# Magnetic Abrasive Finishing- A Review

Harish Kumar
*Department of Mechanical Engg., RIEIT, Railmajra, SBS Nagar, Punjab, India*

Sehijpal Singh
*Department of Mechanical Engg., Guru Nanak Dev Engg. College, Ludhiana, Punjab, India*

Pardeep Kumar
*Department of Industrial and Production Engg., Indian Institute of Technology, Roorkee, India*

## Abstract

*In modern manufacturing practices, it is desired that the final surface produced after many manufacturing operations should have good finish and surface characteristics. But in most of the cases, components produced after manufacturing operations does not have required surface finish and surface characteristics. So, manufacturers have to adopt different methods to obtain the desired surface finish and characteristics. Initially filing, lapping, honing and super finishing was the traditional methods to achieve good surface finish for simple parts. After that polishing and buffing was introduced. For finishing of internal holes and tubes, burnishing was introduced which has given very good results. There is another method called shot blasting or sand blasting which consists of attacking the surface of a material with one of many types of shots. To improve the surface characteristics, a process called shot peening was introduced which was the modification of shot blasting. Presently, it is required that some atomic energy parts, medical instruments and aerospace components need a very precise surface finish. Amongst them, vacuum tubes, wave guides etc. are difficult to finish by conventional finishing methods such as lapping, because of their shapes. For these types of applications where a very close control of surface finish and characteristics are required, a new finishing process called Magnetic Abrasive finishing has been developed. This paper presents recent developments in the field of magnetic abrasive finishing and describes the results obtained by various research scholars based on their experimentation in the field of magnetic abrasive finishing.*

**Keywords:** *Magnetic abrasive finishing, surface roughness, magnetic abrasives, edge finishing, magnetic abrasive brush.*

## 1. Introduction

Magnetic abrasive finishing (MAF) is one of the advanced finishing processes, which produces a high level of surface quality and is primarily controlled by a magnetic field. In MAF[1,3}, the work piece is kept between the two poles of a magnet. The working gap between the work piece and the magnet is filled with magnetic abrasive particles. A magnetic abrasive flexible brush (MAFB) is formed, acting as a multipoint cutting tool, due to the effect of the magnetic field in the working gap. When inserting a cylindrical work piece in such a processing field giving revolution, feed and vibration in axial direction, surface and edge finishing are carried out by magnetic brush. In the application of ferromagnetic substance of work, for instance, work piece is also magnetized and the magnetic force acts on the top of the brush between the work piece and the abrasive grains resulting in pressing the abrasive grains to work surface.The MAF process removes a very small amount of material by indentation and rotation of magnetic abrasive particles in the circular tracks.

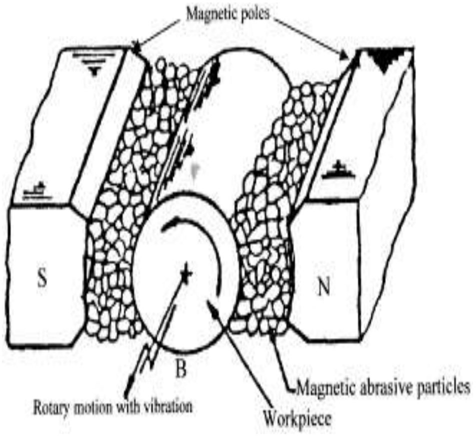

**Fig 1. Finishing Process of cylindrical work piece in magnetic field**

# 1. Classification of Magnetic Abrasive Finishing Processes

Magnetic abrasive finishing can be categorised according to the type of magnetic field in which the work piece is to be held as

1. Magnetic Abrasive Finishing With Permanent Magnet
2. Magnetic Abrasive Finishing With Direct Current
3. Magnetic Abrasive Finishing With Alternating Current

