size does not exceed that of the limit, the larger FP particle size will obtain not only greater material removal but also superior surface roughness. To obtain better surface roughness, a smaller SA particle size should be used. Si content variations and corrosion resistibility were not obvious when steel grit only was employed. Si content had obviously increased, however its corrosion resistibility decreased when SA was added." [6]

T. Mori et al. has carried out cutting force analysis in finishing process by MAPF and concluded that "Most of the normal force concentrates within the area of 1 mm radius and the degree of concentration is larger than that of the magnetic flux density distribution in Magnetic abrasive finishing process. When the magnetic abrasive moves by a small distance dx from the balanced point, the tangential force acts on the abrasive such as it returns at that point." [7]

Sunil Jha, V.K. Jain has notably mentioned in their research article that "The role of magnetic field strength in MRAFF process is clearly distinguished, as at zero magnetic field conditions no improvement in surface finish is observed, and the improvement is significant at high magnetic field strength. This is because, in the absence of magnetic field the CIPs and abrasive particles flow over the work piece surface without any finishing action due to the absence of bonding strength of CIPs." Authors also noted thatAs the magnetic field strength is increased by increasing magnetizing current, CIPs chains keep on holding abrasives more firmly and thereby result in increased finishing action. Even magnetic flux density of 0.1521 T is capable of removing to some extent, loosely held ploughed material left after grinding process and expose the actual grinding marks made by abrasives.[8]

D Singh at el. has carried out parametric analysis of MAPF process and mentioned that "Voltage is the most significant parameter followed by working gap. However, the effects of grain mesh number, and rotational speed seems to be very small. From the main effects of the process parameters, it is concluded that within

the range of parameters evaluated, a high level of voltage (11.5 V), a low level of working gap (1.25 mm), a high level of rotational speed (180 rpm), and a high level of grain mesh number are desirable for improving ΔRa."[9]
Dhirendra Singh at el. has experimentally observed that "The SEM/AFM analysis showed that the finished surface has fine scratches which are farther distant apart resulting in smoothened surface. These fine scratches would also disappear by using finer abrasive particles. The analysis of the surface finished by MAPF process revealed that the micro-cutting and scratching are the mechanisms responsible for finishing. The non-uniform strength of the FMAB resulted in to the non-uniform finished surface is evident from the micrographs. Hence, if refreshing of the ferromagnetic and abrasive particles can take place during MAPF, then it would give more uniform surface after MAPF in lesser time". [11]
S.C. Jayswal et al. has carried out investigation, modelling and numerical simulation of surface roughness in the MAPF process. Authors concluded that "The magnitude of the normal magnetic force is relatively higher near the edge of the magnetic pole due to the edge effect. The surface roughness of the work piece can be found in almost the same way by providing the intermittent motion to the tool either along the x-axis or y-axis. These simulated results compare favourably well with the experimental results after finishing for a period of 4 min." [12]
Yan Wang et al. has experimented on the effect of magnetic field distribution over magnetic forces acting on the abrasive and concluded that it has a predominant effect on the abrasive behavior. Authors also concluded that the MRR increases with the increasing of the rotational speed of magnetic pole. They almost keep a linear relationship under given experimental conditions. There is a optimal magnetic abrasive particle size 30–50% for TiC/Fe (35%), which results in maximum material removal rate."[13]
Ching-Tien Lin et al. has developed setup of ball-shaped magnetic pole with special grooves to form a flexible magnetic brush which increases a high finishing efficiency. The researcher has found that the working gap has the largest impact on the finishing quality. Accordingly, a proper working gap (2.5 mm) can reduce surface imprints and increase quality. After analysis of the Taguchi method, the factors that significantly affected the surface finish include the working gap, feed rate, and the abrasive. The optimal operation condition was a working gap of 2.5 mm, a feed rate of 10 mm/min, and an abrasive mass of two grams. Even though the finishing lubricant and spindle speed were not significant factors affecting the surface finish, the finishing lubricant (liquid, HD-233A) and spindle speed (1000 rpm) were applied to the confirmation tests due to convenience and cost." [14]
TarunGoyal et al. has concluded that "Critical parameters, such as magnetic abrasive type and particles and its volume, magnetic flux density, workpiece material, finishing gap, rotational speed, and are found to be effective for the MAPF process. The maximum percentage improvement in surface roughness for simply mixed magnetic abrasives and Silicon Carbide was approximately 18%.[15]
ShakirMousa has done parametric study and founded that "The optimum parameters are found at the (amplitude of pole 4mm, number of cycle 8,finishing time 10 min, the cutting speed 175rpm, the current 1.5Amp and the working gap 1mm) that gives the highest value of the change in Ra." [16]
LidaHeng et al. has worked on non ferrous material finishing and concluded that "The MAPF process can be successfully used for the finishing of various materials, such as Mg alloys, Al alloys, STS 304, zirconia ceramics, SS 305, SS 316, and brass. Critical parameters, such as magnetic abrasive type and particles, magnetic flux density, workpiece material, finishing gap, grinding oil, rotational speed, and axial vibration, are found to be effective for the MAPF process.MAPF with unbounded magnetic abrasives yields higher MRR, while bonded magnetic abrasives produce a better surface finish." [17]
AtulBabbar et al. hasnotably mentioned that "Magnetic abrasive finishing proved to be suitable for finishing of UNS C26000 brass material. It can be used for soft and ductile materials. With increase in rotational speed, quantity of abrasives, mesh size and machining time the surface roughness decreases." [18]
HitomiGreenslet has noted in his patent that "A magnetic abrasive particle mixture is disposed on a work piece and exposed to a dynamic magnetic field. In response to the dynamic magnetic field, the magnetic particles of the mixture may move along the work piece. The movement of the magnetic particles creates a pattern of grooves on the surface of the work piece." [19]

Challenges ahead…

As the process development in MAPF is still under research phase, there is not any effective set up developed to finish intricate shapes and irregular geometries. MAPF process in conjunction with ultrasonic vibration of the abrasive particles between the workpiece and magnets can provide further improved finishing. Commercialization of MAPF process requires break through, efficient setup and machines, which can reduce overall machining cost and improve finishing process.

CONCLUSION

After the exhaustive literature survey it is observed that the by use of magnetic abrasive particle effectively surface finishing operation can be carried out and also provides good surface integrity. It was observed by the researchers that at higher magnetic flux density, abrasive marks in the direction of motion were also observed due to deep penetration of some abrasive particles during MPAF process in the work piece surface.

In MAPF process surface finishing is carried out by formation of the flexible magnetic abrasive brush which act as a multi-point cutting tool and removes the material with the applied magnetic field strength. Higher the magnetic field strength provides better bonding and increase performance of the MAPF process. As discussed MAPF process can be used for internal, external and flat surface finishing operations. In MAPF process surface roughness can be reduced by controlling the working gap between the magnet and workpiece also the circumferential speed of work piece. Moreover it was also observed that at zero magnetic field condition there is no improvement in surface is observed but surface finishing can improved significantly at high magnetic field strength. It is also concluded by many researchers that use of higher grain mesh for the abrasive particles (Al_2O_3or silicon powder) surface finishing can be more improved. MAPF process can be efficiently used for soft and ductile non-ferromagnetic materials. Using electromagnets of high magnetic field strength and controlling the process parameters such as working gap, input current and voltage between the working gaps precisely, surface finishing can be achieved.

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