Improvement of surface roughness using magnetic abrasive finishing

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(CIM)

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Declaration

This is to certify that

I. The thesis comprises my original work towards the degree of Master of Technology in Mechanical Engineering (Computer Integrated Manufacturing) at Nirma University and has not been submitted elsewhere for Degree.

II. Due Acknowledgment has been made in the text to all other material used.

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Undertaking for originality of the work

I Ridhdhish J Patel Roll No. 11MMCM12, give undertaking that the Major Project entitled "Improvement of surface roughness using magnetic abrasive finishing" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering (Computer Integrated Manufacturing)of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report"Improvement of surface roughness using magnetic abrasive finishing" submitted by Mr.Ridhdhish J Patel (Roll No. 11mmcm12), towards the partial fulfillment of the requirements for the award of Degree of Master of Technology in Mechanical Engineering (Computer Integrated Manufacturing) of Nirma University of Science and Technology is the record of work carried out by him under my supervision and guidance. The work submitted has in my opinion reached a level required for being accepted for examination. The results embodied in this minor project work to the best of my knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

Magnetic abrasive finishing is a process in which workpiece surface is smoothened by removing the material in the form of micro chips by abrasive particles in the presence of magnetic field in the finishing zone. The working gap between workpiece and magnet is filled with magnetic abrasive particles, composed of ferromagnetic particles and abrasive particles (MAPs). These particles form a flexible magnetic abrasive brush (FMAB) which does not require dressing. MAPs are either bonded (sintered) or unbonded. MAF offers many advantages, such as self-adaptability, controllability and the finishing tool require neither compensation nor dressing.

In order to enhance grinding efficiency of the magnetic abrasive finishing (MAF) method. An experimental study is carried out to improve the surface roughness quality of the AISI 52100 steel using magnetic abrasive finishing method. A rotating coil four pole electromagnet have been designed and implemented to use with plane surfaces. An electromagnet can produce magnetic flux density 0-0.2T at 0-100V DC powder source. Four independent operation parameters namely working gap, Voltage to the electromagnet, Mesh number and Percent weight of abrasives and their effects on surface roughness have been investigated. Mixture of iron particles (Fe particles of mesh no. 300) and abrasive particles (SiC) have been prepared in different mesh number. Taguchi method have been used for relation between surface roughness with operation parameters.

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Ridhdhish J Patel

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Nomenclature

B = Magnetic flux density, T (Tesla)

Fn = Total normal force (N)

Fc = Total tangential cutting force (N)

I = Current to the electromagnet (A)

N = Number of turns in the coil

V = Supply voltage to electromagnet(V)

da = Dimension of a single abrasive (m)

g = Machining or finishing gap (m)

n = Number of abrasive particles.

Va = Volume of a single abrasive.

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Chapter 1

Introduction

1.1 Conventional finishing processes

The recent advances in various technological fields demand the development and use of advanced engineering materials like titanium based alloys, ceramics, different kinds of composites etc. These materials have remarkabl characteristics such as high strength, temperature resistance, high hardness, high refractoriness, high wear resistance, high toughness etc., as compared to materials normally used in industries such as different types of steels, cast irons and non ferrous metals. These advanced materials play important role in modern manufacturing industries such as aircraft, aerospace, medical, electronics and semiconductor, tools and dies etc. Shaping of these advanced and difficult to machine materials with stringent design requirements such as high precision, complex shapes, and high surface quality put challenges for modern manufacturing industries.

Abrasive finishing processes can be categorized in two classes i.e. conventional finishing processes (grinding, lapping, honing, buffing etc.) and advanced finishing processes like Abrasive Flow Machining (AFM), Magnetic based finishing processes,Chemo-Mechanical Polishing (CMP) etc.

Grinding is the most common finishing process used in the manufacturing industries (Shaw, 1996). In grinding process, material removal is achieved by means of rotating abrasive wheel in which a large number of abrasive grains are held together with the help of a bonding material. Although, grinding is more efficient for removing materia than any other finishing processes but, it is difficult to achieve desired fine finish by grinding.

Lapping is a low pressure abrading process which is used to produce geometrically true surface, correct minor surface imperfections and improve the fit between the two contact surfaces. Lapping is performed by pressing a lap against the work surface, and moving back and forth over the surface. Lapping process does not produce a large amount of heat or high stresses as evolved in the grinding process. Thus, it avoids the chances of formation of the grinding cracks. Important variables affecting the lapping efficiency are abrasive grain size, lapping pressure, lapping speed, quantity of lapping compound, viscosity of the compound, etc. Lapping is a slow method of material removal and relatively expensive.

Honing is another operation used to finish surface of a cylindrical workpiece. The honing tool basically consists of a set of abrasive bonded sticks that apply a radial force. These sticks are mounted on a mandrel that rotates in the hole and have a reciprocating motion. This action produces a cross-hatched pattern. The stick can be adjusted radially for different hole sizes. It also corrects geometric errors resulting from previous operations, such as machining, heat treating etc. Honing results are often not reproducible in practice.

Buffing operation is the smoothing and brightening of a surface by the rubbing action of fine abrasives (generally alumina) in a lubricating binder, applied intermittently to a moving wheel of a wood cotton or fabric or cloth. The lubricating binder containing abrasives may be applied from a solid bar or by spraying on as fluid.

The conventional abrasive finishing processes employ a rigid tool that subjects the workpiece to substantial normal stresses which may cause micro-cracks resulting in reduced strength and reliability of the machined parts. Therefore, a need is being felt to develop a finishing process which can finish these materials economically with high precision and surface quality.

Recent trends in industries show the need of high quality surface with suitably reduction in terms of time and cost. Finishing operations in the metal working industries are critical and an expensive phase of overall production processes. This has lead to development of many advanced finishing or non-conventional technologies. Some of the advanced finishing processes have been discussed below.

1.2 Advanced finishing processes

With the advent of advanced materials, such as ceramics and glasses, very few cutting tool materials (including diamond and cubic boron nitride) are capable of material removal effectively. Ceramics and glass are inherently brittle and failure of parts made from these materials is initiated by cracks formed during machining as well as by other defects. To minimize the damage due to machining, it is necessary to process advanced ceramics under gentle conditions, i.e. with very low forces. While improved machine tools certainly facilitate reduced deflections and chatter. There is a need to control the force level. Also, the finishing operation has to be economically attractive. This has led to the introduction of Advanced Finishing Processes (AFP).

Abrasive Flow Machining (AFM) is a finishing process in which abrasive grains are mixed with a putty-like matrix material making it as a semisolid medium (visco-elastic polymer medium). This medium is then forced back and forth through openings and passageways in the workpiece. The movement of the abrasive medium under extrusion pressure erodes away both burrs and sharp corners, and polishes the components. The working principle of the abrasive flow machining process has been illustrated in Fig 1.1

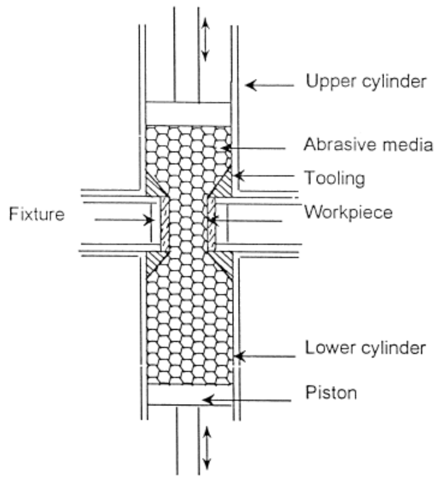

Figure 1.1: Abrasive Flow Machining[14]

Magnetic abrasive flow finishing (MAFF) process is the combination of AFM and MAF. A magnetic field has been applied around a component being processed by abrasive flow machining and an enhanced rate of material removal has been achieved.

Magnetorheological finishing (MRF) process is based on a magnetorheological (MR) fluid that consists of carbonyl iron (CI), nonmagnetic polishing abrasives, water, other carrier fluids and stabilizers are used to finish optical parts With application of a magnetic field, carbonyl iron (CI) particles form a chain-like columnar structure with abrasives embedded in between Optical parts are moved through the polishing zone to polish the surface.

The ranges of the surface roughness values obtainable during conventional finishing processes (grinding, lapping etc.) and some of the advanced finishing processes depending upon the workpiece and the type of abrasives used has been presented in the Table.

Table I: Ranges of the surface roughness

Sr.no	Finishing process	Ra value
1	Grinding	0.025-6.250
2	Honing	0.025-1.5
3	Lapping	0.013-0.75
4	Abrasive Flow Machining (AFM)	0.05
5	Magnetic Abrasive Finishing (MAF)	0.008
6	Magnetic Float Polishing (MFP)	0.004
7	Magnetorheological Finishing (MRF)	0.8

1.3 Magnetic abrasive finishing

Magnetic abrasive finishing (MAF) process was first mentioned and patent by Harry P. Coats in 1938 Japanese did fundamental research related to external finishing and internal finishing of tubes during 1980's . other section.