## 2.1 Magnetic Abrasive Finishing With Permanent Magnet

Shinmura T. et.al. (1985) explained the process principle and method of Magnetic Abrasive process, then confirms experimentally in a model test that magnetic abrasive brush supplies enough pressure to finish the work surface corresponding to the strength of magnetic field. The strength controlling this magnetic force is affected by the material, shape and size of work, and shape and size of magnetic pole. Shinmura T. and Aizawa T. (1989) described the internal finishing process of SUS304 stainless steel sanitary tube by magnetic abrasive machining in which suitable concentrative magnetic field is induced in inner working region of tube by N-S poles of a permanent magnet.. Magnetic abrasive made up of Alumina particles ($Al_2O_3$)and iron particles having mean diameter 80µm (Wt.40 gm) with machining fluid(Wt.15%) is supplied. From experiment results it is found that its surface roughness is improved from 0.4 µm Rmax to 0.1µm Rmax in 10 minutes finishing time. Shinmura T. and Yamaguchi H. (1995) proposed magnetic abrasive Machining for internal finishing of SUS 304 stainless steel tube and to clean gas bomb using mixed type magnetic abrasives. In mixed type magnetic abrasives large iron particles (80µm), generating high pressure is mixed with small magnetic abrasives (10µm). With suitable diameter and weight percentage of iron particles considerable surface finish is achieved. In case of gas bomb to clean its bottom surface, it is concluded that by the use of mixed type abrasives, surface roughness is decreased from 0.7µm to 0.2µm.

Yamaguchi H. and Shinmura T.,(2000) proposed an internal magnetic abrasive finishing process using a pole rotation system to produce highly finished inner surfaces of work pieces used in critical applications. The magnetic force acting on the magnetic abrasive, controlled by the field at the finishing area, is considered the primary influence on the abrasive behavior against the inner surface of the work piece. This study examines the relationships between the magnetic field, the force on the abrasive, and the abrasive behavior. The surface roughness and material removal measurements resulting from finishing experiments demonstrate the effects of the abrasive behavior on the surface modifications. It was concluded 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. Mori T. et al. (2003) examined the mechanism of magnetic abrasive polishing, a planar type process for a non-magnetic material, stainless steel. A magnetic abrasive brush was formed between a magnetic pole and a work piece material, in which the summation of three kinds of energy necessary for magnetization of abrasives, i.e. repulsion between bundles (Faraday Effect) and line tension of outer curved bundle was considered to be minimum. A normal force that pushes the abrasives on the brush end to be indented into the material surface is generated by the magnetic field. . Most of the normal force concentrates within the area of 1mm radius and the degree of concentration is larger than that of the magnetic flux density distribution. The magnetic abrasive brush will then be an extension of the magnetic pole. In this process, the tangential force acts to be the returning force created when the abrasive deviates from the magnetic balance point. Thus, the magnetic abrasives are expected to polish the material surface softly.

Yamaguchi H. and Shinmura T. (2004) proposed a new technique; magnetic field assisted finishing, for finishing of the inner surfaces of alumina ceramic components. Magnetic field assisted finishing process with a mixture of conventional abrasive and ferrous particles for the internal finishing of alumina ceramic tubes is used. Based on experiments it is concluded that the finished surface is highly dependent on the volume of lubricant, which affects the abrasive contact against the surface; on the ferrous particle size, which changes the finishing force acting on the abrasive; and on the abrasive grain size, which controls the depth of cut. By altering these conditions, this process achieves surface finishes as fine as

0.02µm in surface roughness (Ra) and imparts minimal additional residual stress to the surface. As a result, the process enables simultaneous control of the surface roughness and form accuracy. Wanga D. et al.(2004) discussed the finishing characteristics of a magnetic field assisted mechanochemical polishing process using $Cr_2O_3$ abrasive mixed with magnetic particles in the case of wet finishing using distilled water, which was proposed for internal finishing of $Si_3N_4$ fine ceramic tubes. The magnetic particles rotate with the magnetic field and rub against the inner surface of the $Si_3N_4$ tube immediately after the finishing process begins. Initially, some of the magnetic particles adhere to the inner surface of the tube with the rolling $Cr_2O_3$ abrasives and the chemical reaction. Thereafter, $Cr_2O_3$ abrasives become a layer on the finishing surface to obtain the chemical reaction between $Cr_2O_3$ abrasive and the finishing surface by removing the initial deposits while being pressed against the iron particles, and smoothing the finishing surface by mechanochemical polishing. This achieves smooth internal finishing of the tube without contaminating constituent components of the tube material. To achieve the high efficiency finishing, it was shown that choosing the carbon steel pin with a high magnetic susceptibility is advisable.

