Effect of Rotational Motion on the Flat Work Piece Magnetic Abrasive Finishing

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Abstract—*Magnetic Abrasive Finishing (MAF) is a non-conventional finishing process in which material is removed in such a way that deburring and finishing are performed simultaneously by magnetic force which forcing the flexible magnetic abrasive particles (FMAP) across the workpiece surface. The process is controllable because the machining pressure is controlled only by the input current to the coil of solenoid. The process embraces a wide range of feasible applications from critical aerospace and medical components to high production volumes of parts. One serious limitation of almost all such processes is low material removal rate. In recent years hybrid machining processes have been developed to improve the efficiency of such processes. In this research paper new hybrid process was developed by providing the rotational motion to the workpiece for enhancing material removal and surface finish in conventional MAF process. In conventional MAF process only a small fraction of abrasive particles are effective in abrading action. Experiments are performed with ferromagnetic stainless steel SS-409.*

Keywords: *MAF, FMAB, MR, Surface Roughness, RPM.*

INTRODUCTION

The rapid development of the industries like aeronautics, nuclear reactors, semi-conductor, bio-technology, and optical electronics has increased the importance of geometrical precision and part surface quality. Finishing is regularly applied to parts to obtain precise surfaces. Usually in a machining process, simply finishing a product introduces an extra cost that sometimes is as high as 15% of the total cost of production [*Rhoades, 1998*]. Hence, researchers in the industry and academics have attempted to develop a better means of obtaining a high-precision surface, with low cost, high efficiency, ease of operation and limited environmental pollution. To meet such requirements by traditional material removal processes is very difficult and economically not feasible. To get better surface finish and higher metal removal rate, the machine tools need to be rigid, free from static as well as dynamic errors [*Jayakumar et al, 1997*]. It is difficult to economically build machine tools that are extremely rigid, vibration and error free [*Jayakumar et al, 1997*]. So there is a need to economize finishing methods and to bring more of sophistication into surface finishing.

Conventional finishing processes such as grinding, lapping, honing, super finishing are good, but they have some problems such as high cost when finishing high strength materials accurately, high energy consumption, ecologically less safe etc. The pressure they apply on the surface is high and sometimes may damage the surface which they finish. Moreover, control of these conventional finishing processes is also less. Magnetic abrasive finishing (MAF) process was recently created and it is a highly efficient way of obtaining a good surface finish.

Magnetic abrasive finishing process is a magnetic field assisted finishing process by which material is removed in such a way that the surface finishing and deburring is performed with the presence of a magnetic field controls the forces in the machining zone. In magnetic abrasive finishing, machining pressure can be controlled by the input current. Magnetic abrasive finishing has been able to give good surface and edge finishing by means of a flexible magnetic abrasive brush formed in magnetic field. A small amount of material is removed by producing a relative motion between the work surface and abrasive particles, so as to obtain a mirror like finished surface.

The method was originally introduced in the Soviet Union, with further fundamental research in various countries including Japan. Nowadays, the study of the magnetic field assisted finishing processes is being conducted at industrial levels around the world. [*Mori 2003*]

The capability of four important fine finishing processes, are compared in Table 1.

WORKING PRINCIPLE OF MAF

In the Magnetic Abrasive Finishing (MAF) process, the working gap between the workpiece and the magnet is filled with either bonded magnetic abrasive particles (BMAPs) or unbounded magnetic abrasive particles (UMAPs) and form a flexible magnetic abrasive brush (FMAB) between the workpiece and the magnetic pole along the magnetic lines of force. The active magnetic particles trapped between the FMAB and workpiece originate the micro indentation into the work surface. It results in the removal of material due to the relative motion between FMAB and workpiece.