Magnetic abrasive finishing (MAF) can be defined as a process by which surface is smoothened by removing the material in the form of micro chips by magnetic abrasive particles in the presence of magnetic field in the finishing zone.

Mainly Two configuration of MAF process have been used:-

1 Flat work piece

2 Cylindrical work pie

1.4 Working principle

In MAF, the working gap between the workpiece and the magnet is filled with magnetic and abrasive particles (MAPs). MAPs can be used as unbonded or bonded. Bonded MAPs are prepared by ferromagnetic particles and abrasive particles where unbonded MAPs are mixture of ferromagnetic particles and abrasive particles with a small amount of lubricant.

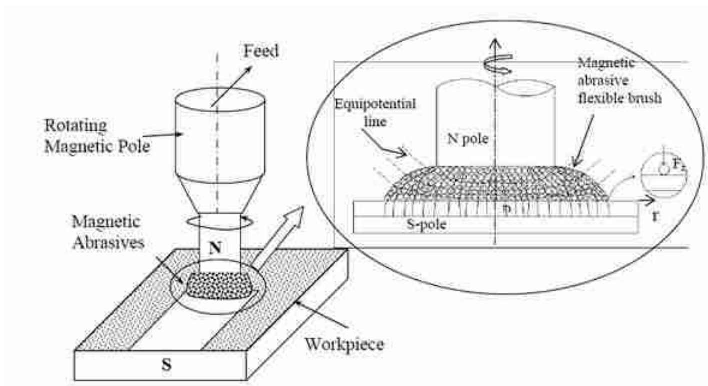

Figure 1.2: Working principle[15]

The abrasives can be used such as alumina (Al2O3), silicon carbide (SiC), diamond and boron nitride.

After the application of magnetic field, the magnetic and abrasive particles join each other along the lines of magnetic force and form a flexible magnetic abrasive brush (FMAB) between the workpiece and the magnetic pole.

This brush behaves like a multi-point cutting tool for finishing operation. When the magnet rotates, also rotates like a flexible grinding wheel and finishing is done according to the forces acting on the abrasive particles.

1.5 mechanism of MAF

The flexible magnetic abrasive brush has multiple random cutting edges and it behaves like a multi point cutting tool. The density and strength of the brush can be varied by changing the magnitude of the magnetic field in the working zone. The abrasive particles trapped between the ferromagnetic particles and the workpiece surface originate micro indentations into the workpiece surface. This results in the removal of material during the rotation of the brush, and smoothening of micro-unevenness.

Abrasive particles do not have magnetic properties and are compressed by the rotating magnetic brush that transfers forces to the abrasive particles, which interact with the workpiece surface to remove material. The magnetic force is influenced by the magnetic field distribution which is mainly affected by the size, shape, and material of the electromagnet and other parameters like voltage/current (or magnetic flux)to the magnet, working gap and magnetic property of the ferromagnetic particles mixed with th abrasives.

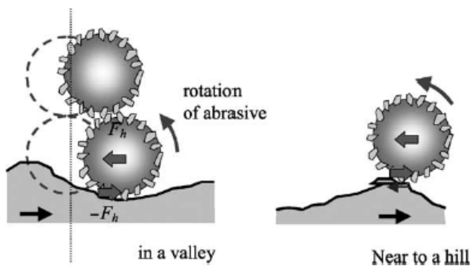

Figure 1.3: mechanism of MAF[16]

In MAF, normal force (Fn or Fy) is responsible for packing the ferromagnetic and abrasive particles forming a flexible magnetic abrasive brush which causes micro indentations into the workpiece. abrasive particles are held by ferromagnetic particles aligned along the magnetic lines of force. Depending upon the magnitude of the magnetic field, FMAB strength varies. The cutting force (Fc or Fx) is responsible for microchipping. The relative motion between the FMAB and the workpiece is provided by rotating the magnet or workpiece. As a result, the abrasive particles remove the material from the workpiece in the form of microchips resulting in the finished surface.

1.6 Advantages

1.MAF process offers advantages, such as self-adaptability and controllability.
2.Minimizes possibility of micro-cracks or surface damage of workpiece, particularly in hard and brittle material like ceramics.
3.MAF is able to produce surface roughness of nanometer range with hardly any surface defects.
4.The flexible magnetic abrasive brush (tool) requires neither compensation nor dressing.

1.7 Application

1.Non -ferromagnetic materials like stainless steel, brass,aluminum.
2.Ferromagnetic materials like steels.
3.Finishing of bearing.
4.Precision of automotive components, shaft and artificial hip joint made by oxide materials like ceramic and cobalt alloy's.
5.Aerospace components.
6.Electronics components with micro meter or sub micrometer ranges.

1.8 Objective

1.To fabricate experimental set-up to perform MAF.

2. Study the effect of process parameters(Voltage to the electromagnet,Mesh number,Working gap,Percent weight of abrasives)on the Surface roughness.

Chapter 2

Literature review

Singh and Jain[1] In magnetic abrasive finishing (MAF) process, magnetic force plays a important role in the formation of flexible magnetic abrasive brush (FMAB). Examines the microscopic changes in the surface texture resulting from the MAF process to characterise the behavior of abrasive particles. The surface texture indicates that the process creates micro scratches having width less than 0.5 m on the finished surface.

Table I: Singh and Jain

Authors	Process parameter	Effect on
Dhirendra K.Singh,V.K. Jain,	Current,Air gap	Normal magnetive force

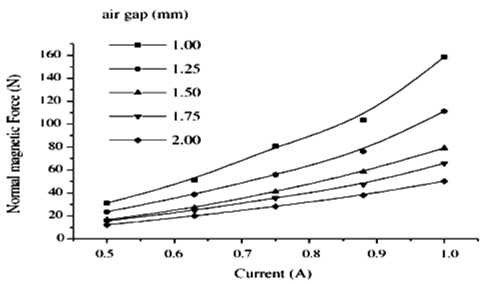

Figure 2.1: Relationship between the magnetic force and the supplied current

There is a close relationship between the magnetic force and the supplied current at different working gaps. This relationship suggests that the depth of penetration by abrasive particle can be controlled by current to the electromagnet.

Jayswal and Behera[2] Studied effects of working gap and circumferential speed on material removal and change 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.

Table II: Jayswal and Behera

Authors	Process parameter	Effect on
S.C. Jayswal,P.K. Behera.	circumferential speed ,Working gap	Material removal,Surface roughness

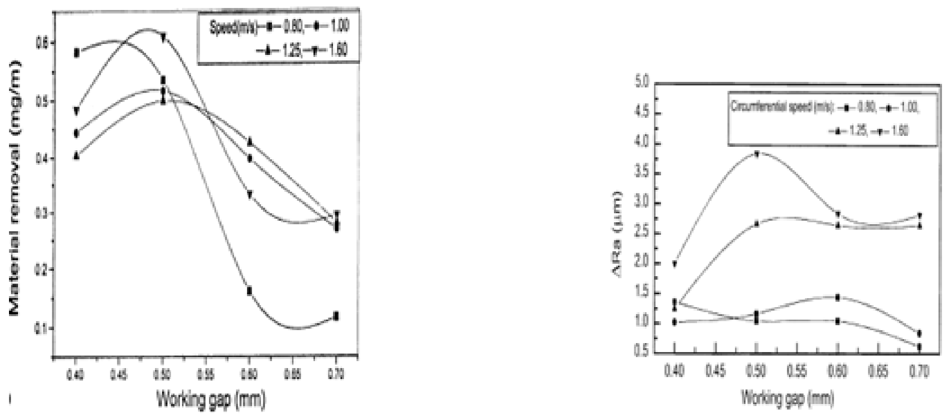

Figure 2.2: Effect of Working gap on Material removal rate and Surface roughness

Abrasive particles fall down in the collecting tray due to very less no. of ferromagnetic particles in their neighborhood. The replacementof fresh MAPs is more in larger working gap as compared to smaller working gap. But in larger gap, the cutting force decreases. So combination of both effects shows a relationship between working gap to material removal and surface roughness.

Park and Baron[3]Examined Application of MAF technology for deburring, the burr formed on plane after drilling. An inductor for removing the burr formed in drilling and analyzed for effective deburring. A method of coolant supply and component of abrasive powde are investigated.

Table III: Park and Baron

Authors	Process parameter	Effect on
J.I. Park,Y.M. Baron.	Height of the work gap,Inductor rotational frequency,Feed effect,Role of a coolant	Specific removed allowance

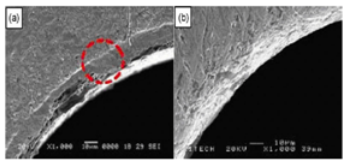

Figure 2.3: Edge quality before(a)and after MAF(b)

The specific removed allowance is defined as the removed volume per unit area, which is used for comparison of deburring conditions. Increase of the work gap decrease of productivity by the decrease of magnetic intensity inside the gap.