Wang Y. and Hu D. (2005) proposed an internal magnetic abrasive finishing (MAF) process for producing highly finished inner surfaces of tubes. The process principle and the finishing characteristics of unbounded magnetic abrasive within internal tubing finishing are described first. 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 behavior. This study showed the feasibility of using a magnetic abrasive finishing with a mixture of conventional abrasives and ferrous particles for the internal finishing of three kinds of metal tubes, such as Ly12 aluminium alloy, 316L stainless steel and H62 brass. It was concluded that the Material Removal rate (MRR) increases with the increasing of the rotational speed of magnetic pole. There is an optimal magnetic abrasive particle size 30–50% for TiC/Fe (35%), which results in maximum material removal rate. Similarly, there is also an optimal magnetic abrasive volume that results in maximum material removal rate. The MRR only increase initially in the magnetic finishing without liquid. However, after the surface roughness is saturated, the increase of MRR gradually slows. Finally the MRR reaches a stable value. Yamaguchi H.et al. (2005) studied the factors affecting the conditions required for successful uniform internal finishing of SUS304 stainless steel elbows by a Magnetic abrasive finishing process. In particular, the effects of the magnetic field and ferrous particles were investigated. It was concluded that the pole arrangement can be adjusted to control the strength of the magnetic field, and a stronger field results in the proper rotation of more types of mixed-type magnetic abrasive. The size of the ferrous particles mixed with the magnetic abrasive changes the force and conformity of the abrasive to the inner elbow surface. A two-phase finishing process controlling the size of the ferrous particles was proposed to achieve efficient fine surface finishing. In particular, the use of 150 µm iron particles after 330 µm iron particles was found to be effective. Local intensification of the magnetic field was accomplished by offsetting the axis of pole rotation from elbow axis. This effect enables local control of the material removal rate. Furthermore, this control of the material removal rate leads to uniformity in the finished surface regardless of the initial surface conditions. Yamaguchi H.et al. (2007) studied the internal finishing of capillary tubes using a magnetic abrasive finishing process. The finishing characteristics are influenced by the magnetic abrasive behaviour against the inner surface of the capillary, which is controlled by the supplied amount of magnetic abrasive and the magnetic force acting on it. Finishing experiments using SUS304 austenitic stainless steel capillary tube with 800 µm inner diameter demonstrate the effects of the supplied amount of the magnetic abrasive on the finishing characteristics, and the results suggest a standard method to determine the amount to achieve sufficient finishing. A three-point tube support method was proposed to diminish the run-out of the capillary tube during rotation at high speed. This resulted in a uniformly finished surface over a larger area.

Lin C.T. et al (2007) employed magnetic abrasive finishing (MAF) to conduct free-form surface abrasion of stainless SUS304 material operations. The operations were demonstrated using a permanent magnetic finishing mechanism installed at the CNC machining center. The operations were performed using the Taguchi experimental design. 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. From the finishing operations, the researcher has found that the working gap has the largest impact on the finishing quality. Accordingly, a proper working gap (in this case, 2.5 mm) can reduce surface imprints and increase quality. Prior to rough finishing, the Rmax value was 2.670 µm; after rough finishing, the value was 0.158 µm. Precise finishing yields an even lower value of 0.102 µm similar to that of the mirror surface. Therefore, the results revealed that MAF provides a highly efficient way of obtaining surface finish.

Yamaguchi H. and Hanada K.(2008) proposed a method to make spherical magnetic abrasive by means of plasma spray to improve the finishing performance, especially for the internal finishing of capillary tubes. Firstly the feasibility of the plasma spray method to make the existing magnetic abrasive more spherical is demonstrated experimentally and suggests the conditions needed to produce the spherical magnetic abrasive. Secondly, it studies the development of the new spherical magnetic abrasive made of separate particles: iron particles and $Al_2O_3$ abrasive grains, which carries the nonferrous abrasive on the outer surface alone. This magnetic abrasive generates greater magnetic force than the existing magnetic abrasive. It was concluded that the thermal conditions of the plasma gas have strong influence on the shapes of the magnetic abrasive but negligible effects on the material structure. In the experiments, the developed spherical magnetic abrasive of 4 µm mean diameter, attached to iron particles of 75 µm mean diameter showed feasibility for finishing SUS304 stainless steel tubes, showing comparable capability to the existing magnetic abrasive.

