STUDYOF ELECTROCHEMICAL FORCE ASSISTED MAGNETIC A BRASIVE FLOW MACHINING

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BY

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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled, "**STUDY OF ELECTROCHEMICAL FORCE ASSISTED ABRASIVE FLOW MACHINING**" in partial fulfillment of the requirements for the award of **Master of Technology Degree** in **Production Engineering** at **Delhi Technological University**, **Delhi** is an authentic work carried out by me under the supervision of Dr. R.S. Walia and Dr. Qasim Murtaza in Mechanical Department. The matter embodied in this report has not submitted to any other university/institute for award of any degree.

(Sourabh Kumar Patel)

This is to certify that above statement made by the candidate is correct to best of my knowledge.

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ABSTRACT

For products having internal inaccessible cavities or recesses, general finishing processes like lapping, honing etc. are used but they suffer from disadvantage of low quality of surface finish and that too with high equipment cost. Therefore need arises for an alternate process which has the capability of nano-level finishing. Abrasive Flow machining (AFM) is such kind of fine finishing technique for such products. This method has a unique property of simultaneous improvement in material removal and surface finish. It employs an abrasives laden semi-solid media, which acts as a self-deforming cutting tool and can finish the complex cavities under a hydraulic pressure. During the finishing of components by using Abrasive Flow Machining, there is a very important role of pressure distribution, velocity and temperature distribution at different points in Abrasive Flow Machining. The work piece hardness, abrasive size, abrasive hardness, Extrusion pressure and properties of carrier media are the important process parameters that affect the performance of AFM. Abrasive flow Machining has a limitation of low material removal. So to reduce this limitation, a variable magnetic field has been introduced in the path of the abrasive particle. So, my main aim in this report work is to study the different types of hybrids are possible in this AFM process and to choose one of them to cause more material removal and better surface smoothness

Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

It has been proved already that quality of surface finish can dramatically improve product performance and lifetime. It means that a product having good quality of surface finish will have greater functional performance as well as longer lifetime as compared to same product with poor quality of surface finish. The quality of the surface finishes along with dimensional and alignment accuracy are taken care of by finishing processes such as grinding, lapping, honing etc. These processes are known as traditional methods of finishing. But these traditional finishing processes are only applicable or limited to the production of workpieces of basic forms such as flat, cylindrical, etc. These finishing processes are being pushed to their limit in components of hard materials and complicated shapes. Hence, need arises to develop a finishing process with wider application area as well as better quality of the surface finish accompanied with higher productivity.

1.1 Nonconventional Manufacturing Processes

An unconventional machining process is a special kind of machining process in which there is no contact directly between the tool and the workpiece which is used for manufacturing. In unconventional machining, various form of energy is used to remove unwanted material from a workpiece. In many of the industries, hard and brittle materials like tungsten carbide, high speed steels, ceramics etc., find a variety of applications.For example, tungsten carbide is used as a cutting tool while high speed steel is used manufacturing of gear cutters, drills, milling cutters etc. If these materials are machined with the help of traditional machining processes, either the tool undergoes extreme wear or the workpiece material is damaged. This is so because, in conventional machining, always there is a direct contact between the tool and the work material. Large cutting force is required and material is removed in the form of chips so huge amounts of heat are produced in the workpiece and this induces residual stresses, which degrades the life and quality of the work material. Hence, conventional machining produces poor quality product with poor surface finish.

To overcome all these drawbacks, we use unconventional machining processes to machine hard and brittle materials. We also use unconventional machining processes to machine soft materials, in order to get better dimensional accuracy.

1.2 **Abrasive Flow Machining Process**

Abrasive flow machine was first introduced by U.S.A. based extrudes hone corporation in 1960. AFM is mainly used for complex internal inaccessible cavity and shapes. Abrasive flow machining (AFM) is a unique non-traditional machining process developed as a method of fine finishing, polishing by flowing an abrasive laden media. It is also use for the finishing of difficult to machine areas and surfaces. In AFM, a semi-solid media consisting of a polymer-based carrier and abrasives in a required proportions is extruded to and fro from the surface to be machined. The mechanism of visco-elastic medium is similar to a deformable grinding tool whenever and wherever it is subjected to restriction to flow. The medium is so flexible enough to mould itself to any complex shape or contour, and it is able to finish hard and tough materials.

1.3 Basic principle of AFM

Commonly used AFM is Two-way AFM in which two vertically opposed cylinders extrude medium back and forth through passages formed by the workpiece and tooling as shown in figure. AFM is used to deburr, radius and finish difficult to reach surfaces by extruding an abrasive laden polymer medium with very special rheological properties. It is widely used finishing process to finish complicated shapes and profiles. The polymer abrasive medium which is used in this process, possesses easy flowability, better self-deformability and fine abrading capability.

Layer thickness of the material removed is of the order of about 1 to 10 μm. Best surface finish that has been achieved is 50 nm and tolerances are +/ - 0.5 μm. In this process tooling plays very important role in finishing of material, however hardly any literature is available on this aspect of the process. In AFM, deburring, radiusing and polishing are performed simultaneously in a single operation in various areas including normally inaccessible areas.

It can produce true round radii even on complex edges. AFM reduces surface roughness by 75 to 90 percent on cast and machined surfaces. It can process dozens of holes or multiple passage parts simultaneously with uniform results. Also air cooling holes on a turbine disk and hundreds of holes in a combustion liner can be deburred and radiused in a single operation. AFM maintains flexibility and jobs which require hours of highly skilled hand polishing can be processed in a few minutes; AFM produces uniform, repeatable and predictable results on an impressive range of finishing operations. 10 Important feature which differentiates AFM from other finis hing processes is that it is possible to control and select the intensity and location of abrasion through fixture design, medium selection and process parameters. It has applications in many areas such as aerospace, dies and moulds, and automotive industries.

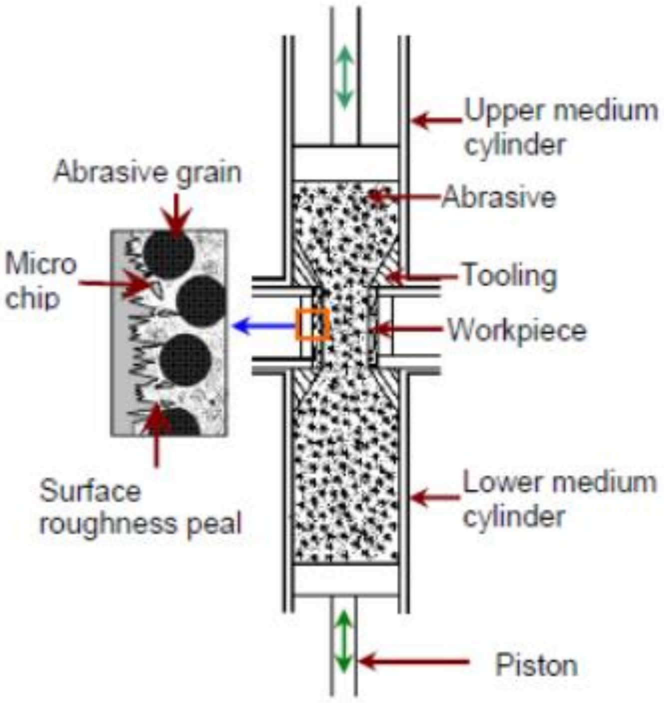


Figure 1: Principle Of Material Removal Mechanism

1.4 AFM TECHNOLOGY

The abrasive media is extruded back and forth through the passages formed by the work-piece and tooling with the help of hydraulic pressure system employing two opposed cylinders.

Abrasion occurs wherever the medium enters and passes through the most restrictive passages. The media act as a self-modulation abrasive medium with good fluidity and viscosity so the cutting tools are flexible. Figure 1 schematically depicts the experimental apparatus for an AFM process. The equipment includes (a) a hydraulic pressure system, (b) a work-piece holding fixture, (c) a pair of medium containers, and (d) a controller. The piston pressurizes the medium in the cylinder in a forward direction and extrudes it through the work-piece into the other cylinder. Consequently, the medium abrade the work-piece in the work holder and fixture. The procedure is reversed and combination of these forward and backward strokes constitutes a process cycle.

1.5 CLASSIFICATION OF ABRASIVE FLOW MACHINING

AFM machines are classified into three categories: one way AFM, two way AFM and orbital AFM. A brief discussion is given below.

1.5.1 One way AFM process: One way AFM process is provided with a hydraulically activated reciprocating piston and an extrusion media chamber which is used to receive and extrude media uni-directionally across the internal surfaces of workpiece having internal cavity . In this fixture directs the flow of the media from the extrusion media chamber into the internal passages of the workpiece. In one way AFM process thereis a media collector collects the media as it extrudes out from the internal passages.

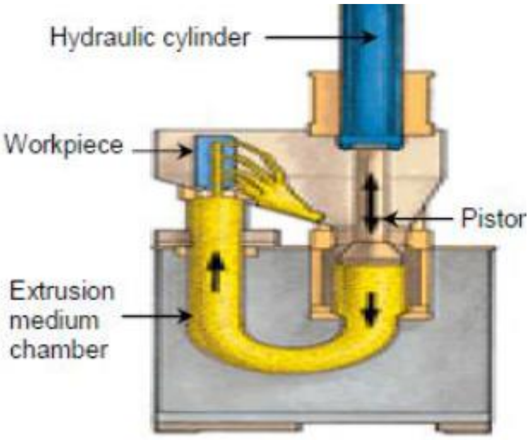


Figure 2: One way AFM machine operation[10]

The hydraulically actuated piston intermittently withdraws from its extruding position to open the extrusion medium chamber access port to collect the medium in the extrusion medium chamber. When the extrusion medium chamber is charged with the working medium, the operation is resumed.

1.5.2 Two-way AFM process: Two way AFM machine has two hydraulic cylinders and two medium cylinders. The medium is extruded, hydraulically or mechanically, from the filled chamber to the empty chamber via the restricted passageway through or past the workpiece surface to be abraded, as illustrated in Figure Typically, the medium is extruded back and forth between the chambers for the desired fixed number of cycles.

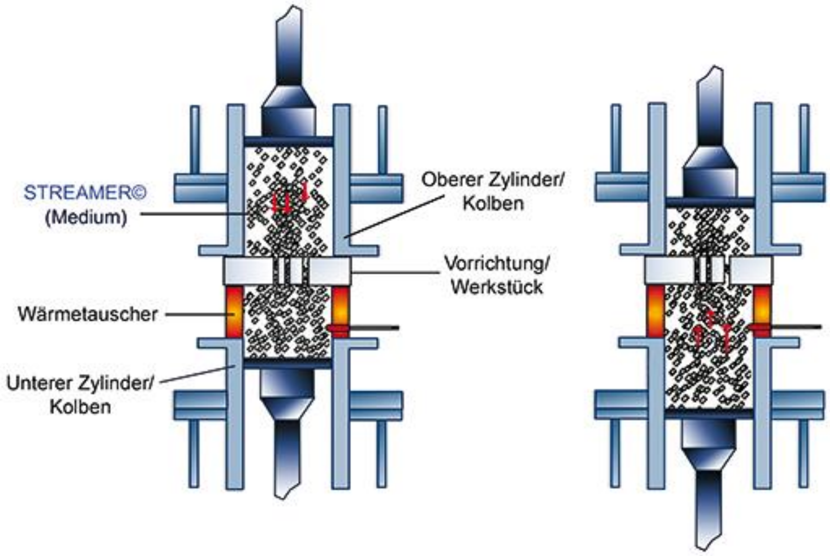


Figure 3: Two way AFM machine operation [12]

Counter bores, recessed areas and even blind cavities can be finished by using restrictors or mandrels to direct the medium flow along the surfaces to be finished.