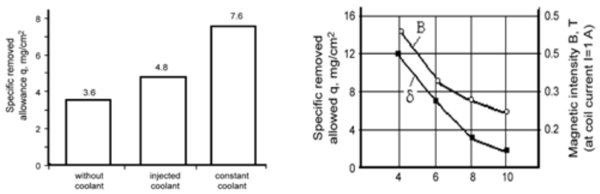

Figure 2.4: Effect of coolant and working gap on specific allowance)

Work surface increases proportionally to the rotation frequency But rate of the increase of productivity becomes slow at the frequency larger than 180 rpm as shown in Fig. This might be caused by the increase of centrifugal forces as the rotational speed increases, by grains is thrown out of the gap.

The specific removed allowance increases when the coolant is injected inside the work gap, and it increases more when the coolant is used like the constant flow.

Jain et al. [4] Studied important parameters for surface quality generated during the MAF are identified as: (i) voltage (DC) applied to the electromagnet(ii) working gap, (iii) rotational speed of the magnet, and (iv) abrasive size, results indicate that for a change in surface roughness (Ra) voltage and working gap are found to be the most significant parameters followed by grain mesh number and then rotational speed.

Table IV: Jain et al

Authors	Process parameter	Effect on
V.K.Jain, V.Raghuram K.Singh	Voltage,Rotational speed,Abrasive,Working gap	Magnetic force,surface roughness

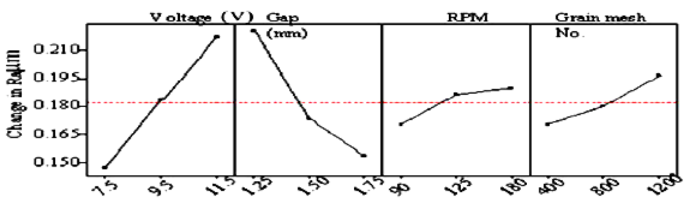

Figure 2.5: Change in surface roughness with different process parameter)

Wani and Yadava[5] Modeled and simulation for the of surface roughness on the workpiece surface finished by Magnetic abrasive flow finishing(MAFF) process. A finite element model is developed to find the magnetic potential distribution in the magnetic abrasive brush formed during finishing action.

Table V: Wani and Yadava

Authors	Process parameter	Effect on
AmitM.Wani and Vinod Yadava,	No.of cycle,Diameter of Magnetic abrasive particle (MAP)	Surface roughness, Material removal

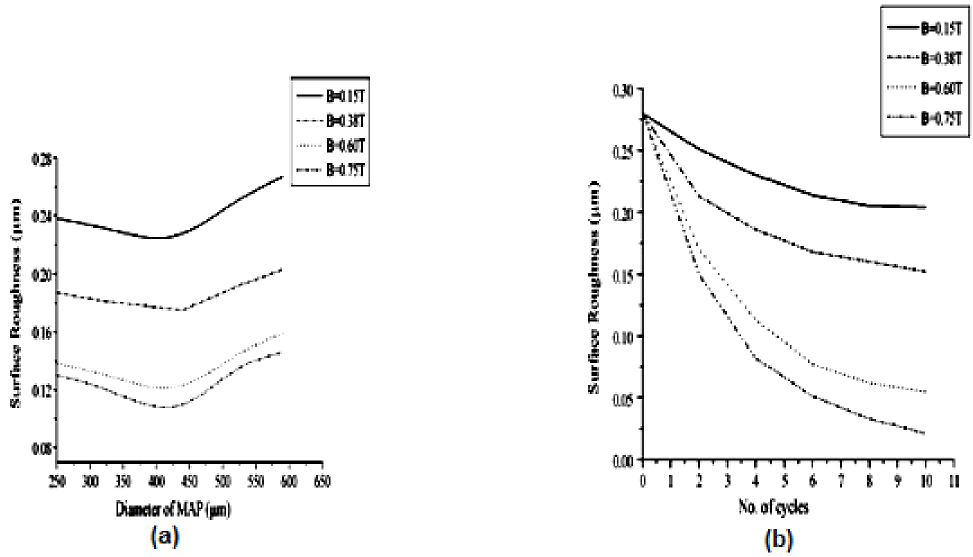

Figure 2.6: (a)Change in surface roughness with diameter of MAP(b) Change in surface roughness with No.fo cycle)

That surface roughness decreases with number of cycle for each value of magnetic flux density. Same value of surface roughness can be achieved in less number of cycles if magnetic flux density is higher.

We know that the force f is proportional to square of the diameter D and machining pressure P. the acting force f increases with increase in diameter D.

Mulik and Pandey[6] Used Ultrasonic vibrations in magnetic abrasive finishing (MAF) process to finish surfaces to nanometer order in a relatively short time. Using this experimental setup and studies with respect to five important process parameters voltage, abrasive mesh number, rotation of magnet, abrasive weight, and pulse on time (Ton) of ultrasonic vibrations.

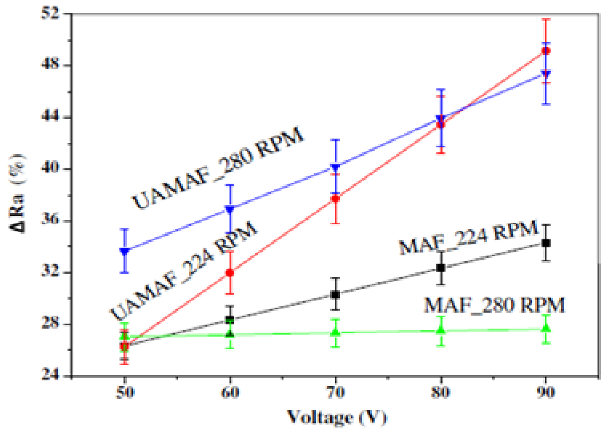

Figure 2.7: (a)Change in surface roughness with voltage

Fox et al.[7] Studied the effect of both unbonded and bonded magnetic abrasives, and reported that the unbonded magnetic abrasive particles give more material removal while bonded magnetic abrasive particles result in good surface finish.

Wang and Hu[8] Studied Finishing characteristics of bonded magnetic abrasive particles for finishing three kinds of materials such as aluminum alloy (Ly12), stainless steel (316L) and brass (H62). Experimental results indicated that finishing parameters such as speed, abrasive material and grain size have critical effects on the material removal rate. They also study how the inner surface micro shape changes during finishing of turned aluminum tube.

Kim et al.[9] Studied internal polishing of circular tubes. Magnetic abrasive jet machining is a new concept in finishing processes, using a working fluid mixed with magnetic abrasives, which is jetted into the internal surface of the tube, with magnetic poles.

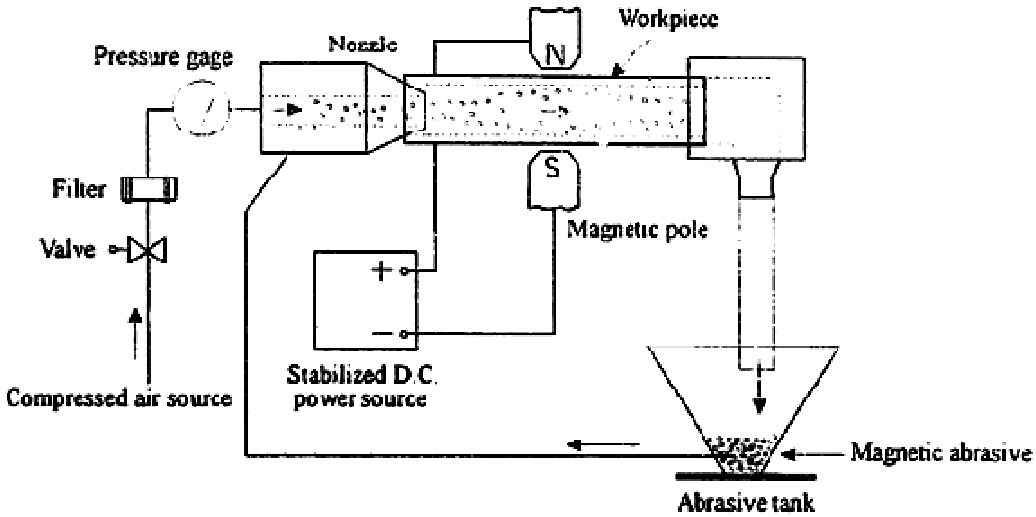

Figure 2.8: Magnetic abrasive jet machining sysyem

Shinmura and Yamaguchi [10] Studied of the surface modification resulting from an internal magnetic abrasive finishing process.An internal magnetic abrasive finishing process was proposed for producing highly finished inner surfaces of tubes used in critical applications including clean gas or liquid piping systems.