Kwak J.S. (2009) proposed a method to improve the magnetic flux density in magnetic abrasive polishing process for non- ferrous materials, specially focused on magnesium. The magnetic flux density for ferrous and non-ferrous materials was simulated. To increase the magnetic flux density for non-ferrous materials, a practical method that installed a permanent magnet at the opposite side of the work piece to be machined was proposed and evaluated by computer simulation and experimental verification. It was concluded that the location of the maximum magnetic flux density during the MAP process was verified as a diameter/4 distance from the centre of the inductor. When the working gap was 2mm, the maximum magnitude of the magnetic flux density for non-ferrous material with a permanent magnet installed at the opposite side of the work piece surface to be machined was increased by about 35%.The optimal conditions for the MAP of the magnesium alloy were an applied current of 2.0 A, working gap of 1mm, rotational speed of 800 rpm and amount of powder of 0.7 g.

## 2.2 Magnetic Abrasive Finishing With Direct Current

Kurobe, T.(1983) developed a polishing set up to perform magnetic field assisted fine finishing. The set up consist of magnetic fluid filled into the grooves in the brass disk covered by rubber plate having thickness 1 mm. The polishing abrasives are mixed with water and placed in disk with two electromagnets set above and below it. When DC voltage is supplied, a magnetic field is set up which induces polishing pressure to perform the operation. Yamaguchi H. and Shinmura T. (1999) proposed internal magnetic abrasive finishing process for producing highly finished inner surfaces of tubes used in critical applications including clean gas or liquid piping systems. This study examines the microscopic changes in the surface texture resulting from magnetic abrasive finishing process. Experiments were conducted on workpiece SUS304 stainless steel disk Ø80x1 mm with mixed type magnetic abrasive Iron particles: 2.4 g and exciting Current 2 Ampere. In addition to the surface roughness measurement, atomic force and scanning electron microscopy were used to characterize the material removal process and provide a fundamental understanding of the process mechanism. The observed surface texture shows that the process is an accumulation of the micro-scratches from the abrasive cutting edges, generating a characteristic magnetic abrasive finished surface. Moreover, the surface is finished by removing the material from not only the peaks but also the valleys of the surface, as far as the cutting edges of the magnetic abrasive are introduced into the valleys. However, the relatively longer wavelength components of the roughness profile tend to remain on the surface after processing; this shows that the magnetic abrasive finishing process belongs to the category of pressure-copying processes.

Jain V. K. et al. (2001) investigated the effect of working gap and circumferential speed on the performance of Magnetic Abrasive Finishing process. MAF setup is designed for finishing cylindrical workpieces and it is mounted on lathe machine. The loosely bounded powder is prepared for experimentation by homogeneous mixing of magnetic powder (Fe powder of 300 mesh size (51.4 μm)), abrasive powder ($Al_2O_3$ of 600 mesh size 25.7 μm), and lubricant called servospin-12 oil. To investigate the effects of working gap and circumferential speed on material removal, change in surface finish and percent improvement in surface finish, a series of experiments have been conducted using in-house fabricated setup. Based upon the results, it is concluded that working gap and circumferential speed of workpiece are the parameters which significantly influence the material removal, change in surface roughness value(ΔRa), and percent improvement in surface finish. Material removal decreases by increasing working gap or decreasing circumferential speed of the workpiece. Change in surface finish increases by increasing circumferential speed of the workpiece.

Chang G.W. et al. (2002) described the process principle and the finishing characteristics of unbonded magnetic abrasive within cylindrical magnetic abrasive finishing. The unbonded magnetic abrasive is a mechanical mixture of SiC abrasive and ferromagnetic particles with a SAE30 lubricant. Iron grit and steel grit, for which three various particle sizes were prepared for both, were used as ferromagnetic particles, each of them being mixed with 1.2 and 5.5 μm SiC abrasive, respectively. Also, the finishing characteristics on surface roughness and material removal as well as their mechanisms were investigated. Experimental results indicate that steel grit is more suitable for magnetic abrasive finishing because of its superior hardness and the polyhedron shape. Due to the smaller particle size of 1.2 μm SiC abrasive, the best surface roughness of 0.042 μm Ra can be obtained if the 180 μm steel grit is mixed. However, owing to the deeper cutting depth for each 5.5 μm SiC particle, although more material is removed, the surface roughness is worse. 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 SiC abrasive was added.