1.5.3 Orbital AFM process: In orbital AFM, the workpiece is precisely oscillated in two or three dimensions within a slow flowing ‘pad’ of compliant elastic/plastic AFM medium, as shown in Figure. In Orbital AFM, surface and edge finishing are achieved by rapid, low-amplitude, oscillations of the workpiece relative to a self-forming elastic plastic abrasive polishing tool. The tool is a pad or layer of abrasive-laden elastic plastic medium (similar to that used in two way abrasive flow finishing), but
typically higher in viscosity and more in elastic.

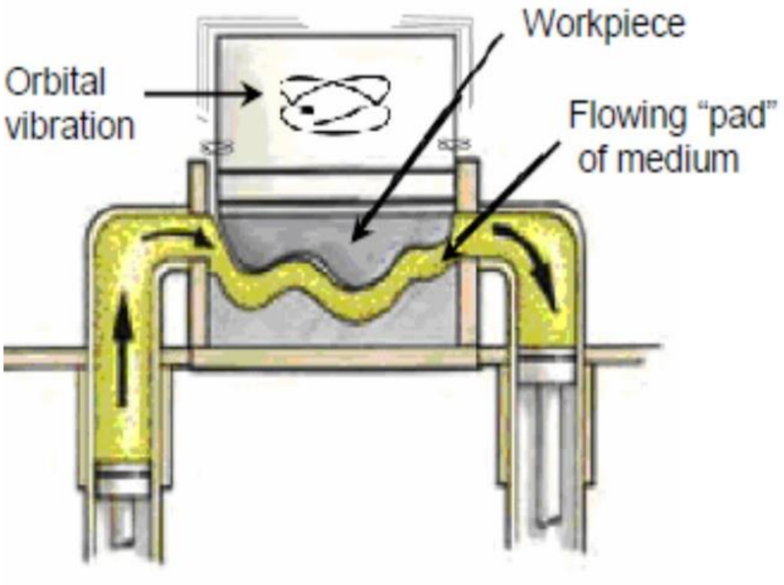


Figure 4: Orbital AFM machine operation [13]

1.6 AFM TOOLING

Fixture is made of steel, urethane, aluminium, nylon, Teflon, or a combination there of. And any number of parallel restrictions can be processed simultaneously with suitable tooling.

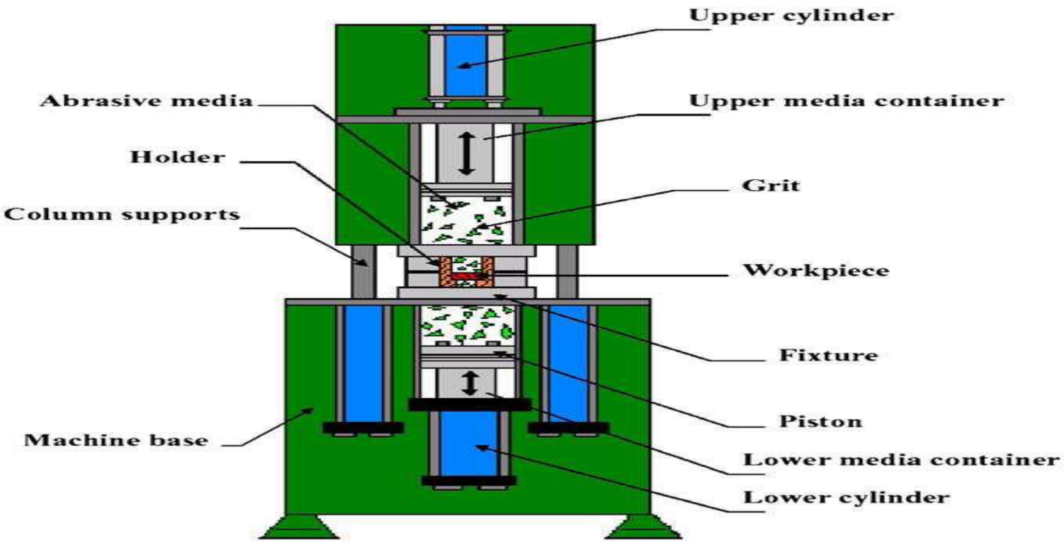


Figure 5: Schematic of Abrasive Flow Machining (Principle and Basic Operation) [10]

1.7 ABRASIVES LADEN MEDIA

This technique uses a non-Newtonian liquid polymer containing abrasive particles of aluminum oxide, silicon carbide, boron carbide or diamond as the grinding medium and additives . The additives are used to modify the base polymer to get the desired flowability and rheological characteristic of the media. The viscosity and the concentration of the abrasives can be varied .A number of researcher have concentrated on the field of media because it work as a carrier and abrasive which is grinding medium

1.8 APPLICATIONS

A higher order of surface finish and close tolerance can be produced on a wide range of components by AFM. Major applications of the process are the finishing of aircraft hydraulic and fuel system components and critical parts, such as fuel spray nozzles, fuel control parts and bearing components which are tedious to machine. The process has ability of achieving high production rates by using the various hybrids of AFM in the processing of fuel injection systems, steering and braking systems, splines and gear, pump, valves and fittings, etc.

AFM is suitable for work-pieces with complicated intersections (complex inlet manifolds and ports are polished with AFM leads to smoothness and thus more precise fuel and air distribution, resulting into more horse power and fuel efficiency of the automobile) refer figure 3, extrusion dies (for Aluminium and Plastic profiles), space and aeronautics Industry (AFM is used to remove very thin layers of coatings from the turbine blades for re-coating.), medical technology((such as machining implantable devices, pharmaceutical machines, or a slot on a staple slide for surgical instruments used to close incisions,

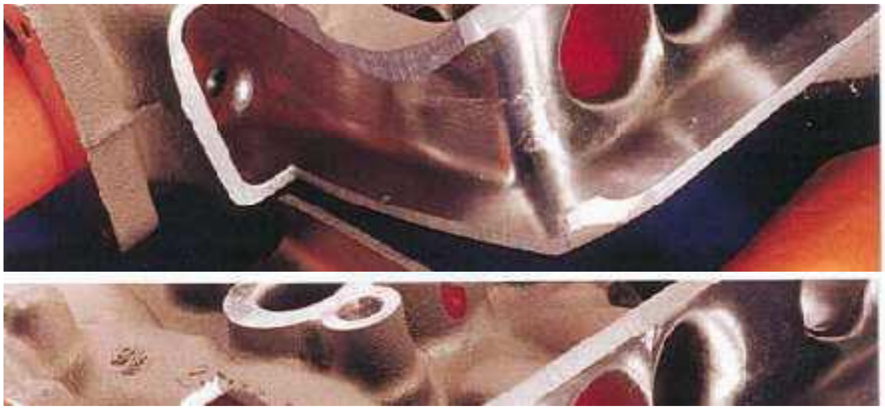


Figure 6: Intake manifold after manual AFM processing [9]

1.9 MAJOR AREAS OF RESEARCH IN AFM

EXPERIMENTAL RESEARCH

Abrasive flow machining is complex because of the little-understood behavior of the non-Newtonian medium and the complicated and random nature of the mechanical action of material removal. There are numerous process parameters affecting the AFM performance and effectiveness (i.e. Material Removal Rate, Surface Finish, Abrasives Wear Rate etc.). Some of the experiments which have been conducted are effects of abrasive flow machining on various machined surfaces , Monitoring of Abrasive Flow Machining Process Using Acoustic Emission , improved fixtures, Temperature Dependence and Effect on Surface Roughness, Mechanism of Material Removal, rheological properties and the finishing behavior of abrasive gels, Forces prediction during material deformation, viscosity of media, cutting forces and active grain density ,and other parameters like number of cycles, extrusion pressure, media temperature, time, media velocity etc. Huge research is going on is going on in the field that how to increase the metal removal rate of the process. Number of researcher has given their views in the field of hybrids of abrasive flow machining ,like the use of magnetic force, centrifugal force etc.

1.10 Theory of electromagnet

An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. The magnetic field disappears when the current is turned off. Electromagnets usually consist of a large number of closely spaced turns of wire that create the magnetic field. The wire turns are often wound around a magnetic core made from a ferromagnetic or ferromagnetic material such as iron; the magnetic core concentrates the magnetic flux and makes a more powerful magnet.

The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be quickly changed by controlling the amount of electric current in the winding. However, unlike a permanent magnet that needs no power, an electromagnet requires a continuous supply of current to maintain the magnetic field.

1.10.1Physics involve behind the electromagnet

An electric current flowing in a wire creates a magnetic field around the wire, due to Ampere's law (see drawing below). To concentrate the magnetic field, in an electromagnet the wire is wound into a coil with many turns of wire lying side by side. The magnetic field of all the turns of wire passes through the center of the coil, creating a strong magnetic field there. A coil forming the shape of a straight tube (a helix) is called a solenoid. The direction of the magnetic field through a coil of wire can be found from a form of the right hand rule. If the fingers of the right hand are curled around the coil in the direction of current flow (conventional current, flow of positive charge) through the windings, the thumb points in the direction of the field inside the coil. The side of the magnet that the field lines emerge from is defined to be the *north pole*.

Much stronger magnetic fields can be produced if a "magnetic core" of a soft ferromagnetic (or ferrimagnetic) material, such as iron, is placed inside the coil. A core can increase the magnetic field tothousands of times the strength of the field of the coil alone, due to the high magnetic permeability μ of the material. This is called a ferromagnetic core or iron core electromagnet. However, not all electromagnets use cores, and the very strongest electromagnets, such as superconducting and the very high current electromagnet

1.10.2 Magnetic field created by a current

The magnetic field created by an electromagnet is proportional to both the number of turns in the winding, *N*, and the current in the wire, *I*, hence this product, *NI*, in ampereturns,

is given the name magnetomotive force. For an electromagnet with a single magnetic circuit, of which length *L* core of the magnetic field path is in the core material and length *L*gap is in air gaps, Ampere'sLaw reduces to:

$$NI = HcoreLcore + HgapLgap$$

$$NI = (\frac{Lcore}{\mu} + \frac{Lgap}{\mu 0})$$

This is a nonlinear equation, because the permeability of the core, μ, varies with the magnetic field *B*. For an exact solution, the value of μ at the *B* value used must be obtained from the core material hysteresis curve. If *B* is unknown, the equation must be solved by numerical methods. However, if the magnetomotive force is well above saturation, so the core material is in saturation, the magnetic field will be approximately the saturation value *Bsat* for the material, and won't vary much with changes in *NI*. For a closed magnetic circuit (no air gap) most core materials saturate at a magnetomotive force of roughly 800 ampere turns per meter of flux path.

1.10.3 Force between electromagnets

The above methods are applicable to electromagnets with a magnetic circuit, and do not apply when a large part of the magnetic field path is outside the core. An example would be a magnet with a straight cylindrical core like the one shown at the top of this article. For electromagnets (or permanent magnets) with well defined 'poles' where the field lines emerge from the core, the force between two electromagnets can be found using the 'Gilbert model' which assumes the magnetic field is produced by fictitious 'magnetic charges' on the surface of the poles, with pole strength m and units of Ampereturn meter. Magnetic pole strength of electromagnets can be found from:

$$m = \frac{NIA}{L}$$

The force between two poles is:

$$F = \frac{\mu 0 M 1 M 2}{R 2}$$

This model doesn't give the correct magnetic field inside the core, and thus gives incorrect results if the pole of one magnet gets too close to another magnet

.