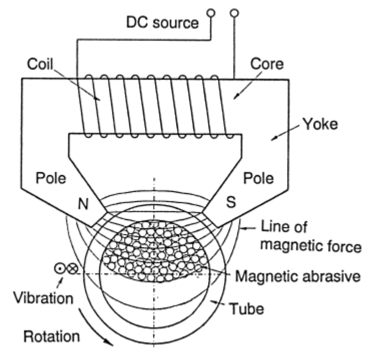

Figure 2.9: magnetic abrasive finishing process using stationary pole system

Singh et al.[11] Examined the microscopic changes in the surface texture resulting from the MAF process using SEM and AFM analysis. They revealed that the micro-cutting and scratching are the mechanisms responsible for finishing in MAF process.

Yamaguchi[12]Gave experimental model for alumina ceramic components by a magnetic field assisted finishing process.This study presents the application of a new technique, magnetic field assisted finishing, for finishing of the inner surfaces of alumina ceramic components. The experiments performed on alumina ceramic tubes examine the effects of volume of lubricant, ferrous particle size, and abrasive grain size on the finishing characteristics.

The poles, consisting of small permanent magnets, generate the magnetic field needed for attracting the ferrous particles to the finishing area and generating the magnetic force needed for pressing the diamond abrasive against the inner surface of the tube. The magnetic force acting on the ferrous particles is a function of the volume and magnetic susceptibility of the ferrous particles in the magnetic field, and more specifically, the magnetic field intensity and the gradients at the finishing area. The ferrous particles are conglomerated by magnetic force at the finishing area and mix with the diamond abrasive, and the diamond abrasive is sandwiched between the inner surface of the tube and the ferrous particles. If the tangential component of the magnetic force acting on the ferrous particles is larger than the friction force between the mixture of ferrous particles and abrasive and the inner surface of the tube, the mixture held at the finishing area shows smooth relative motion against the inner surface of the tube when the tube is rotated at high speed. Material is removed from the surface by the abrasive as a result of this relative motion, and the surface is smoothed.

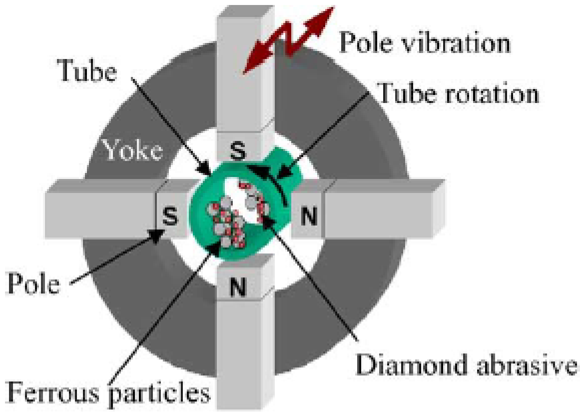

Figure 2.10: Magnetic field assisted finishing process for alumina ceramic tubes.

Deaconescu[13] Developed equipment for magneto-abrasive finishing of roller bearing balls.The finishing procedure consists in rolling the balls by magneto-abrasive brushes achieved by electromagnets and magneto abrasive powders.The kinematics of the equipment consists in driving the two disks in opposed senses of rotation, the balls to be finished being located between these. While the inferior disk will be driven by an electric motor by means of a belt transmission, the superior disk will be driven by the main shaft of the milling machine.

The milling machine also carried out the positioning of the device in relation to the superior disk, by vertically moving the machine table.In order to remove the superior disk for a new charge of balls, the magnetic yokes are rotated by means of a straight cylindrical gear driven by an oscillating pneumatic motor. The cinematic diagram of the equipment is presented in figure.

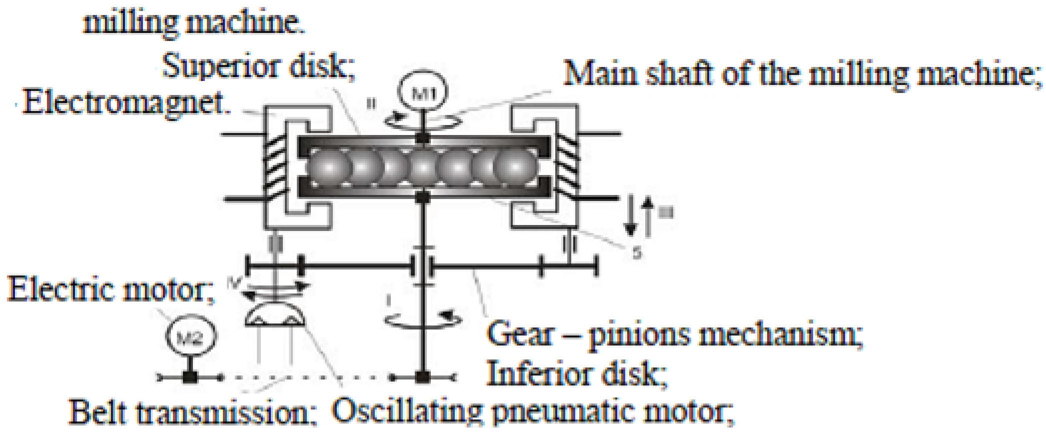

Figure 2.11: Kinematic diagram of the finishing equipment.

Shimamoto[14] Analyzed the characteristic of the friction coefficient and the friction force on magnetic abrasive finishing according as account and experiment data.

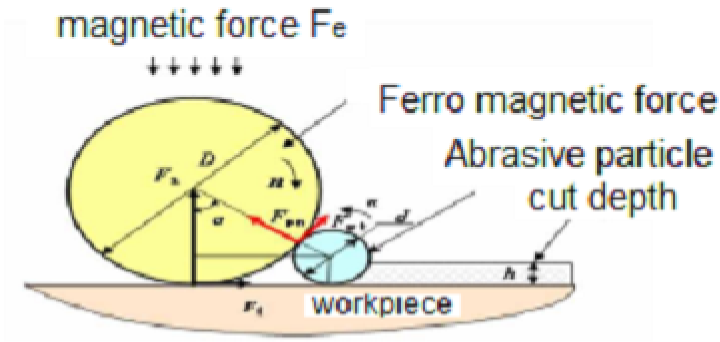

Figure 2.12: simple mixture magnetic abrasive particle.

As shown in Fig.when friction coefficient of the ferromagnetic particle and the abrasive particle is considered, the equilibrium equation of the force is displayed with the next equations in x axis and y axis direction.

$$\sum F_x = F_t - F_{pn} \sin\alpha + F_{pt} \cos\alpha = 0 \tag{2.1}$$

$$\sum F_y = F_o - F_a - F_{pn} \cos\alpha - F_{pt} \sin\alpha = 0 \tag{2.2}$$

Each friction.

$$F_{pt} = F_{pn} \times \mu_p F_t = F_a \times \mu_w \tag{2.3}$$

$$F_t = F_a \times \mu_w \tag{2.4}$$

where,

$$\cos\alpha = R - r \setminus R + r \tag{2.5}$$

$$\cos\alpha = 2\sqrt{Rr} \setminus R + r \tag{2.6}$$

Khairy et al.[15] Developed a mathematical model to evaluate magnetic finishing pressure on the workpiece surface and studied the magnetic properties of the particles. Analytically modeled the MAF process kinematics, supported with experiments.

Mori et al.[16] Gave theoretical explanation for the formation of magnetic abrasive brush. They stated the mechanism of magnetic abrasive polishing on the basis of normal and tangential force acting on the edges of magnetic abrasive brush.

Hou and Komanduri [17] Studied of temperature in the range of 150-9800C. find out the temperature resulted during MAF or process related to MAF. Therefore, it was planned to measure temperature during MAF as well as UAMAF (ultrasonics assisted magnet abrasive finishing) processes and to develop a mathematical model to predict the temperature during UAMAF.

Chapter 3

Fabrication of experimental setup

3.1 Introduction

It is difficult to finish advanced engineering materials such as silicon nitride, silicon carbide, and aluminum oxide by conventional grinding and polishing techniques with superfinish, accuracy, and minimum surface defects such as microcracks. These advanced engineering materials are being used in high-tech industries because of their lightweight and high corrosive resistance. Recently, application of magnetic field in the control of manufacturing processes has become of interest. For example, magnetic abrasive flow machining, magnetic float polishing, magnetorheological abrasive flow finishing, and magnetic abrasive finishing are some of such processes. Magnetic field assisted manufacturing processes are relatively new finishing processes and they are becoming effective in finishing, cleaning, deburring and burnishing of metal and advanced engineering material parts.