Yan B. et al. (2003) studied Electrolytic magnetic abrasive finishing (EMAF) process, involving traditional magnetic abrasive finishing (MAF) and an electrolytic process. The aim of including the electrolytic process into the EMAF system is to produce a passive film (or oxide film), which is much easier to remove than the original metal surface during processing. This study describes the process principles, the finishing characteristics of surface roughness and material removal, and the associated mechanisms. Based upon experimental results it is concluded that the parameters of electrode gap, magnetic flux density and electrolytic current must be appropriately fitted to produce a passive film quickly, and the rate of workpiece revolution must also be matched to the formation rate of the passive film to remove the passive film rapidly. Under conditions of high electrolytic current and slow rate of workpiece revolution, some of the steel grit and abrasives are easily extracted from the working gap, especially for a workpiece with a rough work surface. Increasing both the electrolytic current and the rate of workpiece revolution increases finishing efficiency, and the surface roughness improves rapidly. However, high electrolytic current severely disturbs the distribution of the existing magnetic field, facilitating the extraction of the steel grit from the working gap. Therefore, the use of high electrolytic current is limited.

Singh D.K. et al (2004) applied Taguchi design of experiments to find out important parameters influencing the surface quality generated. Based on investigation it is concluded that, voltage is found to be 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 observed 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 $\Delta R_a$. Linear regression models for change in Ra, magnetic force, and tangential cutting force indicate that both change in Ra (ΔRa) and the forces increase with increase in voltage and decrease in working gap.

Yin S. and Shinmura T. (2004) used vertical vibration-assisted magnetic abrasive finishing process for the plane and edge surface finishing and deburring of magnesium alloy. In the vibration-assisted process, a vibrating table was installed on the feeding table. The workpiece may be vibrated in the vertical direction by the use of motorized cam systems. A relative motion is obtained consisting of vertical vibration and rotation between the magnetic brush and workpiece. The finishing experiment results demonstrate that realization of the efficient finishing of magnesium alloys is possible by using magnetic abrasive finishing process. The removal volume per unit time of magnesium alloys is larger than that of the brass and stainless steel. Micro-burr of magnesium alloys could be removed easily in a short time by the use of the conventional magnetic abrasive finishing. However, deburring efficiency considerably increases with vibration assistance.

Jha S. and Jain V.K. (2004) investigated a new precision finishing process for complex internal geometries using smart magneto rheological polishing fluid. Magneto rheological (MR) polishing fluid comprises of carbonyl iron powder and silicon carbide abrasives dispersed in the viscoplastic base of grease and mineral oil; it exhibits change in rheological behavior in presence of external magnetic field. This smart behavior of MR-polishing fluid is utilized to precisely control the finishing forces, hence final surface finish. A hydraulically powered experimental setup is designed to study the process characteristics and performance. The setup consists of two MR-polishing fluid cylinders, two hydraulic actuators, electromagnet, fixture and supporting frame. Experiments were conducted on stainless steel workpieces at different magnetic field strength to observe its effect on final surface finish. No measurable change in surface roughness is observed after finishing at zero magnetic field. However, for the same number of cycles the roughness reduces gradually with the increase of magnetic field. This validates the role of rheological behaviour of magneto rheological polishing fluid in performing finishing action.