CHAPTER 2

LITERATURE REVIEW AND PROBLEM IDENTIFICATION

Abrasive flow machining is a purely mechanical process. A chemically inactive and noncorrosive media, similar to soft clay is used to improve surface finish and edge condition be used the abrasive particle in the media grind away rather than shear of the material. The same type of media can be used on different used. In some cases batch of media can be used of different metals without transferring removed material between workpieces. AFM is used for surface or edge condition of internal or external or otherwise inaccessible holes, slots and edges. It is highly efficient and accurate. And can be used in one way or two way applications. The most abrasive action during AFM if a hole changes size or direction in any industry the final finishing of complex and precision component is the most time consuming and labor intensive part. This considers about 15 % expenditure on the overall manufacturing process. The complex finishing process requires manual handling which is very slow and detrimental to the health of workers. AFM process replace a lot of manual work leading to more standardization of manufactured parts, hence their interchangeability, mass production and reduced costs.

2.1 EFFECT OF AFM PROCESS PARAMETERS

The material removed from the surface and surface quality depends on the following.

1. No of Cycle
2. Extrusion pressure
3. Temperature
4. Viscosity
5. Abrasive particle size
6. Abrasive concentration
7. Particle density
8. Media flow rate
9. Particle hardness

A lot of work has been done to study the effects of important AFM process parameters. Some of the work has have been reported.

There are several research has been carried in the field of increasing the material removal rate and percentage improvement in surface roughness. These research are also known by the term ie Hybridization of Abrasive flow machining

2.2HYBRID AFM PROCESSES

The concept of Hybrid machining processes (HMPs) is in vogue in the latest manufacturing practices in order to meet the challenges of high surface quality and tolerance requirements, often coupled with high production rates of parts having complex shapes and contours (Dubey, et al., 2008) and for the finishing of hard materials (Kim & Choi, 1997)(Yan, et al., 2003). In the development of Hybrid Abrasive Flow Machining Processes the aim is to improve the performance by clubbing the advantages of different machining processes and to avoid or to reduce the limitations or adverse effects (if any) of the constituent processes (Walia, 2006). Towards the development of Hybrid AFM processes, researchers have successfully integrated AFM with a number of non-conventional machining processes or clubbed additional energy sources with it to achieve the higher material removal and to produce better polished surfaces in a faster way (using less number of fast extrusion cycles).

(Kozak & Rajurkar, 2000) quoted that a hybrid approach where two or more material removal processes act simultaneously offers more scope, if not to enable a single cut from solid, then as a means to increase productivity in completion of an intermediate (semi finishing) or finishing task. Typically such approaches involve the combination of different physiochemical actions.Kozak J, Rajurkar KP (2000) quoted that a hybrid approach where two or more material removal processes act simultaneously offers more scope, if not to enable a single cut from solid, then as a means to increase productivity in completion of an intermediate (semi finishing) or finishing task. Typically such approaches involve the combination of different physiochemical actions.

There are generally two categories of HMPs:

- Processes in which all constituents processes are directly involved in the material removal and surface finish.
- Processes in which only one of the participating processes directly removes the material and improves the surface finish while the others only assist in removal/finishing by changing the conditions of machining in a “positive” direction from the point of view of improving capabilities of machining

In both of these categories thermal, chemical, electro-chemical and mechanical interactions occur. In general AFM process is marred by low material removal rate. Hence in the direction of efficiency enhancement of AFM, cross-process innovations or hybrid technology is a viable and feasible approach (Walia, 2006).

Some of the recent trends in the development of Hybrid Abrasive Flow Machining Processes are as follows:

2.2.1Ultrasonic Flow Polishing (UFP) Process

An example of HMP is the Ultrasonic Flow Polishing (UFP) and was developed by (Jones & Hull, 1995), (Jones & Hull, 1998)), (Extrude Hone, 1994) which is the combination of AFM and USM. AFM is an excellent finishing and polishing process but has disadvantage that is can be utilized with open dies whilst the USM is a highly accurate material removal method which can operate in closed dies. The combination of these two processes in the form of ultrasonically energized AFM media has the potential to be an excellent method of polishing closed dies. (Jones & Hull, 1995)developed an empirical model for UFP. (Jones & Hull, 1998) developed a test rig and for the process during a research on development of an automated polishing method to be applied on surfaces used in the forming and shaping of materials such as powder metallurgy products, casting and forging alloys, plastics and glass. In this process, the abrasive/polymer mix was pumped down to the vibrational node of the ultrasonically energized tool (Sonotrode) and on its exit the flow was constrained between the end face of the tool and the aluminium work-piece. Surface roughness improvements of up to 10:1 have been recorded from 2 µm to 0.1-0.2 µm. The combination of flow and vibration resulted in the more effective abrading of work-piece and surface finish also improved. This is suitable for closed dies. (Fletcher & Fioravanti, 1994)developed a model to determine the heat generation and temperature distribution for a mixture of polyborosiloxane and silicon carbide abrasive, which has been agitated using an ultrasonic system. (Fletcher & Fioravanti, 1996)determined the various thermal properties like thermal conductivity, specific heat capacity and heat transfer coefficient for this media. The thermal conductivity of the mixture was found to increase sharply when the concentration of abrasive increases beyond the 50 % point by mass. It is due to more inter particle contacts between the more thermally conductive abrasive particles. Specific heat capacity of the media decreases and surface heat transfer coefficient between the AFM media and its containment die increases with the increase in the abrasive concentration. (Fioravanti & Fletcher, 1996)further modified the model for the determination of temperature distribution in the complex geometries.

2.2.2 Magnetic Assisted Abrasive Flow Machining (MAAFM) Process

The pioneering work in this regard was done by Singh S. et al. (Singh, 2002), (Singh, et al., 2001), (Singh & Shan, 2002). Successful attempts have been made in improving the material removal rate by mixing the ferromagnetic abrasive particles with the polymer base and applying the magnetic field around the work-piece leading to the development of Magnetic Assisted Abrasive Flow Machining (MAAFM). Application of magnetic field around the work-piece during processing by AFM resulted in an increase in the number of dynamic active grains taking part in the cutting action. Also, the magnetic field increased the cutting force acting on the surface because of the acquired momentum by the abrasive particles and change in abrasive grains incidence angle of impingement and consequently the micro-ploughing and micro-chipping of the work-piece surface take place. With the application of magnetic field, results in increase in material removal rate, hence less number of cycles are required to achieve higher material removal. They concluded that the effect of magnetic field is observed only on non-ferromagnetic work materials. The investigations showed that under the effect of magnetic field, brass work-piece experiences more abrasion as compared to aluminium work-piece. Further it was observed that the magnetic field does not appreciably improve surface roughness of aluminium work-pieces while significant improvement was observed in case of brass specimens. (Singh, et al., 2002), (Singh, et al., 2006) applied the Taguchi method to optimize the parameters of MAAFM. (Singh, et al., 2002), (Singh, et al., 2008) reported that if the work piece was processed in magnetic field assisted AFM, extrusion pressure affects both material removal and surface roughness. It was also reported that the magnetic field is more influential at lower extrusion pressure. It was also reported that when work-piece was processed by magnetic field assisted AFM, the media viscosity interacted with magnetic flux density while affecting material removal as well as surface roughness. The effect of magnetic field has been shown to be dominant for low viscosity media. It was also reported that the magnetic field is more influential at the lower extrusion pressure.

Besides this (Singh, et al., 2004), (Singh, et al., 2005) successfully applied magnetic force in the formation of flexible magnetic abrasive brush (FMAB). (Cheung, et al., 2008)polished the HSS drilling bits in the magnetic polishing machine setup similar to magnetic stirrer with a polishing tank and stainless steel polishing shots. The polished edge-radiused drills demonstrate a remarkable improvement in tool life compared to unpolished sharp drills.

(Wani, et al., 2007)developed the FEM model for the Magnetic abrasive flow finishing (MAFF) and simulation of the results predicted a high level of surface finish and close tolerances in this process.

Overall the application of magnetic field to AFM leads to more material removal and better surface finish. It is mentioned that (Mulik & Pandey, 2011), (Mulik, et al., 2012) conceived a new hybrid of Ultrasonic machining and Magnetic abrasive finishing, namely Ultrasonic-assisted Magnetic Abrasive Finishing (UAMAF) and reported that the UAMAF process yielded better finishing characteristics compared to those obtained using the MAF process. The surface roughness value as low as 22 nm was obtained by UAMAF within 80s on a hardened AISI 52100 steel work-piece. Mulik and Pandey further experimentally determined the finishing forces and torques and studied their influence on the finished surface and proposed mathematical models for the MAF and UAMAF processes (Mulik & Pandey, 2012) to predict the finishing forces and torque. (Kwak & Kang, 2011)developed a magnetic array table with 32 electro-magnets for the Magnetic Abrasive Polishing (MAP) to increase the magnetic forces in the polishing of non-ferrous materials.

2.2.3 Magnetorheological abrasive flow finishing (MRAFF) Process

Magnetorheological abrasive flow finishing (MRAFF), is basically a combination of abrasive flow machining (AFM) and magnetorheological finishing (MRF), has been developed for nano-finishing of parts even with complicated geometry for a wide range of industrial applications.

MRF is used for external finishing of optical lenses to the nanometer level in which forces can be controlled by external means (i.e., magnetic field). (Jha & Jain, 2002)developed this process for the finishing of silicon nitride.

(Jha & Jain, 2004)employed this precision finishing process for complex internal geometries using smart magnetorheological polishing fluid. Magnetorheological abrasive flow finishing (MRAFF) process provides better control over rheological properties of abrasive laden magnetorheological finishing medium. Magnetorheological (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 behaviour in presence of external magnetic field. This smart behaviour of MR-polishing fluid is utilized to precisely control the finishing forces, hence final surface finish. The role of magnetic field strength in MRAFF process is clearly distinguished, as at zero magnetic field conditions no improvement in surface finish is observed, and the improvement is significant at high magnetic field strength. This is because; in the absence of magnetic field the CIPs and abrasive particles flow over the work-piece surface without any finishing action due to the absence of bonding strength of CIPs. As the magnetic field strength is increased by increasing magnetizing current, CIPs chains keep on holding abrasives more firmly and thereby result in increased finishing action. (Jha & Jain, 2006)also developed the models for MRAFF. (Jha, et al., 2007)studied the effect of pressure and number of cycles on surface roughness in MRAFF and reported a new observation of "illusive polishing" action with the initial increase in number of finishing cycles is reported. The actual finishing action is possible only after removal of initial loosely held material remaining after grinding.

(Das, et al., 2008), (Das, et al., 2008) developed MRAFF and reported various advantages of this process as follows: The MRP-fluid used for finishing exhibits real time controllable change in flow properties of fluid enabling in-process control of finishing forces through magnetic field, (or current to the electromagnet). Any complex geometrical surface, internal or external, inaccessible to existing finishing processes can be finished. Authors also developed models for the formation of CIP chain structures around Sic abrasive for this process; Surface finish of 0.4 micron R_a has been achieved.

(Sadiq & Shunmugam, 2009)developed a setup to finish external curved surfaces, by imparting rotation while the abrasive –mixed magnetorheological fluid is pushed up and down and termed this process as Magneto-rheological Abrasive Honing (MRAH) process. This makes use of the abrasive mixed magneto-rheological fluid as the finishing medium and ca combination of rotaty and reciprocating motion as is employed in conventional honing process. (Sadiq & Shunmugam, 2010)further improved the finishing performance of MRAH in the finishing of non-magnetic specimens by introducing magnetic specimens along with the non-magnetic specimens.