3.2 Experimental setup

There was four equipment required to perform this experiment.
1)Variac

2)Rectifier

3)Multi meter

4)Milling machine

1)Variac:-It is used for vary the voltage .It can vary the voltage from 0 to 260 voltage

Figure 3.1: Variac

2)Rectifier:-Rectifier is used for convert the Ac voltage to DC voltage. A capacity of rectifier is 1000 V.
3)Multi meter:-Multi meter is used for measure the applied voltage and current.
4)Milling machine:-The entire assembly is mounted on a milling machine spindle. A tool attach in milling machine and rotates. It have capacity to rotate in different rpm.

The schematic diagram of the plane magnetic abrasive finishing apparatus is shown in fig. In this process, the magnetic flux density of 0-0.2 T is used in the working gap of 1.00-2.00 mm.

The magnetic flux density in the working gap is varied by changing input current to the electromagnet.

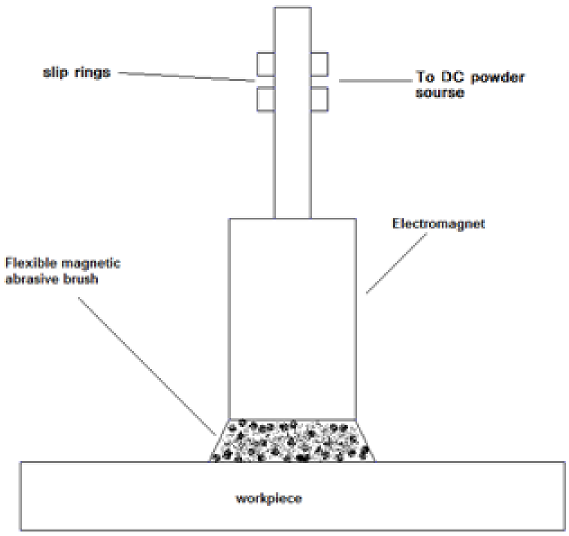

Figure 3.2: Schemaic diagram of Magnetic abrasive finishing process

On the supply of current to the magnet, the workpiece gets magnetized and magnetic lines of force emanate from north pole of the magnet and terminate at south pole through the FMAB and workpiece completing magnetic circuit.

The space between the flat workpiece and flat-faced pole (known as working gap/machining gap) is filled with a mechanically mixed homogeneous mixture of silicon carbide abrasives and ferromagnetic iron particles (known as unbounded magnetic abrasive particles).

The electromagnet was attached to the spindle of milling machine to get rotational speed necessary for finishing action.

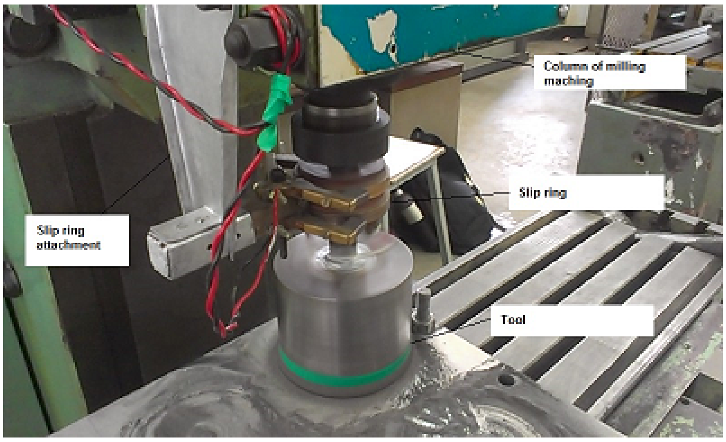

Figure 3.3: Experimental setup

3.3 Details of electromagnet

The electromagnet was connected to a DC power source (0 to 100 V) through an arrangement of brass rings so that the magnetic poles received supply as they rotate. The entire assembly was mounted on a milling machine spindle. When apply power flexible magnetic abrasive brush (FMAB) of magnetic abrasive particles (MAPs) was formed.

In the present study, an electromagnet with four poles, arranged alternately as shown in Fig. The number of turns was 900 on each winding for all four magnetic poles with maximum current rating of 1.5A. that the electromagnet could generate magnetic field intensity up to 0.2 T in between the bottom of the tool and workpiece.

The pattern of magnetic lines of forces has also been shown in Fig. Magnetic flux density in the working gap may be varied by changing input voltage to the electromagnet, and it was measured by using a digital Gauss meter.

Figure 3.4: Electromagnet winding

3.4 Experimental procedure

The workpiece material 52100 with hardness 195 HV shown in fig. Mixture of iron particles (Fe particles of mesh no. 300) and abrasive particles (Sic) was prepared in different mesh no. The working gap was maintain between 1 to 1.5mm.
Workpiece composition(AISI 52100)

Carbon0.980-1.10
Chromium1.30 - 1.60
Iron96.5 - 97.32
Manganese0.250 - 0.450
Phosphorous¡= 0.0250
Silicon0.150 - 0.300
Sulfur¡= 0.0250

Total weight of Mixture is 12 g in which iron particles and SiC particles are mix by percentage weight (15-35

The surface roughness (Ra) values of grounded workpiece was measured at three

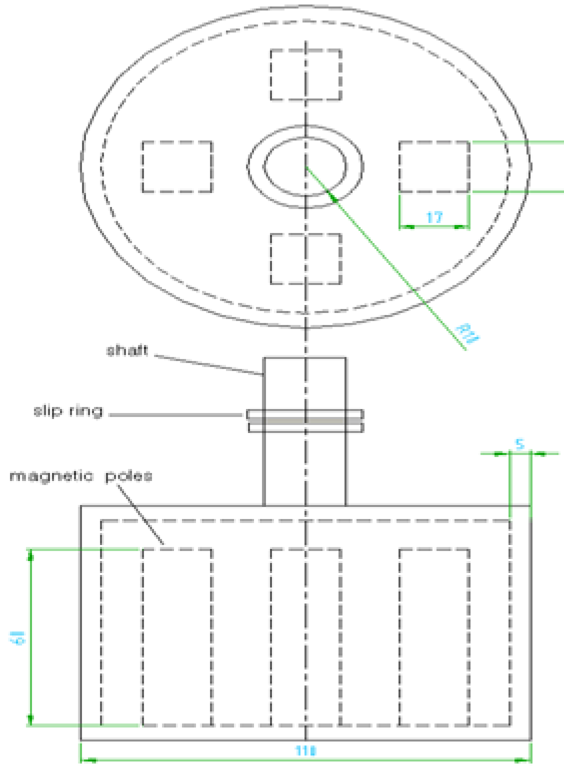

Figure 3.5: Diagram of electromagnet

different positions to get average surface roughness value.

These three positions are based on distribution of magnetic flux in radial direction and the variation of surface roughness on the workpiece.The feed value is zero , no feed give during experiment

The factors and ranges, coded values and actual values to study the percentage change in surface roughness (?Ra)during MAF processes have been listed in Table

voltage to the electromagnet has been selected on the basis of voltage range prescribed for electromagnet based on power rating and current range. The mesh number has been selected appropriately in the range of coarse to fine size of abrasives with

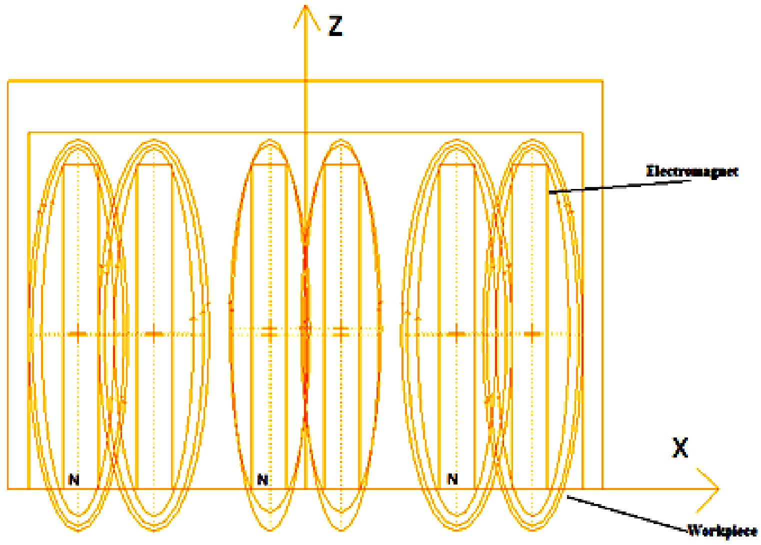

Figure 3.6: Magnetic flux

the help of literature

The rotation of electromagnet has been selected based on literature survey and the range of rpm available with milling machine.

Selection of process parameters to study percentage change in surface roughness shown in table.

X1	Voltage to the electromagnet (V)	**40**	55	**70**
X2	Mesh number	**400**	800	**1000**
X3	Working gap(mm)	**1.25**	1.50	**1.75**
X4	Percent weight of abrasives	**15**	20	25

An orthogonal array (OA) L27 for a three-level factor is used in the present investigation.