Singh D.K. et al.(2005) studied magnetic abrasive finishing (MAF) process in which magnetic force plays a dominant role in the formation of flexible magnetic abrasive brush (FMAB) and developing abrasion pressure to improve surface texture. This study examines the microscopic changes in the surface texture resulting from the MAF process to characterize the behavior of abrasive particles during finishing. Here, the workpiece and workpiece fixture are made of the same ferromagnetic alloy steel. The working gap is filled with a homogeneous mechanical mixture of silicon carbide abrasive particles and ferromagnetic iron particles (mesh no. 300) in the ratio of 1:3 by weight, respectively. In addition to the surface roughness measurement, atomic force and scanning electron microscopy have been carried out to gain insight of the wear pattern of the finished surface. The observed surface texture indicates that the process creates micro scratches having width less than 0.5 µm on the finished surface. Moreover, the surface is finished by the shearing of the peaks resulting in circular lays formed by the rotation of the FMAB. The magnetic abrasive brush, which is flexible, changes its shape to adapt to the workpiece surface irregularities, thereby removing the material from the peaks of the workpiece surface. Further, due to non-uniform strength of the FMAB, the finished surface is also non-uniform in nature as is evident from the micrographs. Hence, if jumbling/ refreshing of the ferromagnetic and abrasive particles can take place during MAF, then it would give more uniform surface after MAF in lesser time.

Girma B. et al.(2006) investigated Magnetic abrasive finishing (MAF) process for the analysis of surface roughness and material removal using response surface method in plane surfaces. It is observed that the surface roughness is significantly influenced by the MAP grain size, size-ratio, feed rate and current. The larger grain size of MAP was found to improve the surface finish significantly in finishing of plane surfaces. This effect is explained by the possible difference in the mechanics of material removal in MAF of plane and cylindrical surfaces. An improvement of 54% in surface roughness over its initial value could be achieved. The material removal is significantly affected by the MAP grain size, size ratio and current. The higher magnetic force and more number of cutting edges are the advantages of using larger MAP grain size, which causes higher stock removal. The response surface method has been used to analyze the influence of various factors on

MAF of plane surfaces, and also to obtain optimum parameter levels that give better surface finish and the higher material removal. It is evident that the ideal parameter settings to achieve these could be MAP gain size: 180–210 mm; size-ratio: 1.5–2.0; and current: 3.0–3.5A for the process and material in this study. The feed rate can be maintained in the range of 0.01–0.045mm/rev. The experimentation with these parameters setting results in more than 50% reduction in surface roughness from its initial value and an average stock removal of 14.0mg.

Singh D. K. et al (2006) investigated the forces acting during Magnetic Abrasive Finishing process and provided correlation between the surface finish and the forces. The resistance type force transducer (ring dynamometer) has been designed and fabricated. It is used to measure the normal magnetic force component responsible for micro indentation into the workpiece and tangential cutting force component producing microchips. The force data have been recorded on-line by making use of virtual instruments (using Lab-View software). Regression models for magnetic force, tangential cutting force, and change in Ra indicate that both forces and change in surface roughness (ΔRa) increase with increase in current and decrease in working gap.

## 2.3 Magnetic Abrasive Finishing With Alternating Current

Shinmura T. et. al. (1986) suggested rotating magnetic field obtained by electrifying three coils arranged in the directions at intervals of 120 degrees with three phase AC current for internal finish cylindrical work pieces. Experiments were conducted on Mild steel, Hardened steel and Brass using straight oil type grinding fluid with magnetic abrasive particles made by mixing $Al_2O_3$ and iron particles. After experimentations, it is concluded that as compared with static magnetic field, stock removal is increased by using rotating magnetic field but surface finish is reduced. For non ferromagnetic substances, it was found that as the work pieces are not magnetized, the magnetic field strength is weak. So stock removal is very small and the proposed apparatus is not suitable for non ferromagnetic materials.

Shinmura T. et. al. (1992) devised the new finishing process by generating a rotating magnetic field with six coils installed on a circular yoke electrified with three phase AC current, and driving a magnetic finishing tool to finish the internal surface of SUS 304 stainless steel tube. Experiments were conducted with loose abrasive slurry C# 280 in first finishing step, Wa # 8000 in second step and 0.1 µm diamond grains in third step. Experimental results revealed that the surface roughness of 4 µm Rmax in internal surface of SUS 304 stainless steel tube was able to be finished to 0.4 µm Rmax. It was also concluded that this finishing process can also be applied to the precision finishing of internal surface of bent circular tubing which cannot be rotated at all like stainless steel 180 degree elbow.