Besides AFM, (Jung, et al., 2009) studied the main mechanism responsible for the decrease of the material removal rate on hard materials for a wheel-type magnetorheological finishing process both theoretically and experimentally, and a solution to this problem is devised via two approaches. The first uses a rectilinear alternating motion to improve processing conditions, and the second focuses on the use of more effective abrasives, namely magnetizable abrasives made of iron powders sintered with carbon nanotubes, which are new abrasives that have not yet been introduced in the field of surface finishing. Furthermore, it is shown that these abrasives increase the lifetime of consumables (magnetorheological fluid and abrasives) and the material removal rate.

MRAFF is a process whose fluid flow properties can be controlled by altering the magnetic field for the hard or soft materials as per the requirement.

2.2.4 Centrifugal Force Assisted AFM (CFAAFM) Process

(Walia, et al., 2004),Walia et al. (2006c) developed this new Hybrid AFM process by introducing the centrifugal force in the extruding media to achieve more material removal and improved surface finish. The application of centrifugal force (by using rotating rectangular rod inside the hollow workpiece) had been explored for the productivity enhancement of the process. (Walia, 2006) (Walia, et al., 2009), (Walia, et al., 2006), (Walia, et al., 2008), (Walia, et al., 2008)optimized this process by using Taguchi Method, developed FEM model, used Utility concept to multi-response optimization of CFAAFM, developed analytical model, improved the fixturing for the provision of rotating rod inside the hollow cylindrical work-piece. It has been reported that centrifugal force enhances the material removal rate (MRR) and improves the scatter of surface roughness (SSR) value in AFM leading to the development of Centrifugal Force assisted AFM (CFAAM). (Singh & Walia, 2012), (Singh, et al., 2012) further optimized the various parameters of CFAAFM process like the number of cycles, shape and rotational speed of the CFG rod to achieve polished surfaces. The increased machining rate in CFAAFM process results in faster cutting and thus less number of cycles are required to achieve higher material removal.

(Reddy, et al., 2008)studied the effect of key parameters on the performance of the process through response surface methodology (RSM). Relationships were developed for material removal and percentage improvement in surface finish of cast Al alloy (2014) cylindrical components. It was observed that the combination of a high extrusion pressure and a higher speed of the centrifugal force generating (CFG) rod are more favourable to obtain a higher degree of surface finish, while the combination of a larger grain size and a higher speed of the CFG rod cause higher material removal.

2.2.5 Drill Bit-Guided Abrasive Flow Finishing (DBG-AFF) Process

(Sankar, et al., 2009) developed Drill Bit-Guided Abrasive Flow Finishing (DBG-AFF) process, and employed drill bit in place of prismatic rods, for the simultaneous rotation of abrasives laden media and observed better results due to a combination of abrasives laden media flows leading to better mixings of media and thus more number of active grains. (Sankar, et al., 2011)further studied the rheological characteristics of the AFF media for the DBG-AFF process. The major difference between AFF and DBG-AFF machines is in its tooling. In AFF machine, circular fixture plate allows the medium to flow as a cylindrical slug. The abrasive intermixing (or reshuffling) purely depends on medium self-deformability and for most of the time the same active abrasive grains keep taking part in finishing. The abrasive particles follow the shortest contact length (straight line) in AFF. In DBG-AFF process, the cylindrical slug gets divided in two halves while entering in the finishing zone; at the exit side these two halves recombine resulting in better intermixing of the medium. The abrasive intermixing depends not only on the medium self-deformability but also on the pressure from the drill bit being exerted on the medium (reciprocating axial flow, flow along the flute, and scooping flow—all the three flows take place at the same time). Moreover, the rotating drill-bit introduces additional centrifugal forces on the active abrasive grains resulting in deep digging of abrasives into the work-piece surface and thus more vigorous abrasion. Moreover the slug length is more and due to the combination of different modes of flow, the work-piece (AISI 4340)–abrasive contact length is no longer a straight line, rather it becomes inclined. Hence, the number of peaks that can be sheared off in a single cycle increases, leading to higher material removal rate hence finishing rate also (Jain, 2009). Thus more material is removed from the work-piece surface and surface finish is also better.

2.2.6 Rotational Abrasive Flow Finishing (R-AFF) Process

(Sankar, et al., 2009), (Sankar, et al., 2010)also experimented by rotating the cylindrical work-piece and termed is as Rotational Abrasive Flow Finishing (R-AFF) process. In this process better surface finish was observed due to the shearing of more number of peaks during the extrusion and also due to additional shearing forces (Sankar, et al., 2009). Preliminary experimental study reported R-AFF can produce 44% better ΔR_a and 81.8% more MR compared to AFF process. This was due to the fact that in the R-AFF process, the abrasives are cutting the material along a helical path so the abrasives-work-piece contact length increases, leading to more machining. Moreover, the rotation of work-piece imparts additional component of tangential force along with the radial and axial forces which are acting on the active abrasive grains, this enhances micro-chipping of work-piece material with lower chance of rolling of abrasive grains. (Sankar, et al., 2010)finishedAl alloy and Al alloy/SiC metal matrix composites (MMCs) with the R-AFF process. Based on the experimental findings, themechanism of material removal of matrix and reinforcement in MMC using R-AFF has been proposed. Further, in the AFM process, since the medium flow is nearly perpendicular to the initial grooves lays (grinding marks) on the surface, evacuation of the ploughed material is minimum. So, abrasives entering the valley are less and they try to shear only the top surface peaks. But in the R-AFF process abrasives help in evacuating the ploughed material (accumulated during grinding, if any) as they flow at a certain angle to the initial grinding lay. Further (Sankar, et al., 2008), (Sankar, et al., 2011) studied the various flow and deformation properties for a specially co-polymered soft styrene butadiene based polymer, plasticizer and abrasives, and noted viscoelastic behaviour with shear thinning nature in the machining of Al-alloy and MMCs for the R-AFF process.

2.2.7 Rotational-Magnetorheological Abrasive Flow Finishing (R-MRAFF) Process

(Das, et al., 2010)developed a new polishing method called Rotational-Magnetorheological Abrasive Flow Finishing (R-MRAFF) process by rotating a magnetic field applied to the Magnetorheological polishing (MRP) medium in addition to the reciprocating motion provided by the hydraulic unit to finish internal surface of cylindrical stainless steel (non-magnetic) work-piece. The two motions of rotation of magnetic field and reciprocation of abrasives laden magnetorheologicalmedia were controlled to get smooth mirror like finished surface of the order of 16 nm. (Das, et al., 2012)further employed this method for the nanofinishing of flat work-pieces and noted that highest contribution to the percentage improvement in surface roughness is of rotational speed of the magnet followed by number of finishing cycles, extrusion pressure, and fluid composition. The best surface finish obtained on stainless steel and brass workpieces with R-MRAFF process are 110 and 50 nm and the abrasive cutting marks generate cross-hatch pattern on the finished surface.

2.2.8 Helical AFM (HLX-AFM) Process

In the development of Helical Abrasive Flow Machining (HLX-AFM) process, (Sharma, 2011) employed a stationary-coaxially fixed helical twist drill bit for the finishing of internal cylindrical surface and observed that material removal increased by a factor of 2.66 over the basic AFM process, along with a maximum percentage improvement in surface roughness of 74.69% (form 2 µm to 0.5 µm). The increase in efficiency is due to increase in active grain density due to a combination of flows as well as due to increased cutting forces on the active abrasive grains. (Singh, 2011)further improved the performance of HLX-AFM by using different helical profiles namely, standard helical twist drill, spline and 3-start profile. More improvement in surface roughness of 61.40 % (From initial surface roughness of 1.3 µm to 0.50 µm) was observed for 3-strat helical profile with no effect on material removal (means no extra machining effort). (Kumar & Walia, 2012)employed HLX-AFM process for the processing of different work-piece materials namely mild steel, brass and aluminium. More material removal was observed in brass than the mild steel work-pieces and so is the percentage improvement in surface roughness. Although, aluminium is soft and more volumetric material removal takes place (highest percentage improvement in surface roughness was reported), but low material removal (in mg) was reported due to the low density of aluminium. Again the 3-start profile is the most effective among the selected profiles in improving the surface roughness. (Wang, et al., 2012)developed a mechanism with a four helices passageway to perform multiple flowing paths of abrasive media, whose flowing behaviour enhanced polishing effectiveness and uniformity of the surface finish by increasing the abrasive surface area and radial shear forces.

2.2.9 Electrochemical Aided AFM (ECAFM) Process

Dabrowski et al. successfully experimented on the integration of Electro-chemical Machining (ECM) with the AFM and developed Electrochemical Aided AFM (ECAFM) by employing polymeric electrolytes for the finishing of flat work-pieces only. Dabrowski et al. used a number of electrolytic pastes for these experiments for the finishing of steel and observed more material removal with KSCN salt based electrolytic pastes than with NaI salt based pastes. Material Removal increased with the electrochemical aid (Dabrowski, et al., 2006), (Dabrowski, et al., 2006)experimented with the electrochemically assisted abrasive flow machining (ECAFM) using polypropylene glycol PPG with NaI salt share and the ethylene glycol PEG with KSCN salt share. The abrasive properties of the electrolytes have been enhanced by adding the Al_2O_3 and SiC grains. Voltage was varied from 15 V to 50 V and at 15V with KSCN salt the larger material removal is observed. Application of potassium thiocyanate (KSCN), with voltage 50 V, caused change of roughness of flat surfaces from $Ra = 0.81\ \mu m$ to $Ra = 0.57\ \mu m$. They further reported that the ion conductivity of electrolytes is many times lower than the conductivity of electrolytes employed in ordinary electrochemical machining (ECM). Additions of inorganic fillers to electrolytes in the form of abrasives decrease conductivity even more. These considerations explain why the inter-electrode gap through which the polymeric electrolyte is forced should be small. This in turn results in greater flow resistance of polymeric electrolyte, which takes the form of a semi-liquid paste. Electrochemically assisted abrasive flow machining (ECAFM) is possible using polymeric electrolytes.

2.3 MOTIVATION

After the literature reviews there are various points come out of the box which gives the interest motivation towards this project due to following reason-

- Because of industrial revolution manual work has been replaced by machines in many industrial process but there are still many complex task and have higher demand in-
    - Surface finishing
    - Economic viability

  Where our mechanical systems are too clumsy.

- While working manually there are also some health and safety issues.

Abrasive flow machining is complex because of the little-understood behavior of the non-Newtonian medium and the complicated and random nature of the mechanical action of material removal.

2.4 OBJECTIVE OF THE THESIS

As discussed earlier Abrasive Flow Machining has a limitation of less material removal. Many researchers used hybrid machining process to reduce its limitation. In this thesis attempt is made to increase the material removal by applying variable electromagnetic field. By using the combination of the gel with silicon carbide as a abrasive and this media is pressurized to flow through a workpiece which is surrounded by two electromagnet. Brass workpiece have internal diameter 8 mm

CHAPTER 3

RESPONSE SURFACE METHODOLOGY (RSM)

3.1 Introduction of RSM

RSM is nothing but an amalgamation of the statistical methods available and their usage in the mathematical manner so that they could be utilized to find out the desired values which are to be controlled. It is a method which uses apt number of experiments to find out the solutions to the multi variable problems which depend upon the factors.

Graphical depictions of these obtained problems are coined as the response surfaces, which are used to designate the individual and combined effect of the input variables on the output and to find out the relationship these variables share among themselves or between the output also known as response.