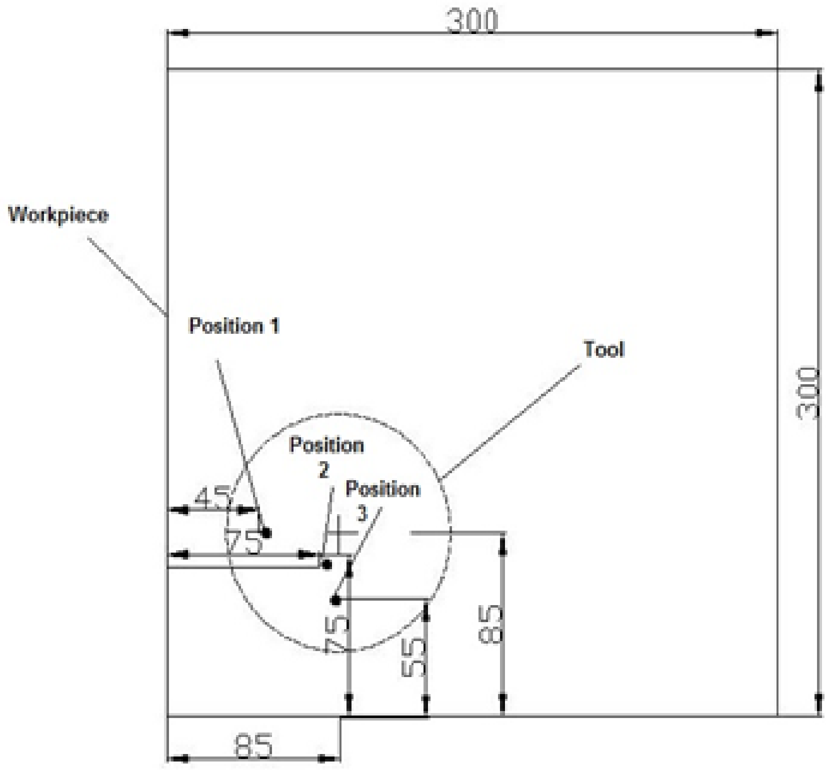

Figure 3.7: Work piece

The vertical columns correspond to the factors specified in the study and each contains three levels 1, three levels 2, and three levels 3 conditions (a total of nine conditions) for the factor assigned to the column.

Deny No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	1	1	2
5	1	2	2	3
6	1	3	3	1
7	1	1	1	3
8	1	2	2	1
9	1	3	3	2
10	2	2	3	1
11	2	3	1	2
12	2	1	2	3
13	2	2	3	2
14	2	3	1	3
15	2	1	2	1
16	2	2	3	3
17	2	3	1	1
18	2	1	2	2
19	3	3	2	1
20	3	1	3	2
21	3	2	1	3
22	3	3	2	2
23	3	1	3	3
24	3	2	1	1
25	3	3	2	3
26	3	1	3	1
27	3	2	1	2

Table I: Experimental design and result

Deny no	Mesh no	Weight(abrasive)	Voltage	Working Gap	Initial Ra	After MAF	Delta Ra
1	400	10	25	1	0.029	0.011	0.018
2	400	20	40	1.5	0.789	0.722	0.064
3	400	30	55	2	0.321	0.218	0.100
4	400	10	25	1.5	0.411	0.401	0.010
5	400	20	40	2	0.454	0.433	0.021
6	400	30	55	1	0.558	0.377	0.181
7	400	10	25	2	0.210	0.208	0.002
8	400	20	40	1	0.225	0.136	0.089
9	400	30	55	1.5	1.401	1.294	0.150
10	800	20	55	1	1.401	1.308	0.093
11	800	30	25	1.5	0.225	0.213	0.012
12	800	10	40	2	0.197	0.190	0.007
13	800	20	55	1.5	0.162	0.086	0.076
14	800	30	25	2	0.397	0.389	0.008
15	800	10	40	1	0.151	0.131	0.020
16	800	20	55	2	0.404	0.382	0.022
17	800	30	25	1	0.402	0.379	0.023
18	800	10	40	1.5	0.133	0.122	0.011
19	1200	30	40	1	1.294	1.195	0.110
20	1200	10	55	1.5	0.561	0.480	0.081
21	1200	20	25	2	0.130	0.120	0.010
22	1200	30	40	1.5	0.575	0.487	0.088
23	1200	10	55	2	0.226	0.203	0.023
24	1200	20	25	1	0.542	0.509	0.040
25	1200	30	40	2	0.080	0.017	0.063
26	1200	10	55	1	0.733	0.639	0.109
27	1200	20	25	1.5	0.465	0.450 7	0.015

To remove material from the peaks of the workpiece surface, the strength of the FMAB must be high enough to overcome the resistance offered by the workpiece material to deform. The magnetic force controlled by the input current to the coil of the electromagnet, plays a dominant role in strengthening the brush as well as in controlling micro indentations by active abrasive particles trapped randomly between the iron particles and the workpiece surface.

As the magnetic field strength increases, the magnetization of iron particles increases hence they come closer to each other. These particles are having trapped SiC abrasive particles between them. As a result, the density of the brush as well as mechanical strength of the brush get increased. Hence, brush is strengthened by increasing the field strength in the working gap.

voltage to the electromagnet has insignificant effect on the change in surface roughness. This may be because at higher voltage values formation of FMAB is strong resulting in more indentation on the top surface of workpiece.

Percentage change in surface roughness increase with increase in mesh number of abrasives,weight of abrasive and voltage. When abrasives of smaller diameter (or larger mesh number) are used, the number of abrasives available per unit volume is more.

Chapter 4

Experimentation

Taguchis parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Two major tools used in robust design are signal to noise ratio, which measures quality with emphasis on variation, and orthogonal array, which accommodates many design factors simultaneously. Taguchis design is a fractional factorial matrix that ensuresa balanced comparison of levels of any factor.(Park, 1996; Unal and Dean, 1991; Phadke, 1989)

Taguchi's work includes three principle contributions to statistics

1)A specific loss function.

2)The philosophy of off-line quality control.

3)Innovations in the design of experiments.

4.1 loss function

1) Loss functions

Taguchi realized that in much industrial production, there is a need to produce an outcome on target, for example, to machine a hole to a specified diameter, or to manufacture a cell to produce a given voltage. He also realized, as had Walter A. Shewhart and others before him, that excessive variation lay at the root of poor manufactured quality and that reacting to individual items inside and outside specification was counterproductive.therefore argued that quality engineering should start with an understanding of quality costs in various situations. In much conventional industrial engineering, the quality costs are simply represented by the number of items outside specification multiplied by the cost of rework or scrap. However, Taguchi insisted that manufacturers broaden their horizons to consider cost to society. Though the short-term costs may simply be those of non-conformance, any item manufactured away from nominal would result in some loss to the customer or the wider community through early wear-out; difficulties in interfacing with other parts, themselves probably wide of nominal; or the need to build in safety margins. These losses are externalities and are usually ignored by manufacturers, which are more interested in their private costs than social costs. Such externalities prevent markets from operating efficiently, according to analyses of public economics. Taguchi argued that such losses would inevitably find their way back to the originating corporation (in an effect similar to the tragedy of the commons), and that by working to minimise them, manufacturers would enhance brand reputation, win markets and generate profits.(Donald J. Wheeler,1989)

All these losses are, as W. Edwards Deming would describe them, unknown and unknowable, but Taguchi wanted to find a useful way of representing them statistically. Taguchi specified three situations.
1)Larger the better.
2)Smaller the better.
3)On-target, minimum-variation.

4.2 Off-line quality control

Taguchi realized that the best opportunity to eliminate variation is during the design of a product and its manufacturing process. Consequently, he developed a strategy for quality engineering that can be used in both contexts. The process has three stages.(Karna et al.2012)

1)System design.

This is design at the conceptual level, involving creativity and innovation.

2)Parameter design.

Once the concept is established, the nominal values of the various dimensions and design parameters need to be set, the detail design phase of conventional engineering. Taguchi's radical insight was that the exact choice of values required is under-specified by the performance requirements of the system. In many circumstances, this allows the parameters to be chosen so as to minimize the effects on performance arising from variation in manufacture, environment and cumulative damage. This is sometimes called robustification.

3)Tolerance design.

With a successfully completed parameter design, and an understanding of the effect that the various parameters have on performance, resources can be focused on reducing and controlling variation in the critical few dimensions.

4.3 Design of experiments

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.(Yuvaraj and Patil,2012)

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there is an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.(Yuvaraj and Patil,2012)

- Philosophy of the Taguchi Method:-

  a. Quality should be designed into a product, not inspected into it.
     Quality is designed into a process through system design, parameter design, and tolerance design. Parameter design, which will be the focus of this article, is performed by determining what process parameters most affect the product and then designing them to give a specified target quality of product. Quality "inspected into" a product means that the product is

produced at random quality levels and those too far from the mean are simply thrown out.

b. Quality is best achieved by minimizing the deviation from a target.
The signal (product quality) to noise (uncontrollable factors) ratio should be high.

c. The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide.
This is the concept of the loss function, or the overall loss incurred upon the customer and society from a product of poor quality. Because the producer is also a member of society and because customer dissatisfaction will discourage future patronage, this cost to customer and society will come back to the producer.