Table 1: Comparison of Common Conventional and Non-Conventional Finishing Processes

S. No.	Process Features	Lapping	Honing	Abrasive Flow Finishing	Magnetic Abrasive Finishing
1	Surface Finish (µm)	0.025–0.1	0.025–0.5	0.05–1.0	0.01–0.05
2	Dimensional Tolerance (µm)	0.5	0.5–1.25	5.0	0.5
3	Material Removal (mm)	<0.0025	0.061- 0.183	0.008–0.010	0.002–0.007
4	Pressure (MPa)	0.01–0.2	1–3	0.69–22.0	$7x10^{-6}$
5	Abrasive Product Type	Abrasive grain entrained in a liquid vehicle	Bonded abrasives	Semisolid abrasive media composed of viscoelastic carrier and abrasive grits	Magnetic abrasives composed of ferromagnetic particles and conventional abrasive grits
6	Work Surface	Flat, cylindrical, and spherical surfaces	Cylindrical surfaces	Inaccessible areas and complex internal passages	Flat, cylindrical, complex and inaccessible internal and external surfaces

The magnetic abrasive particles (MAP) join each other which are composed of ferromagnetic particles and abrasive powder. MAPs can be used as bonded or unbonded. Bonded MAPs are prepared by sintering of ferromagnetic particles and abrasive particles where as unbonded MAPs are mechanical mixture of ferromagnetic particles and abrasive particles with a small amount of lubricant .The purpose of lubricant is to provide some holding strength between the constituents of MAPs. MAPs of unbonded type are considered in the present work due to their excellent finishing effects.

This brush behaves like a multi-point cutting tool for finishing operation. When the magnetic N-pole is rotating, the MAFB also rotates like as a flexible grinding wheel and finishing is done according to the forces acting on the abrasive particles by the magnetic lines of force. It is usually assumed that there is no slip between the N-pole and MAFB.

SOME PRODUCTIVITY ENHANCEMENT TECHNIQUES

Literature survey indicates that limited efforts have hitherto been directed towards improving the efficiency of MAF Process to achieve higher material removal rates and better quality surface by applying different techniques. Some of the contributions given by researchers are mentioned below:

- An ultrasonically energized magnetic abrasive finishing process, suitable for high-precision finishing for 3-dimentional curve surfaces of micro components. It is a combination of two non-conventional finishing processes of MAF and ultrasonic machining. It increases the material removal rate but a little rougher surface than conventional MAF process. Vertical vibration-assisted magnetic abrasive finishing process is a better process for removing the micro-burr of magnesium alloys could be removed easily in a short time by the use of conventional MAF process [Shaohui Yins 2004].
- Electrochemical magnetic abrasive finishing process is the hybrid machining process of electrochemical and magnetic abrasive finishing process that improves the material removal rate (MRR) and reduces surface roughness than conventional magnetic abrasive finishing process on 6061 Al/Al_2O_3 composite [Taweel T.A. 2007].

In spite of the development of above hybrid techniques, they are not being commercially exploited. One reason could be the cumbersome requirements of the process.

ROTATED WORKPIECE MAGNETIC ABRASIVE FINISHING PROCESS (RWMAF)

In the present study of plane surface RWMAF process experimental setup was designed and fabricated with keeping in mind, the fundamental requirements of the process. The fundamental requirements of the experimental setup are Machine Frame, Magnetization unit, Magnet rotary motion unit and Workpiece rotary unit (Main parts of the unit are DC Motor (0 to 30Volt), Variable DC supply (0 to 30V, 0 to 5A) and Gear-pinion arrangement) as shown in the figure 1. This arrangement provides the rotation motion to flat workpiece in the opposite direction to the electromagnet. It enhances the surface finish and the material removal from the workpiece by increasing the contact number of active MAP with the workpiece and enhances the productivity of MAF process. This process termed as Rotated workpiece Magnetic Abrasive finishing process (RWMAF).

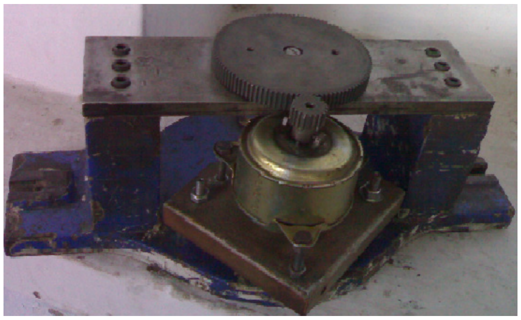

Fig. 1: Photograph of Rotary Motion Assembly

The block diagram of RWMAF process is shown in figure 2. Machine frame of vertical milling machine is used for the RWMAF setup.