3.2 Uses of RSM

1. To find out the factor level and this will be able to satisfy the desired dimensions.
2. To find the relationship of responses on individual input parameter.
3. To obtain a quantitative knowledge of the system performance in the area
4. To forecast the properties of the product and to find out the responses it would give when the obtained settings are given.
5. To find out the all the necessary situations for the stability of the process.

3.3 METHODOLOGY OF RSM

Whole process of rsm can be divided into different parts and those parts are the sequences in which the process has to be done. In design optimization using RSM, the first task is to determine the optimization model, such as the identification of the interested system measures and the selection of the factors that influence the system measures significantly.

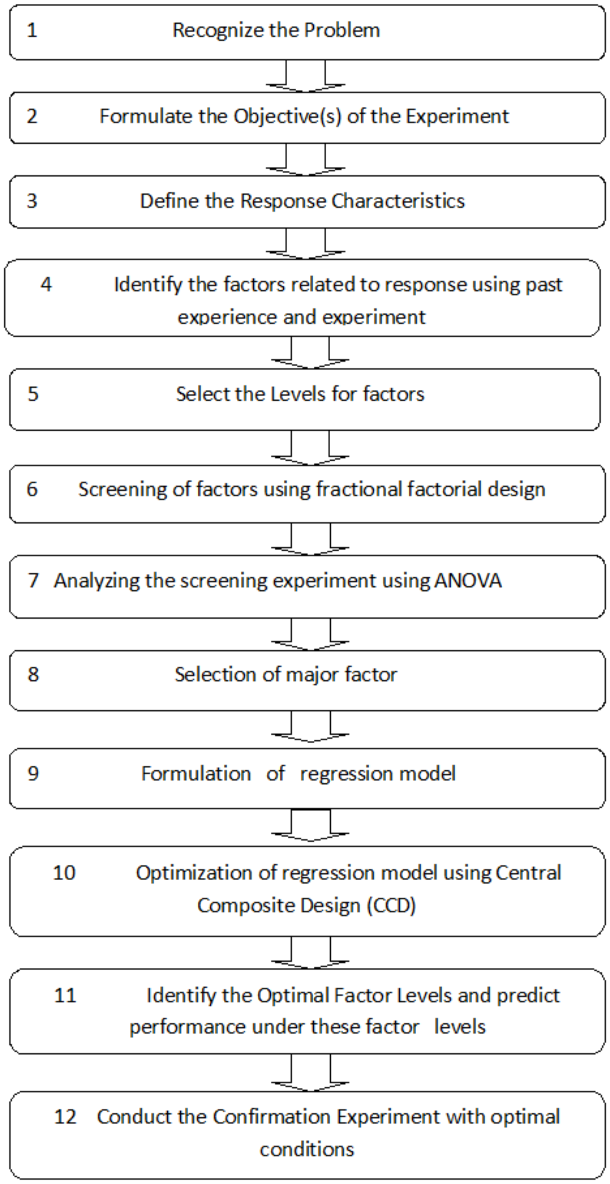


Figure7: Flow diagram of RSM methodology

To do this, an understanding of the physical meaning of the problem and some experience are both useful. After this, the important issues are the design of experiments and how to improve the fitting accuracy of the response surface models. DOE techniques are employed before, during, and after the regression analysis to evaluate the accuracy of the model. RSM also quantifies relationships among one or more measured responses and the vital input factors.

RSM, or RSM, is a collection of mathematical and statistical techniques in which a response of interest is influenced by several variables and the objective is to optimize this response. For example, suppose that a chemical engineer wishes to find the levels of temperature (x1) and pressure (x2) that maximize the yield (y) of a process. The process yield is a function of the levels of temperature and pressure, y = f (x1, x2) +e

Where e represents the noise or error observed in the response y. Then the surface depicted by h= f (x1, x2), which is called a Response surface. We usually represent the response surface graphically, where h is plotted versus the levels of x1 and x2. To help visualize the shape of a response surface, we often plot the contours of the response surface as well. In the contour plot, lines of constant response are drawn in the x1, x2 planes. Each contour corresponds to a particular height of the response surface. Objective is to optimize the response. In RSM, polynomial equations, which explain the relations between input variables and response variables, are constructed from experiments or simulations and the equations are used to find optimal conditions of input variables in order to improve response variables. For the design of RSM, many researchers have used central composite design (CCD) for their experiments. CCD is widely used for fitting a second-order response surface. CCD consists of cube point runs, plus center point runs, and plus axial point runs.

The three factors speed, feed rate, depth of cut, selected in the screening experiment, will be used in CCD. The process can be studied with a standard RSM design called a Central composite design (CCD). The factorial portion is a full factorial design with all factors at three levels, the star points are at the face of the cube portion on the design which

Correspond to value of -1. This is commonly referred to as a face centered CCD. The center points, as implied by the name, are points with all levels set to coded level 0, the midpoint of each factor range, and this is repeated six times. Twenty experiments to be performed. For each experimental trial, a new cutting edge to be used. The latest version of the Minitab or Design Expert may be used to develop the experimental plan for RSM. The same software can also be used to analyze the data collected.

3.3.1Objective of RSM

Our goal is to start from using our best prior or current base and find for the optimum spot where the response is either maximized or minimized.

Here are the models that we will use.

Screening Response Model :

$yy=\alpha\alpha+\beta\beta xx1+\gamma\gamma xx2+\delta\delta xx1xx2+\varepsilon\varepsilon$ (1)

The screening model that we used for the first order situation involves linear effects and a single cross product factor, which represents the linear x linear interaction component.

Steepest Ascent Model

If we ignore cross products which gives an indication of the curvature of the response surface that we are fitting and just look at the first order model this is called the steepest ascent model:

$y = \beta x1 + \gamma x2 + \varepsilon$

3.3.2 Optimization Model

After this, it is known that we are somewhere near the maximized or optimized value so, a second order model. This includes in addition the two second-order quadratic terms.

If the plot is in more than 2 dimensions, the method is not best suited as per the obtained plot. The method of steepest ascent tells where to take new measurements, and the response at those points can be recorded. it might move a few steps and it may be seen that the response persistently strived to move up or perhaps not - then you might do another first order experiment and reorganize the efforts. The point is, when the experiments are done for the second order model, it is hoped that the optimum will be in the range of the experiment - if it is not, then, it is extrapolation to find the optimum. In this case, the safest thing to do is to do another experiment around this estimated optimum. Since the experiment for the second order model requires more runs than experiments for the first order model, it is required to move into the right region before starting fitting second order models.

Steepest Ascent - The Second Order Model

This second order model includes linear terms, cross product terms and a second order term for each of the x's. If in generalized way, various values have k first order terms, k second order terms and all possible pairwise first-order interactions. The linear terms just have one subscript. The quadratic terms have two subscripts. There are k*(k-1)/2 interaction terms. To fit this model, it is needed to have a response surface design that has more runs than the first order designs used to move close to the optimum.

This second order model is the basis for response surface designs under the approximation that optimized value is not a perfect quadratic polynomial in k dimensions, but it provides a good approximation to the surface near the maximum or a minimum.

CHAPTER 4

Development of magnetic force assisted abrasive flow machining

4.1 AFM SET UP

Figure8: Shows an AFM set up

The 2 way AFM pressurize the abrasive media to flow through the internal cylindrical surface of the hollow workpiece. The abrasive laden media interacts with the surface and causes material removal from it. In the two way AFM the motion from top to bottom and from bottom to top constitutes a single cycle. Figure no.8 shows the AFM setup which is available in Precision Engineering lab of DTU. The main components in the AFM machine are as follows-

4.1.1 Hydraulic Power Pack

It is the main driving component of the workpiece. It has major function teo supply the oil from the reserviour to the respective hydraulic cylinder which causes the back and forth movement of piston in the hydraulic cylinder. It consists motor, reservoir, filter and hydraulic pump along with accompanying hydraulic circuit.

4.1.2 Hydraulic Cylinders

In the AFM set up there are two vertical cylinders which are in the opposite of each other. These hydraulic cylinders are connected through hydraulic power pack through the pipie line. Here the diameter of pipe line is an important parameter because it develops the pressure. In this the piston moves from top to bottom and from bottom to top due to pressure difference in the cylinder barrel. The barrel is closed on one side by cylinder bottom and other end by cylinder head called as gland. The cylinder acts as a mechanical actuator by driving the piston through the action of a pressurized hydraulic fluid to generate a unidirectional force.

4.1.3 Media Cylinders

In the 2 way AFM two media cylinders are used which are vertical and opposite to each other. The media cylinder consists the mixture of the gel and the abrasive particles which is forced to flow through the hollow workpiece. The inner surface of the media cylinder should be smooth so that loss should be minimize because of the friction between the wall and media surface

4.1.4 Fixture

The fixture is made of Nylon. It holds the workpiece and magnetic setup and causes the media to flow through the workpiece. The fixture is made of Nylon because it has good wear properties.
Dimension of the nylon fixture is given below

4.1.5Machine Frame

It provides the support and the holding strength.

4.1.6 Power supply

There are two type of power supply is needed for the machining, one is for the electric motor of the loading unit and loading cylinder.this power supply is of 220volt,single phase. Electric motor of loading unit is of 0.5 HP. The other power supply is needed for the working of electro magnet. This power supply is used in such a way that we can generate the magnetic flux between two magnet in such a way that flux intensity can be varied. Input of this unit is also 220voly AC .

4.1.7Magnetic Field setup

To create the magmetic flux around the workpiece there is a need of electromagnet whose intensity can be varied from 0 Tesla to 1 Tesla.

4.1.8 WORKPIECE preparation

I am using brass as workpiece .The workpiece taken is of outside diameter of 10 mm, and length of 16 mm. Workpiece is prepared by first of all drilling of 7 mm drill bit and after that 1mm diameter is removed by the boring operation so that there will be clear boring tool mark, which is our aim to remove by finishing operation. The workpiece has internal diameter of 8 mm.

Figure 9: Shows brass workpiece

20 samples of workpiece were taken and experiment was done on it according to response surface methodology usinf magnetic force.

4.2 PREPARATION OF POLYMER

For preparation of polymer take a vessel .Then take 1 litre of silicon oil and mix it with 60 gram boric acid. It will become of green color after stirring. Then mix 10 gram lewis acid in it. It will become of yellow color. Stirring is done till all the particles are properly mixed. After that it was heated in a vessel and stirring is done continuously. When the mixtures starts boiling and it becomes viscous rubber type then mix 10 gram $NH4CO3$ in it and stirring is done continuously till it becomes very viscous which is non sticky type. Then allow it to cool .The polymer is prepared.

Figure 10. Polymer after processing

4.3 PREPARATION OF GEL

For making gel a vessel is taken and then take half kg of hydrocarbon oil and it is mixed with 30 gram aluminium stearate .It will become of white color. Proper stirring is done till the particles are properly dissolved. Then heat it for 20 to 25 minute and stirring is done continuously till it becomes a thick gel type .After that it is allowed to cool. Then the gel is prepared.

4.4 PREPARATION OF MEDIA

I took 300 gram of polymer and 80 gram of gel and then it is mixed by hand properly. Then I added 400 gram of Aluminium oxide and it is properly mixed with it. The media is prepared now.