- Taguchi Method Design of Experiments.

a. Define the process objective, or more specifically, a target value for a performance measure of the process. This may be a flow rate, temperature, etc. The target of a process may also be a minimum or maximum; for example, the goal may be to maximize the output flow rate. The deviation in the performance characteristic from the target value is used to define the loss function for the process.

b. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance measure such as temperatures, pressures, etc. that can be easily controlled. The number of levels that the parameters should be varied at must be specified. For example, a temperature might be varied to a low and high value of 40 C and 80 C. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.

c. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter, and will be expounded below.

d. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.

e. Complete data analysis to determine the effect of the different parameters on the performance measure.

4.4 Taguchi Loss Function

The goal of the Taguchi method is to reduce costs to the manufacturer and to society from variability in manufacturing processes. Taguchi defines the difference between the target value of the performance characteristic of a process T and the measured value, y, as a loss function as shown below.[13]

$$l(y) = K_c(y - T)^2 \tag{4.1}$$

The constant, kc, in the loss function can be determined by considering the specification limits or the acceptable interval, delta.

$$k_c = c \setminus \Delta^2 \tag{4.2}$$

If the goal is for the performance characteristic value to be minimized, the loss

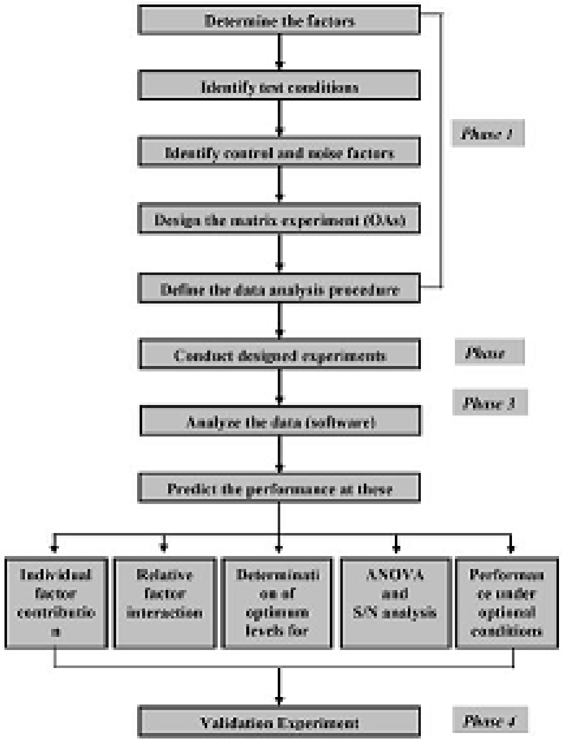

Figure 4.1: Design of Experiments

function is defined as follows.

$$l(y) = K_c y^2 \tag{4.3}$$

If the goal is for the performance characteristic value to maximized, the loss function is defined as follows.

$$l(y) = K_c \setminus y^2 \tag{4.4}$$

The loss functions described here are the loss to a customer from one product. By computing these loss functions, the overall loss to society can also be calculated.

4.5 Important Notes Regarding Use of Orthogonal Arrays

Note 1) The array selector assumes that each parameter has the same number of levels. Sometimes this is not the case. Generally, the highest value will be taken or the difference will be split.(Phadke, 1989; Wille, 1990).

Example

A reactor's behavior is dependent upon impeller model, mixer speed, the control algorithm employed, and the cooling water valve type. The possible values for each are as follows.

Impeller model: A, B,or C
Mixer speed: 300, 350, or 400 RPM
Control algorithm: PID, PI, or P
Valve type: butterfly or globe

There are 4 parameters, and each one has 3 levels with the exception of valve type. The highest number of levels is 3, so we will use a value of 3 when choosing our orthogonal array.
Using the array selector above, we find that the appropriate orthogonal array is L9:

Note 2)If the array selected based on the number of parameters and levels includes more parameters than are used in the experimental design, ignore the additional parameter columns. For example, if a process has 8 parameters with 2 levels each, the L12 array should be selected according to the array selector. As can be seen below, the L12 Array has columns for 11 parameters (P1-P11). The right 3 columns should be ignored.

Experiment	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Figure 4.2: L9 Orthogonal array

Experiment	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	2	2	2	2	2	2
3	1	1	2	2	2	1	1	1	2	2	2
4	1	2	1	2	2	1	2	2	1	1	2
5	1	2	2	1	2	2	1	2	1	2	1
6	1	2	2	1	2	2	1	2	1	[illegible]	1
7	1	2	2	2	1	2	2	1	2	1	1
8	2	1	2	1	2	2	2	1	1	1	2
9	2	1	1	2	2	2	1	2	2	1	1
10	2	2	2	1	1	1	1	2	2	1	2
11	2	2	1	2	1	2	1	1	1	2	2
12	2	2	1	1	2	1	2	1	2	2	1

Figure 4.3: Orthogonal array

4.6 Method for analyze the Experimental Data

Once the experimental design has been determined and the trials have been carried out, the measured performance characteristic from each trial can be used to analyze the relative effect of the different parameters.

To determine the effect each variable has on the output, the signal-to-noise ratio, or the SN number, needs to be calculated for each experiment conducted.

For the case of smaller the better characteristic, the following definition of the SN ratio should be calculated.

$$S/N = -10log1 \setminus n(\sum y^2) \quad (4.5)$$

For the case of larger the better characteristic, the following definition of the SN ratio should be calculated.

$$S/N = -10log1 \setminus n(\sum 1 \setminus y^2) \quad (4.6)$$

After calculating the SN ratio for each experiment, the average SN value is calculated for each factor and level.Once these SN ratio values are calculated for each factor and level, they are tabulated

4.7 Advantages

An advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality.

Additionally, Taguchi's method for experimental design is straightforward and easy to apply to many engineering situations, making it a powerful yet simple tool. It can be used to quickly narrow down the scope of a research project or to identify problems in a manufacturing process from data already in existence.

Taguchi method allows for the analysis of many different parameters without a prohibitively high amount of experimentation.

4.8 Disadvantages

The main disadvantage of the Taguchi method is that the results obtained are only relative and do not exactly indicate what parameter has the highest effect on the performance characteristic value. Also, since orthogonal arrays do not test all variable combinations, this method should not be used with all relationships between all variables are needed.

The Taguchi method has been criticized in the literature for difficulty in accounting for interactions between parameters. Another limitation is that the Taguchi methods are offline, and therefore inappropriate for a dynamically changing process such as a simulation study.

4.9 Introduction of ANOVA

Analysis of variance (ANOVA) is the most efficient parametric method available for the analysis of data from experiments. It was devised originally to test the differences between several different groups of treatments thus circumventing the problem of making multiple comparisons between the group means using t-tests (Snedecor and Cochran, 1980).

ANOVA is a method of great complexity and subtlety with many different variations, each of which applies in a particular experimental context. Hence, it is possible to apply the wrong type of ANOVA in a particular experimental situation and, as a consequence, draw the wrong conclusions from the data.(R. A. Armstrong,2000)

4.10 Types of ANOVA

1) one way ANOVA(random effect)

There is, however, an alternative model called the random effects model in which the objective is to estimate the degree of variation of a particular measurement and in many circumstances to compare different sources of variation in space and time.(Armstrong et al., 2000)

2) Two-way ANOVA in randomised blocks

In the one-way, fixed effects ANOVA described previously each observation was classified in only one way, i.e. in which treatment or subject group the observation fell. Replicates were either allocated to treatment groups at random or subjects within a group were a random sample of a particular population. Such an experiment is often described as randomised design. More complex experimental designs are possible, however, in which an observation may be classified in two or more ways(Armstrong et al., 2000).

3)The three-way ANOVA

In the two-way ANOVA in randomised blocks, when treatments are given sequentially to a subject, there is a possible carry-over effect of one treatment on to the next or the subject may become fatigued as the tests proceed. An example of the former might include the sequential application of two drugs without a sufficient recovery period between them and of the latter, reading tests with different filters or magnifiers applied sequentially to the same subject. The solution is to have each combination of treatments given to the same number of subjects such that systematic effects due to treatment order will not create bias in the comparison of the treatment means.

4)Factorial ANOVA

In a factorial experiment, the effects of a number of different factors can be studied at the same time. Combining factors usually requires fewer experimental subjects or replications than studying each factor individually in a separate experiment. In addition, by contrast with the three-way design, the between treatments or groups sums of squares is partitioned into specific comparisons or contrasts (Ridgman, 1975,Armstrong et al., 2000)

5)Factorial ANOVA(split-plot design)

The experimental subjects were assigned at random to all possible combinations of the two factors. However, in some designs, the two factors are not equivalent to each other. A common case, called a split-plot design, arises when one factor can be considered to be a major factor and the other a minor factor.(Snedecor and Cochran, 1980).