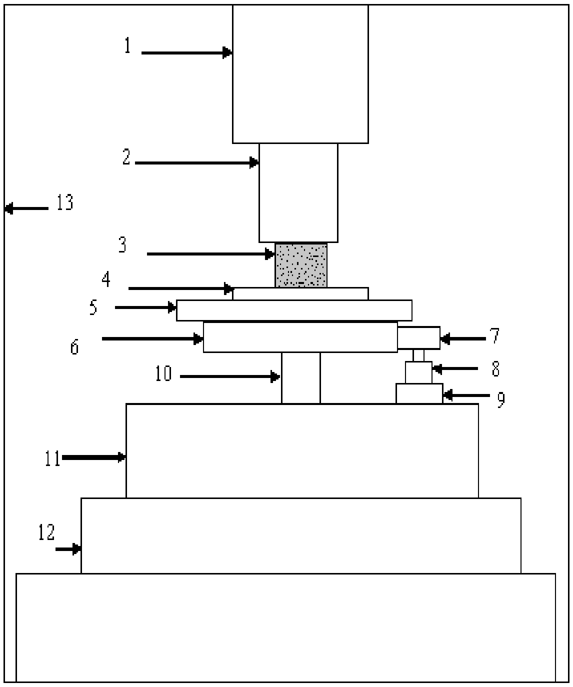

Fig. 2: Block Diagram of MAF setup: 1 Spindle; 2 Electromagnet; 3 MAP; 4 Work Piece; 5 Cover Plate; 6 Gear; 7 Pinion; 8 DC Motor; 9 Supporting Plate; 10 Supporting Shaft with Bearing; 11 Base Plate; 12 Table; 13 Frame of Vertical Milling Machine

The size of the work piece should always be slightly greater than the diameter of the FMAB diameter because in this case there will be no chance of breaking of flexible brush during finishing. An electronic balance (least count 0.001 gm) was employed for the measurement of material removal and the surface roughness is obtained by using Talysurf. Several Ra values were taken and their average value was estimated. Material Removal (MR) and surface roughness was estimated as:

Material removal = Initial mass of the workpiece–final mass of the workpiece

ΔR_a = (Initial roughness–final roughness after finishing) x 100 / Initial roughness

RWMAF PROCESS PARAMETERS

The optimum level of RWMAF parameters were determined in order to obtain high material removal and better quality of surface produced. Based on the literature survey and the brain storming session, process variables for the RWMAF were grouped in the following three categories are:

Machine Based Parameters

Flux density/current supplied to the magnet, working gap, RPM of magnet and finishing time

MAP Based Parameters

Type and size of abrasive particles used in MAP, percentage composition of iron particles and abrasive particles in MAP, Size of iron particles used in the MAP and amount of oil added to MAP as a bonding agent.

Workpiece and Fixture Based Parameters

Initial surface roughness of the work piece, property of work material, RPM of the work piece. Effects of rotational speed of workpiece on surface finish are in under consideration in our research.

The Ishikawa cause and effect diagram illustrating the possible of process parameters on the material removal and surface quality is shown in the figure 3. All the above parameters have their direct effect on the material removal and surface quality produced by RWMAF.

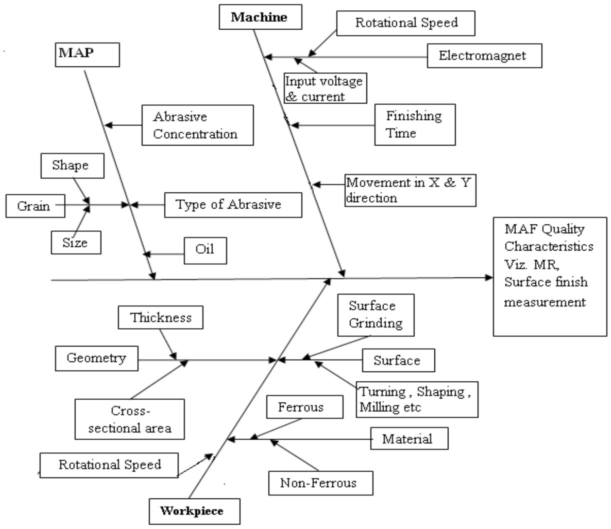

Fig. 3: The Ishikawa Cause and Effect Diagram

RESULTS AND DISCUSSION

During the experimentation, it is found that the rotational speed of work piece have the major role on improving the response parameters (Surface Roughness and Material Removal) in the MAF process on the ferromagnetic stainless steel due to increasing the active no of particles in the finishing process.