Figure11: prepared media has shown

4.5 Development of Magnetic field setup

To create the electromagnetic effect around the work piece there is a need of electromagnet. After the study of electromagnet I found the electromagnet can be created turning the copper wire around the soft iron rod.There are three factors on which the intencity of electromagnet depends

1 current supply
2 Number of turns
3 Material of core (Permeability)

In this project I have fixed the number of current and material of core and by varying current supply I have changed the intensity of electromagnet from 0Tesla to 1Tesla

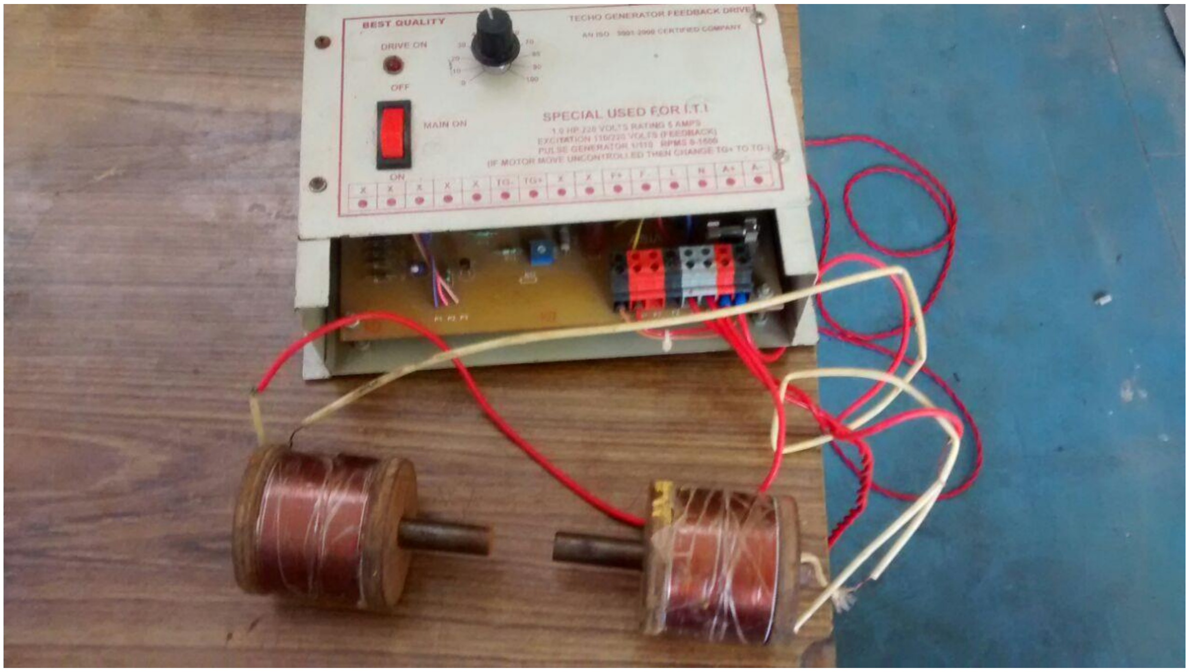


Figure 12: Magnetic Setup

CHAPTER 5

PROCESS PARAMETER SELECTION AND EXPERIMENTATION

To draw valid and objective conclusions from an experimental investigation requires conducting experimentation in accordance with proper planning and design of experiments. In performing a designed experiment, the input variables are varied and the corresponding changes in the output variables are observed. The input variables are called factors and the output variables are called response. Factors may be either qualitative (such as type of material, colour of sample etc.) or quantitative in nature. Each factor can take several values during the experiment wherein each such value of a factor is referred to as a level. A trial or run is a certain combination of input factor levels whose effect on the output is of interest. It is essential to incorporate statistical data analysis methods in the experimental design in order to draw sound and reliable conclusions from the experiment. Firm conclusions cannot be drawn from an experimental study unless proper planning, careful study and due diligence is observed in the selection of input variable factors, their chosen levels and proper recording of all the possible output responses. The selection of input variable parameters and their levels is thus a pre-requisite to a successful experimental study besides of course following the protocol in the conduct of The literature review suggested the possible process parameters that may be influencing the capability and efficiency of the process and the subsequent quality of components finished by AFM. The parameters can be classified on the basis of three major elements of the process, as mentioned below,

1. **Machine Parameters:** Extrusion pressure, media flow rate, media flow volume, number of cycles.
2. **Medium Parameters:** Abrasive Size, Abrasive Type, Abrasive Concentration, Additives/Oil Concentration, Temperature and Viscosity of the medium.
3. **Work-piece Parameters:** Work-piece Material, Passage Geometry, Reduction ratio, Initial surface roughness.
4. **Magnetic parameter:** Intensity of magnetic flux, ferromagnetic abrasive used

Selection of workpiece

Workpiece Parameter

I am using brass as workpiece .The workpiece taken is of outside diameter of 10 mm, and length of 16 mm. Workpiece is prepared by first of all drilling of 7 mm drill bit and after that 1mm diameter is removed by the boring operation so that there will be clear boring tool mark, which is our aim to remove by finishing operation. The workpiece has a internal diameter of 8 mm.

5.1 MACHINE PROCESS PARAMETER AND THEIR RANGES

Type of Press- 2 Pillar type fabricated Design
Capacity- 25 + 25 Ton
Stroke length -96 mm
Hydraulic cylinder Bore dia – 2 No.130mm
Hydraulic cylinder Stroke- 90 mm
Working Pressure-210 kg/Cm^2
Maximum Pressure in the Cylinder – 35 MPa
Stroke Length of Piston - 300mm

5.2 RESPONSE CHARACTERISTICS

The effect of these process parameters were studied on the following response characteristics of AFM process-

1. Percentage improvement in surface finishing (ΔRa)
2. Material Removal (MR)

5.2.1 PERCENTAGE IMPROVEMENT IN SURFACE FINISHING

The surface roughness was measured at several random locations on the internal cylindrical surface of the Aluminium workpiece. The mean value was taken of the random values of roughness. Then the percentage improvement in surface finishing was calculated from the formula

$$\Delta\text{Ra} = \frac{\text{(Initial Roughness – Roughness after Machining)/(Initial Roughness)}}{\mathit{Initial\ Roughness}} \times 100$$

SURFACE ROUGHNESS INSTRUMENT: Surface roughness is an important parameter required for the measurement of the quality of the product. Surface measurement is nothing but the comparison of the previously fixed value with the new value obtained.

The taylsurf instrument used in this experiment is a Taylor Hobson unit with surtonic3+ as its product name. Surtronic 3+ is nothing but an amalgamation of technology so as to achieve high meticulousness and exactitude to have an accurate measurement of surface finish in the process no matter where the work is done, laboratory or the inspection room. With Surtronic 3+, a beginner with no skills can achieve wide range of skills that can be understood within minutes. In this device the cycles in the function are minimum during the process of measurement and the variations are minute and the response can be obtained on the screen available. The process of measurement is easy and the whole machine can be operated or navigated through a wide variety of navigations and selection

Figure12: a taylsurf instrument by taylor hobson surtonic 3+ at metrology lab, DTU

Table1: Specification of Taylsurf instrument for measurement of surface roughness

Gauge Range	±150μm (0.006in)
Pick up type	Variable reluctance
Traverse length (Max)	25.4mm (1.0in)
Stylus	112/1502: Diamond tip radius 5μm (200μin) 112/1503: Diamond tip radius 10μm (400μin)
Cut Off Values	0.25, 0.8, 2.5, 8mm (0.01, 0.03, 0.1, 0.3in) (8mm Cut off only available when using Talyprofile or Macro-Maker Software)
Parameters	Ra, Rq, Rz (DIN), Ry, Sm, Rt
Traverse length (Min)	0.25mm (0.01in)
Optional additional parameters	Pc (in place of Sm), tp% (in place of Rq) - with optional EPROM available on request
Overall Dimensions	130 x 80 x 65mm (5.1 x 3.3 x 2.5in)
Data Processing Module	185 x 140 x 50mm (7.5 x 5.5 x 2in)
Resolution	0.01μm (0.4μin)
Traverse Speed	1mm/sec (0.04in/sec)
Accuracy of Parameters	2% of reading + LSD μm
Power	Battery or Mains (optional)

5.2.2 Material removal (MR)

Material removal signifies the amount of material removed from the specimen in a specified number of process cycle. Material removal was calculated from the formula

MR= (weight of the workpiece before machining – weight of workpiece after machining

5.3 Scheme of experiments

The experiments were designed to study the effect of some of the AFM parameters on response characteristics of AFM process. Here Response Surface methodology is adopted to design the experiments. The selected number of process parameters and their levels aregiven in the table:

Table 2: Process parameter and their value at different level

Symbol	Procss Parameters	Unit	Level 1	Level 2	Level 3
A	Magnetic flux	Tesla	0	0.5	1
B	Abrasive concentration	Percentage	65	70	75
C	Number of cycle	Number	4	8	12

Workpiece Material- Brass

Media flow volume-290 cm^3

Temperature-32±2’C

Initial Roughness -1.10 to2.96 micron

CHAPTER 6

RESULT AND DISCUSSION

6.1 Analysis of DATA

The design table to be used was made by deciding the values of the parameters to be set in the experiment. Namely, the number of cycle, magnetic flux and abrasive concentration were set accordingly. The values were defined on basis of the values available in the machine so as to perform the experiment

Table3: Input parameter of variable

Magnetic flux(Tesla)	Abrasive concentration	Number of cycle
0	65	4
0.5	70	8
1	75	12

The values or the factors were thus defined and with help of Design Expert the RSM value table was then generated which would set the values or the order of the readings in the experiment.

CCD:-

Nos of Factor: 3
Replicas: 1
Total runs: 20
Number of Base blocks: 1
Total number of blocks: 1
2-level factorial: Full factorial
Number of Cube points: 8
Center points taken in the cube: 6
Number of Axial points taken: 6
Center points taken in axial: 0
Alpha: 1

6.2 Design Table

Table 4 : Design table in terms of actual factors

Run	Mag. Flux	Abrasive Concentration	No. of cycle
1	0	65	4
2	0.5	75	8
3	1	65	12
4	0.5	70	12
5	0	75	12
6	0	75	4
7	0.5	70	8
8	1	70	8
9	0.5	65	8
10	0.5	70	4
11	0.5	70	8
12	0.5	70	8
13	1	75	4
14	0.5	70	8
15	1	65	4
16	0.5	70	8
17	0	70	8
18	0	65	12
19	1	75	12
20	.5	70	8

The parameters thus after being defined were made constant for the process and the optimization was thus taken forward. The design was then set and the graphs were obtained between different values depending upon the required values and considerations

Table5: Table shows value of response as well as variable parameter

Run	Magnetic flux	Abrasive concentration	Number of cycle	% improvement in Ra	MR (mg)
1	0	65	4	12.5	0.608
2	0.5	75	8	28	1.136
3	1	65	12	31	0.928
4	0.5	70	12	29.62	0.849
5	0	75	12	21	0.823
6	0	75	4	16	0.638
7	0.5	70	8	21	0.725
8	1	70	8	26	0.835
9	0.5	65	8	16	0.611
10	0.5	70	4	20	0.729
11	0.5	70	8	26.8	0.827
12	0.5	70	8	27.3	0.937
13	1	75	4	26	0.759
14	0.5	70	8	25	0.789
15	1	65	4	19	0.699
16	0.5	70	8	24	0.865
17	0	70	8	16	0.61
18	0	65	12	18	0.621
19	1	75	12	35	1.406
20	.5	70	8	21	0.852

6.3Discussion on Percentage improvement in surface roughness

ANOVA table for Percentage improvement in Ra

Table 6: ANOVA table for Percentage in Ra

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	1436.10	4	359.03	31.69	< 0.0001	Significant
A-mag flux	*313.60*	*1*	*313.60*	*27.68*	*< 0.0001*	
B-abr conc	*348.10*	*1*	*348.10*	*30.72*	*< 0.0001*	
C-no of cycle	*562.50*	*1*	*562.50*	*49.65*	*< 0.0001*	
C^2	*211.90*	*1*	*211.90*	*18.70*	*0.0006*	
Residual	169.95	15	11.33			
Lack of Fit	*143.74*	*10*	*14.37*	*2.74*	*0.1385*	Not significant
Pure Error	*26.21*	*5*	*5.24*			
Cor total	1606.05	19				

The Model F-value of 31.69 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 2.74 implies the Lack of Fit is not significant relative to the pure error. There is a 13.85% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Table 7: Table shows the statics control terminology

Std. Dev.	2.62	R-Squared	0.8318
Mean	22.96	Adj R-Squared	0.8003
C.V. %	11.40	Pred R-Squared	0.7463
PRESS	165.40	Adeq Precision	21.205
Std. Dev.	2.62	R-Squared	0.8318

The "Pred R-Squared" of 0.7463 is in reasonable agreement with the "Adj R-Squared" of 0.8003; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 21.205 indicates an adequate signal. This model can be used to navigate the design space.