6)Factorial ANOVA(repeated measures design)

The repeated measures factorial design is a special case of the split-plot type experiment in which measurements on the experimental subjects are made sequentially over several intervals of time. The ANOVA is identical to the preceding example but with time constituting the subplot factor.

Repeated measurements made on a single individual are likely to be highly correlated and therefore the usual posthoc tests cannot be used.Nevertheless, it is possible to partition the main effects and interaction sums of squares into contrasts. In a repeated measures design the shape of the reponse curve, i.e. the regression of the measured variable on time, may be of particular interest. A significant interaction between the main-plot factor and time would indicate that the response curve with time varied at different levels of the main-plot factor.(Snedecor and Cochran 1980).

4.11 Classes of models

There are three classes of models used in the analysis of variance, and these are outlined here.

1)Fixed-effects models (Model 1)

The fixed-effects model of analysis of variance applies to situations in which the experimenter applies one or more treatments to the subjects of the experiment to see if the response variable values change. This allows the experimenter to estimate the ranges of response variable values that the treatment would generate in the population as a whole.Montgomery (2001, Chapter 12: Experiments with random factors)

2)Random-effects models (Model 2)

Random effects models are used when the treatments are not fixed. This occurs when the various factor levels are sampled from a larger population. Because the levels themselves are random variables, some assumptions and the method of contrasting the treatments (a multi-variable generalization of simple differences) differ from the fixed-effects model.Gelman (2005, pp 2021)

3)Mixed-effects models (Model 3)

A mixed-effects model contains experimental factors of both fixed and random-effects types, with appropriately different interpretations and analysis for the two types. Cochran and Cox (1992, p 48)

4.12 Characteristics of ANOVA

ANOVA is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations: Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance.

So ANOVA statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations. In the era of mechanical calculation it was common to subtract a constant from all observations (when equivalent to dropping leading digits) to simplify data entry.

4.13 ANOVA results for surface roughness

Table I: Analysis of variance (ANOVA)

Parameter	DF	Seq.SS	MS	F	P	R-Sq
Mesh no	2	0.00930	0.00465	2.17	0.136	15.32
Percentage weight	2	0.01145	0.00573	2.79	0.081	18.87
Voltage	2	0.02149	0.01075	6.58	0.005	35.41
Working gap	2	0.00677	0.00338	1.51	0.242	11.15
Total						80.75

There are three kinds of characteristic value.Nominal is best,smaller is better and larger is better.As the objective of this study larger the better.S/N ratio formulated as follows.

$$S/N = -10log1 \setminus n(\sum 1 \setminus y^2) \tag{4.7}$$

Following linear regression models for change in surface roughness have been evolved.

$$\Delta R_a = -0.0255 - 0.000003A + 0.00252B + 0.00229C - 0.0388D \tag{4.8}$$

A = Mesh number.

B = Weight of abrasive.

C = Voltage to the electromagnet.

D = Working gap.

where n is the number of measured characteristic value.The unit of S/N ratio are given in table.

Table II: Response Table of S/N ratios

Level	Mesh no	Weight of abrasive	Voltage	Working gap
1	-28.74	-35.44	-36.39	-24.95
2	-33.95	-26.68	-28.78	-28.86
3	-24.85	-25.42	-22.37	-33.73
Delta	9.09	10.03	14.02	8.7

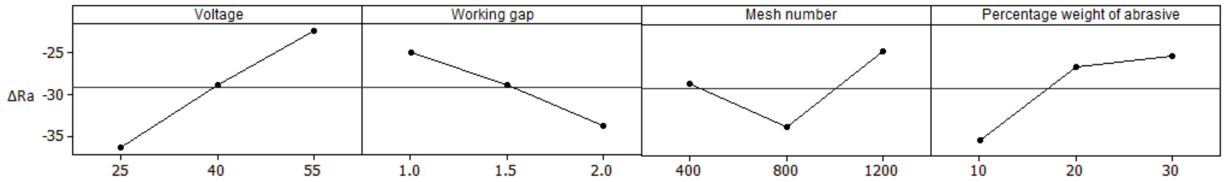

Figure 4.4: Effect of process parameter on surface roughness

4.14 Effect of process parameters on surface roughness

The main effects plot of different factors considered in the present study have been given in Fig.4.1. It can be seen from Fig. 4.1 that voltage to the electromagnet has insignificant effect on the change in surface roughness.

This may be because at higher voltage values formation of a flexible magnetic abrasive brush is strong resulting in more indentation on the top surface of workpiece. Similar effect has been observed by Lambropoulos et al. (2010) in case of magneto rheological finishing (MRF).

Percentage change in surface roughness increase with increase in mesh number of abrasives.This is so because in the same machining area there will be many more cutting edges if finer grains are used.Although the value of normal magnetic force and cutting force per grain will decrease, the equivalent normal magnetic and tangential cutting forces increase.Hence, microcutting increases resulting in reduced surface roughness value.

Percentage change in surface roughness decrease with increase in working gap.The trend of the curves is the same for different working gap values but the magnitude of

Delta Ra is more for lower working gap.

The effect of percentage weight of abrasives and mesh number on Ra has been shown in Fig.4.1.It is evident from the Fig. 4.1 that Delta Ra increases with increase in percentage weight of abrasives when mesh number is smaller or average diameter of abrasives is larger in the range of 400 to 1200 mesh number of SiC abrasives.With increase in percentage weight of abrasives the average magnetic force per unit volume of MAPs reduces as the percentage of ferromagnetic particles decreases. But at the same time number of cutting edges increases due to increase in percentage weight of abrasives for a given mesh number.

It may be because of domination of number of cutting edges over the effect of reduction of average normal magnetic force, an improvement in change in surface roughness is observed.

However, when mesh number is large (average diameter of abrasive particles is small) there is reduction in percentage change in surface roughness with increase in percentage of abrasives. Very large number of fine abrasive particles may not be able to penetrate into the hard workpiece surface under lower strength of FMAB and reduction in percentage change in surface roughness is observed. In case of plane MAF, reduction in Delta Ra has been reported for higher mesh numbers (or less abrasive grain diameter) by Girma et al. (2006).

Chapter 5

Summary, conclusions and the future scope

5.1 Summary

Requirements of high finish, accuracy, and minimal surface defects, such as microcracks have necessitated the development of an alternate finishing technology, namely, magnetic abrasive finishing (MAF). The MAF apparatus neither needs a very precise worktable nor a very stiff structure since its cutting tool is a unique flexible magnetic brush. Nevertheless, a mirror like refined surface of high quality can be obtained easily.Finished surface neither showed a deteriorated layer nor micro-cracks. MAF yielded bettersurfaces, especially of complex shapes. However, the MAF process has limitation in finishing effectively when applied to hard materials. Therefore, attempt has been made tocombine MAF process with ultrasonic vibrations to overcome the limitation.

Chapter 1 presented an introduction of abrasive based finishing processes, conventional finishing methods and their limitations. An introduction to magnetic field assisted finishing methods in general and magnetic abrasive finishing process (MAF) in particular has been discussed. This chapter also gave an overview of the research problem, objectives, methodology and thesis organization.

Chapter 2 described current state of the art and literature available in the focused area of research. Major contributions in the past in the related areas of research like surface roughness improvement and limitations of MAF were discussed.

Both the experimental investigations and theoretical studies related to MAF (processes related to enhancement of MAF) in terms of modeling and optimization of MAF, optimization of parameters for multi-performance characteristics, material removal mechanisms were discussed. Based on the literature survey, the research gaps were identified to formulate the objectives of the present work.

Chapter 3 was focused on design and fabrication of experimental set-up of MAF processes.It also included identification of key process parameters, their ranges and design of experiments technique that were used.chapter 4 focused on analysis of variance(ANOVA).Effect of different process parameter on change in surface roughness were studied.Examined the contribution on different process parameter.

5.2 Conclusions

Following inferences have been derived on the basis of above results and discussion.

The analysis of the surface finished by MAF process reveals that the micro-cutting and scratching are the mechanisms responsible for finishing.The magnetic abrasive brush, which is flexible, changes its shape to adapt to the workpiece surface irregularities, there by 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.

Based on the above results, voltage is found to be the most significant parameter followed by abrasive weight. However, the effects of grain mesh number, and working gap seems to be very small.

5.3 The future scope

1)In the present work, plane workpieces were considered for study. The work can be extended to cylindrical and workpiece of contoured shapes.

2)The effect of feed rate on surface roughness improvement can be studied.

3)The mathematical or finite element model may be developed for prediction of MAF.

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