Yamaguchi H. et.al. (2003) proposed a new precision internal machining process that controls the surface integrity of internal surface of components used in such critical applications as high-pressure gas or liquid piping systems. This process utilizes an alternating magnetic field to control the force and dynamic motion of the tools needed for finishing. In this study, the magnetic abrasives were replaced by tiny steel pins. Machining experiments using SUS304 stainless steel tubes demonstrated that the process generates a machined surface by an accumulation of plastic deformations as a result of collisions of the tools with the surface and controls the surface integrity, including increases in hardness and compressive residual stress. The machining behaviour of the tools and machining force acting on the tools, which drives the machining characteristics, can be controlled by the alternating magnetic field and the geometry of the tools (Magnetic Pins). It is concluded that reducing the tool diameter restrict the changes in surface roughness with machining time while still achieving the desired hardness improvement.

## 3.Conclusion

(1) Magnetic abrasive finishing process can be used for surface finishing as well as surface modification of hard to finish surfaces such as brass, stainless steel, etc.

(2) Magnetic abrasive finishing can be successfully used for finishing of internal as well as external surfaces of complicated design

(3) In magnetic abrasive finishing process, magnetic force is affected by the material, shape and size of work, and shape and size of magnetic pole, work-pole gap distance, and composition of magnetic abrasives.

(4) Magnetic abrasive finishing with permanent magnetic has been proved as good finishing process for many engineering applications by decreasing surface roughness to a considerable extent.
(5) Magnetic abrasive finishing with direct current has been used successfully for surface finishing as well as surface modification of external and internal surface and has given very good results.
(6) Magnetic abrasive finishing with alternating current is not a common practice as it is difficult to maintain and control the alternating magnetic field to finish the surfaces. But still, it has been used for finishing and modification of surfaces.

## References

### Magnetic Abrasive Finishing With Permanent Magnet

[1] Shinmura T., Takazawa K., Hatano E., and Aizawa, T., (1985), "Study On Magnetic Abrasive Process – Process Principle And Finishing Possibility", Bulletin Japan Society for Precision Engineering, 19(1), pp 54-55.
[2] Shinmura T. and Aizawa T., (1989),"Study on Internal Finishing of a Non-Ferromagnetic Tubing by Magnetic Abrasive Machining Process", Bulletin, Japan Society for Precision Engineering, 23(1), pp 37-41.
[3] Shinmura T., Takazawa K., Hatano E., and Matsunaga, M., (1990), "Study On Magnetic Abrasive Finishing", Appals of CIBP, 39(1), pp 325-328.
[4] Shinmura T., and Yamaguchi H., (1995), “Study On A New Internal Finishing Process By The Application of Magnetic Abrasive Machining”, JSME International Journal, Series C, 38 (4), pp 798-804
[5] Yamaguchi H., and Shinmura T.,(2000), “Study of An Internal Magnetic Abrasive Finishing Using A Pole Rotation System”, Journal of International Societies for Precision Engg. and Nano Technology, 24, pp 237-244.
[6] Mori T., Hirota K., and Kawashima Y.,(2003), “Clarification of Magnetic Abrasive Finishing Mechanism”, Journal of Materials Processing Technology, 143–144, pp 682–686
[7] Yamaguchi H. and Shinmura T., (2004), “Internal Finishing Process For Alumina Ceramic Components By A Magnetic Field Assisted Finishing Process”, Precision Engineering, 28, pp 135–142
[8] Wanga D., Shinmura T., and Yamaguchi H.,(2004), “ Study of Magnetic Field Assisted Mechanochemical Polishing Process For Inner Surface of Si3N4 Ceramic Components, Finishing Characteristics Under Wet Finishing Using Distilled Water”, International Journal of Machine Tools & Manufacture, 44, pp 1547–1553
[9] Wang Y., and Hu D.,(2005), “Study On The Inner Surface Finishing of Tubing By Magnetic Abrasive Finishing”, International Journal of Machine Tools & Manufacture, 45, pp 43–49
[10] Yamaguchi H., Shinmura T., and Sekine M.,(2005), “Uniform Internal Finishing of SUS304 Stainless Steel Bent Tube Using a Magnetic Abrasive Finishing Process”, Journal of Manufacturing Science and Engineering, 127, pp 605-611
[11] Yamaguchi H., Shinmura T., and Ikeda R.,(2007), “Study of Internal Finishing of Austenitic Stainless Steel Capillary Tubes by Magnetic Abrasive Finishing”, Journal of Manufacturing Science and Engineering, 129 , pp 885-892
[12] Lin C.T., Yang L.D., and Chow H.M.,(2007), “Study of Magnetic Abrasive Finishing In Free-Form Surface Operations Using The Taguchi Method”, International Journal of Advance Manufacturing Technology ,34, pp 122–130
[13] Yamaguchi H., and Hanada K.,(2008), “ Development of Spherical Magnetic Abrasive Made by Plasma Spray”, Journal of Manufacturing Science and Engineering,130, pp 031107-1-9
[14] Kwak J.S., (2009), “Enhanced Magnetic Abrasive Polishing of Non-Ferrous Metals Utilizing A Permanent Magnet,” International Journal of Machine Tools & Manufacture , 49, pp 613–618