6.3.1 Final Equation in Terms of Coded Factors:

% improvement Ra =
+31.81
+5.60 * A
+5.90 * B
+7.50 * C
-6.51 * C^2

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

6.3.2Final Equation in Terms of Actual Factors:

% improvement Ra =
-31.91300
+10.70000 * mag flux
+0.59000 * abr conc
+1.02800 * no of cycle

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

6.3.3Diagnosis of static properties of the model

Check point for the Diagnosis

1) Normal probability plot of the studentized residuals to check for normality of residuals.

2) Studentized residuals versus predicted values to check for constant error.

3) Externally Studentized Residuals to look for outliers, i.e., influential values.

4) Box-Cox plot for power transformations.

If all the model statistics and diagnostic plots are OK, finish up with the Model Graphs icon. After the analysis, various curve has been drawn depends upon the factor . these grafsare between actual value predictable normal % probability

6.3.4Residual curve for % improvement in Ra

In this Data points should be approximately linear. A non-linear pattern (such as an S-shaped curve) indicates non-normality in the error term, which may be corrected by a transformation. The only sign of any problems in this data may be the point at the far right and the plotted gaph also shows the same.

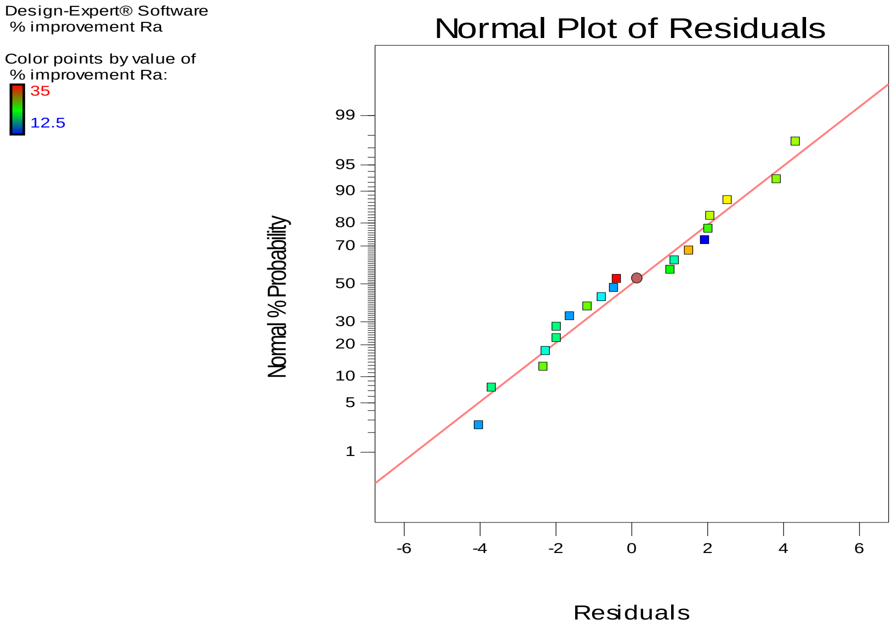


Figure 12: Residual vs. Normal probability graph

As shown in figure,plot of normal % probability against residual(-6to6), the scattered point lie near to the straight line graph that concludes the positive result of the diagnosis of % improvement in Ra.

6.3.5 Residual V/S predicted

As shown in figure no12 ,On Y axis externally studerized residual is parallel to Residual vs predicted and that variation is within the limit

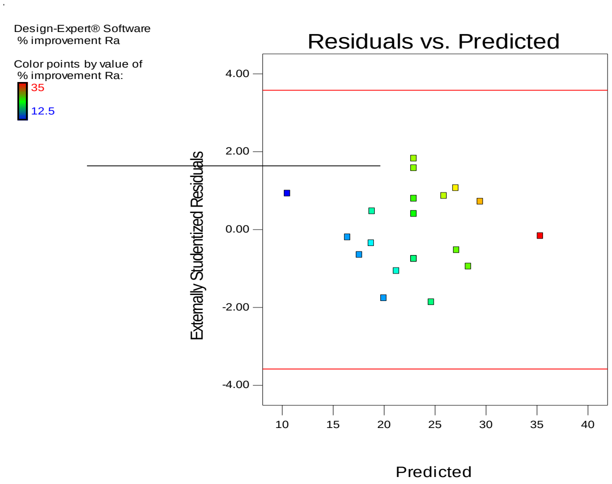


Figure13: Graph of residual vs. predictable

6.3.6 Residuals vs. run

This graph shows the variation of residual with respect to the run number that how variation takes place with respect to the run order of the experiment.

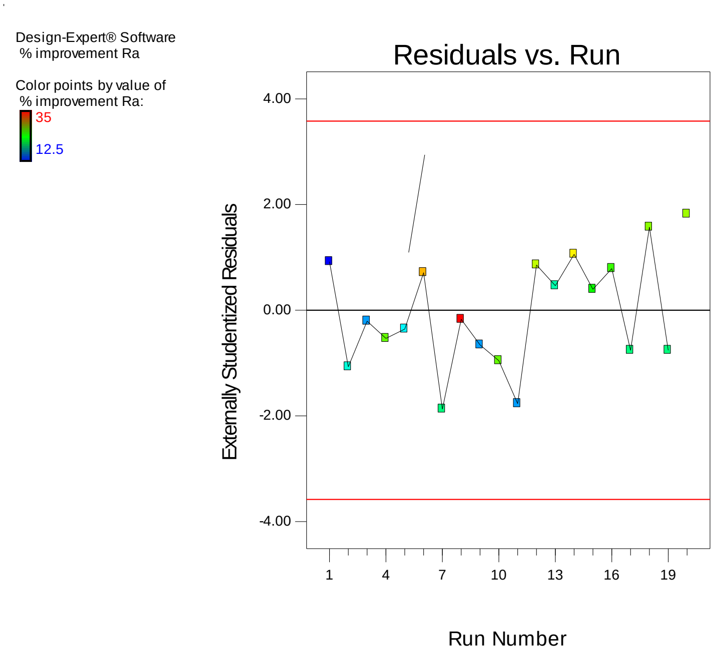


Figure14: Graph for run number vs. Residuals

6.3.7 Predictable vs. Actual

Always there is a variation between tha actual value and predicted value. These graphs tell the same story. From the graph we can conclude that there is a linear variation between predicted value and actual value

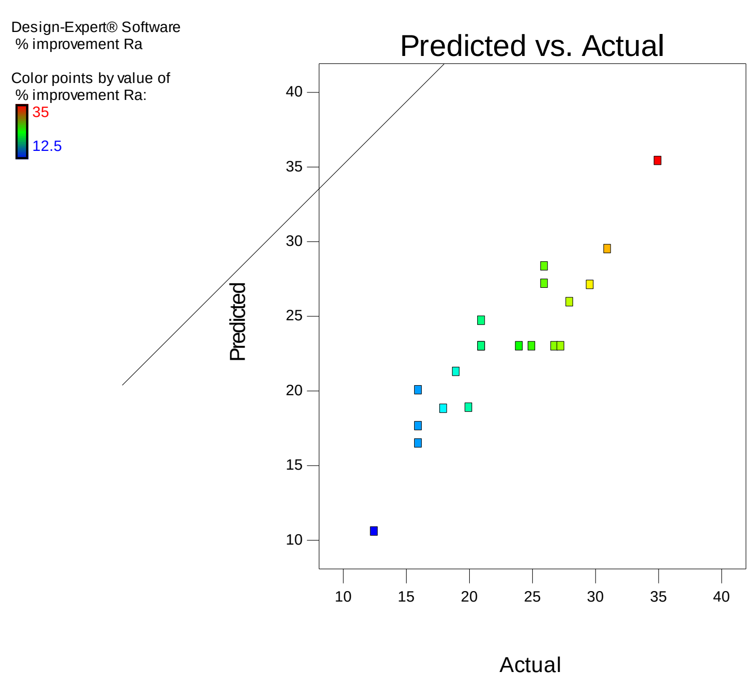


Figure15: Graph shows Predicted vs. actual

6.3.8 Resudial vs. Magnetic Flux

Residual of % improvement in Ra and magnetic flux are shown in this figure, and as the graph indicated the variation is within the permissible limit

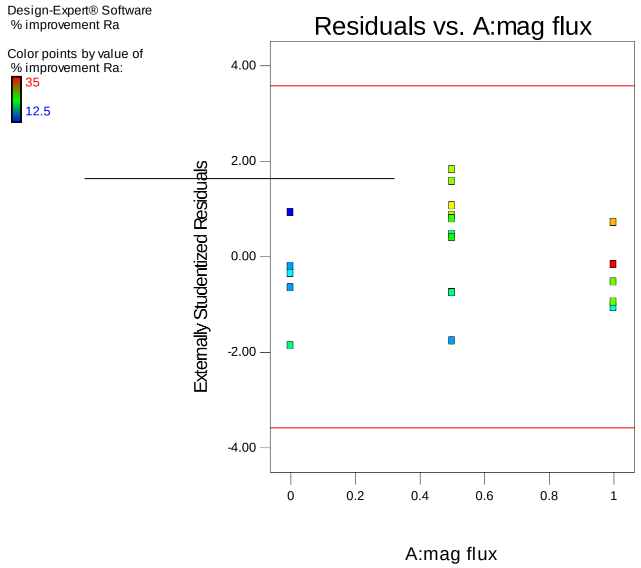


Figure 16: Graph shows residual vs. Magnetic flux

6.3.9 Influence analysis

The influence analysis of the parameter shows that which parameter most influence the response which we want to get. Here the response is %improvement in Ra and run number. There are various model for influence analysis one of them is DEFBETAS which is suggested by the model . Rest of the things is well explained by the graph.