In the first set of study, the following process parameters are chosen: Fixed parameters are type of abrasive (SiC), size of abrasive particle (200 mesh), size of iron powder (300 mesh), percentage of iron powder (65%), percentage of bonding oil (3%), working gap (4mm), RPM of electromagnet (56), power supply to electromagnet (18V, 0.75A), and finishing time (15 min.). Variable parameter was rotational speed of workpiece for study the effect on percentage improvement in Surface Roughness and Material Removal on work surface.

It has been observed that maximum percentage improvement in surface roughness by removing the minimum material removal at 70 RPM of workpiece as shown in the figure 4. and figure 5.

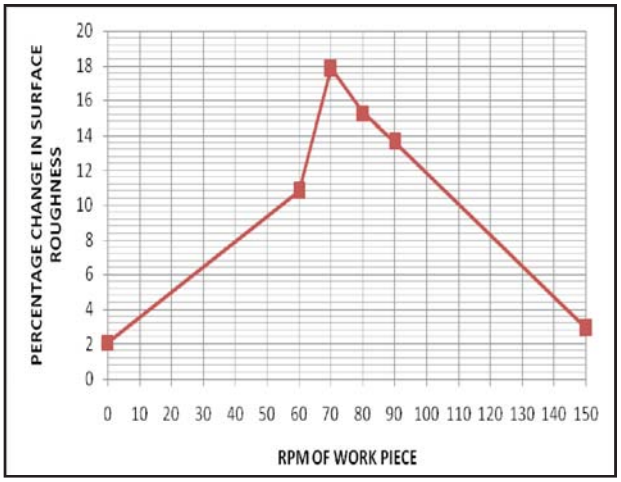

Fig. 4: Effect of RPM of Work piece on %age ΔR_a

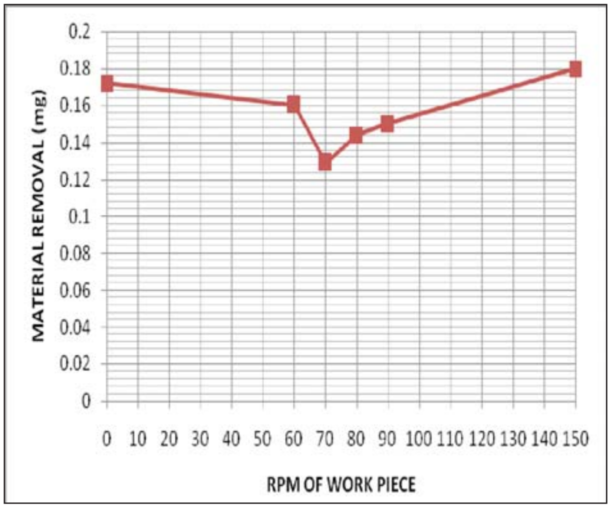

Fig. 5: Effect of RPM of Work Piece on Material Removal

In the second set of experiment, the effect of working gap on percentage improvement in surface roughness and material removal by reducing the working gap and other parameters remains same. The observations has been taken at 3mm working gap, it has been found that maximum percentage improvement in surface roughness and the value of material removal increases by reducing the working gap and found that the best values at the same speed.