### Magnetic Abrasive Finishing With Direct Current

[15] Kurobe T., (1983), "Magnetic Field Assisted Fine Finishing”, Bulletin Japan Society for Precision Engineering, 17(1), pp 49-53.
[16] Yamaguchi H., and Shinmura T.,(1999), “Study of The Surface Modification Resulting From An Internal Magnetic Abrasive Finishing Process”, Wear, 1(3), pp 246–255
[17] Khairy A. B., (2001), “Aspects of Surface And Edge Finish By Magneto Abrasive Particles”, Journal of Material Processing Technology, 116, pp 77-83
[18] Jain V. K., Kumar P., Behera P.K., and Jayswal S. C.,( 2001), “Effect of Working Gap and Circumferential speed On The Performance of Magnetic Abrasive Finishing Process”, Wear, 250, pp 384-390
[19] Chang G.W., Yan B.H., and Hsub R.T., (2002), “Study On Cylindrical Magnetic Abrasive Finishing Using Unbonded Magnetic Abrasives”, International Journal of Machine Tool and Manufacturer, 42, pp 575-583
[20] Yan B., Chang G., Cheng T., and Hsu R.,(2003), “Electrolytic Magnetic Abrasive Finishing”, International Journal of Machine Tools & Manufacture, 43, pp 1355–1366
[21] Singh D. K., Jain V. K., and Raghuram V., (2004),“Parametric Study of Magnetic Abrasive Finishing Process”, Journal of Materials Processing Technology, 149(1-3), pp 22-29

[22] Yin S. , and Shinmura T., (2004), "Vertical Vibration-Assisted Magnetic Abrasive Finishing And Deburring For Magnesium Alloy", International Journal of Machine Tools & Manufacture, 44, pp 1297–1303

[23] Jha S., and Jain V.K.,(2004), "Design And Development of The Magnetorheological Abrasive Flow Finishing (MRAFF) Process", International Journal of Machine Tools & Manufacture, 44, pp 1019–1029

[24] Singh D.K., Jain V.K., Raghurama V., and Komanduri R.,(2005), "Analysis of Surface Texture Generated By A Flexible Magnetic Abrasive Brush", Wear, 259, pp1254–1261

[25] Girma B., Joshi S.S., Raghuram M. V. G. S., and Balasubramaniam R.,(2006), "An Experimental Analysis of Magnetic Abrasive Finishing of Plane Surfaces", Machining Science and Technology, 10, pp 323–340

[26] Singh D. K., Jain V. K., and Raghuram V. ,(2006),"Experimental Investigations Into Forces Acting During A Magnetic Abrasive Finishing Process", International Journal of Advanced Manufacturing Technology, 30, pp 652-662

## Magnetic Abrasive Finishing With Alternating Current

[27] Shinmura T., Hatano E., and Takazawa K.,(1986), "The Development of Magnetic Abrasive Finishing And Its Equipment By Applying A Rotating Magnetic Field", Bulletin Japan Society of Mechanical Engineering, 29(258), pp 4437-4443

[28] Shinmura T., Yamaguchi H. and Shinbo Y.,(1992), "A New Internal Finishing Process of A Non-Ferromagnetic Tubing By Applying A Rotating Magnetic Field", Precision Engineering, 26(4), pp 302-304

[29] Yamaguchi H., Shinmura T., and Takenaga M., (2003), "Development of A New Precision Internal Machining Process Using An Alternating Magnetic Field", Precision Engineering, 27, pp 51–58