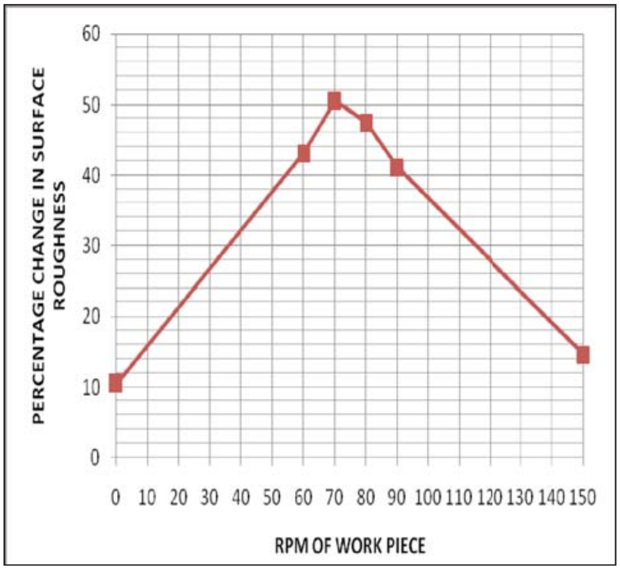

Fig. 6: Effect of RPM of Work Piece on % Age ΔR_a

Fig. 7: Effect of RPM of Work Piece on Material Removal

In the third set of experimental work, the effect of speed of electromagnet on percentage improvement in surface roughness and material removal at 3mm working gap, 70 RPM of workpiece and other parameters remains same. It has been found that maximum percentage improvement in surface roughness at 224 RPM of electromagnet but the value of material removal is minimum at the same speed of electromagnet as shown in the figure 8 and Fig. 9.

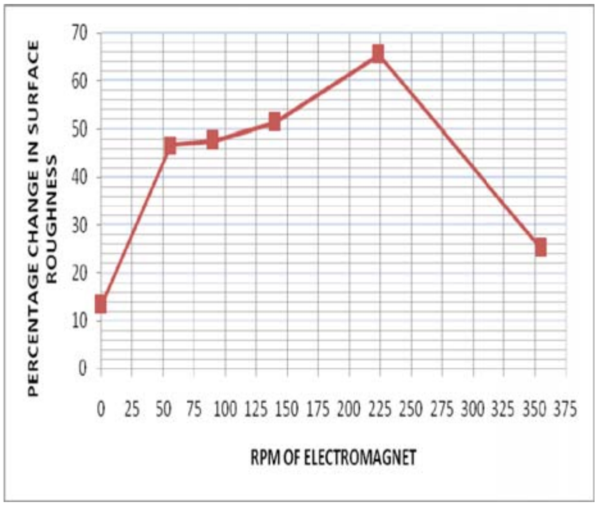

Fig. 8: Effect of RPM of Electromagnet on %age ΔR_a

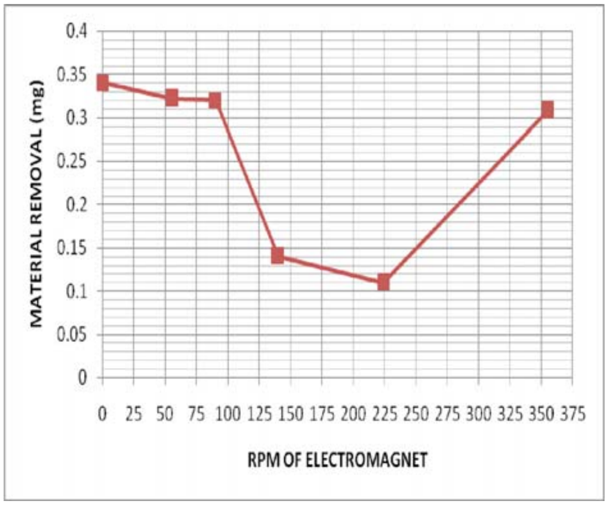

Fig. 9: Effect of RPM of Electromagnet on Material Removal

CONCLUSION

The following conclusions can be drawn from the study:

1. Surface roughness value of 275 nm has been achieved. This shows the capability of this process to get nano-finish on the work piece.
2. RPM of work piece and electromagnet, both are most significant factor for ferromagnetic work piece material.
3. The percentage improvement in surface roughness value increases as the RPM of the work piece and electromagnet increases but it starts reducing after getting an optimum value because abrasive particles scattered by increasing the centrifugal force beyond a limit. It has been observed that after a certain value of centrifugal force decreases the machining force/bonding force (i.e. magnetic lines force) of abrasive.
4. The material removal decreases initially and starts increasing after achieving the minimum value of material removal as RPM of work piece and electromagnet increases.
5. Working gap is also the most significant factor for ferromagnetic work piece material.
6. Percentage improvement in surface roughness and material removal increases as the working gap reduces but it starts decreasing after a certain limit.

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