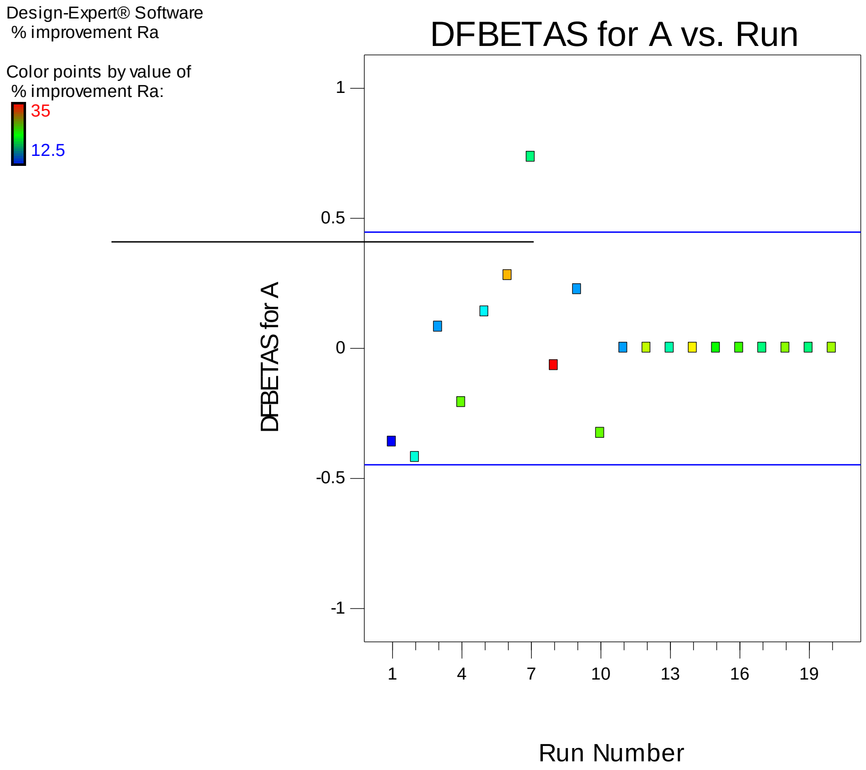


Figure 17: Graph shows DFBETAS for magnetic flux and Run

6.3.10 Model Graphs

Pertubation graph for % improvement in Ra

The real benefit of this plot is when selecting axes and constants in contour and 3D plots. For response surface designs, the perturbation plot shows how the response changes as each factor moves from the chosen reference point, with all other factors held constant at the reference value. Design-Expert sets the reference point default at the middle of the design space (the coded zero level of each factor)

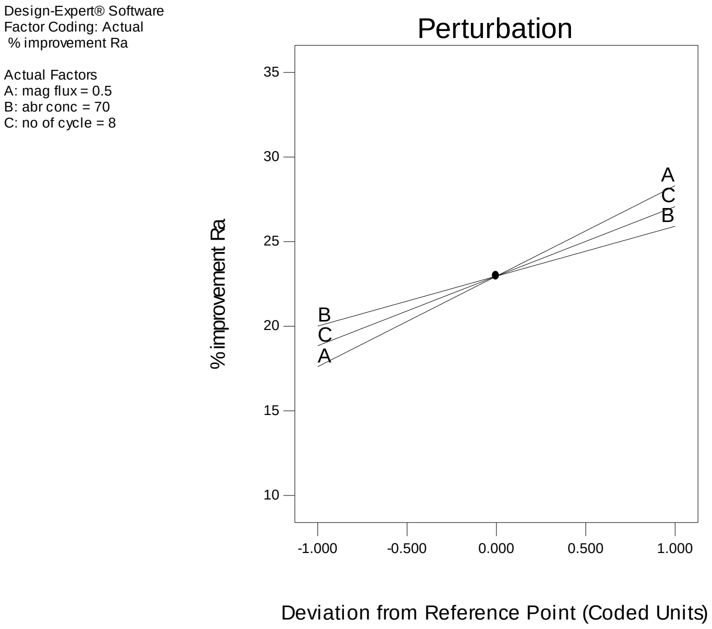


Figure18: Graph shows the variation of reference point

One factor curve

This graph shows the the variation of any one factor to the aur response parameter which is the % improvement Ra and in the graph it is clear that as the flux is increased the response value is also increased.

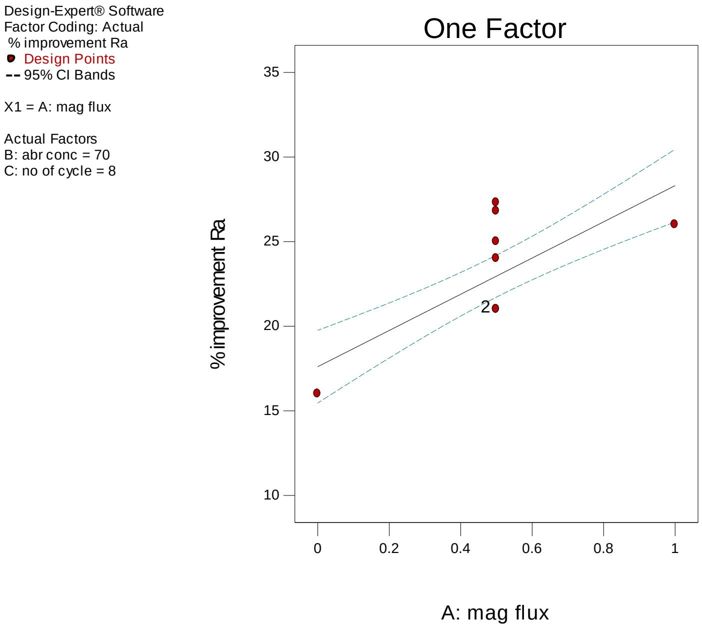


Figure19: Variation of Magnetic flux to the % improvement in Ra

6.3.11 Variation in 3D Surface

As this graph clearly says that the value of % improvement in Ra is increasing as the value of magnetic flux is increasing

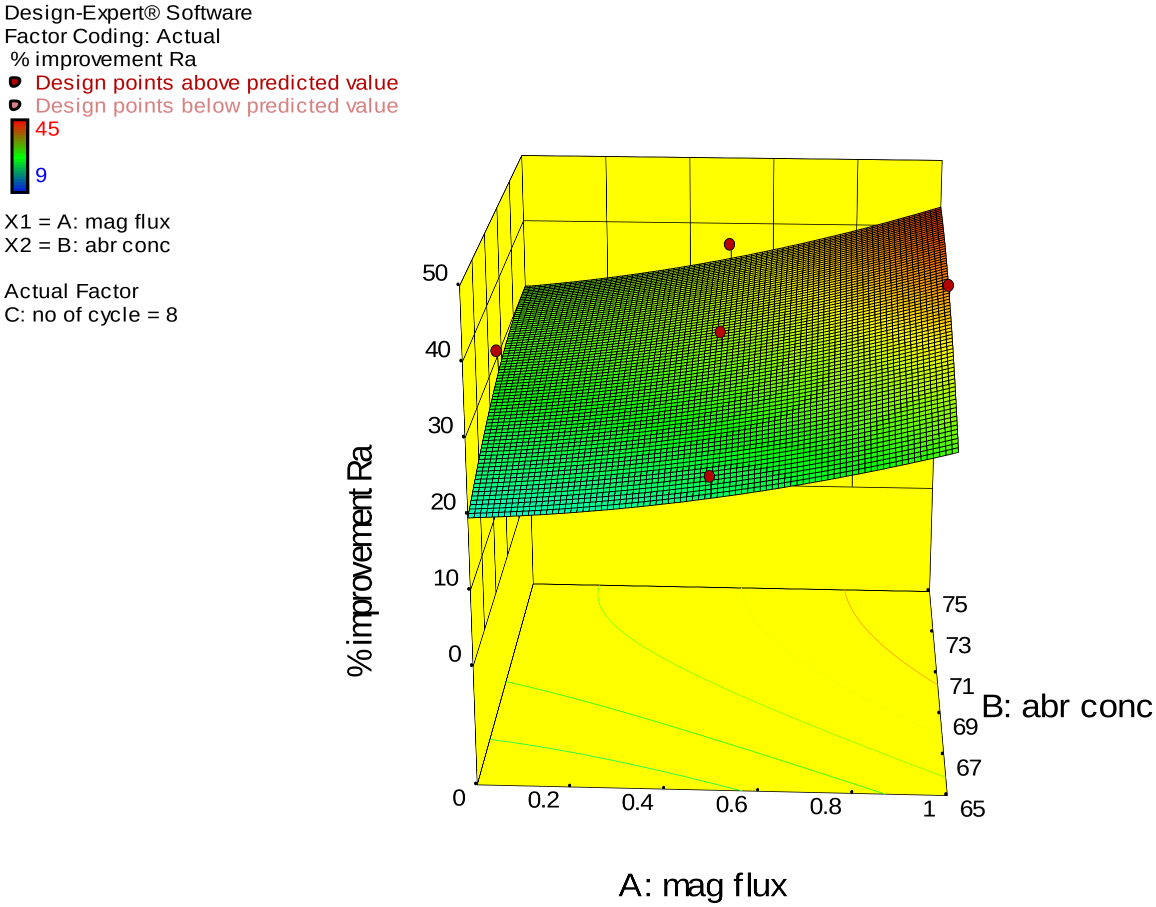


Figure20: 3D surface for magnetic flux

3D surface model for abrasive concentration

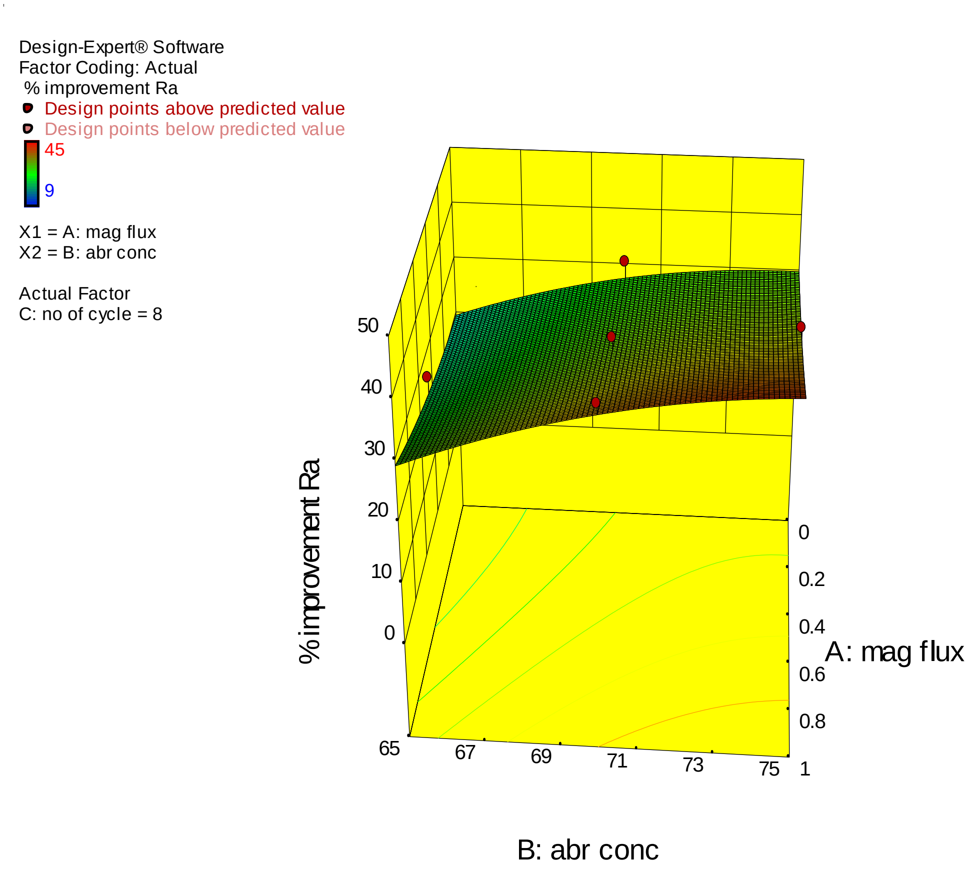


Figure21: 3D surface model for abrasive concentration

6.4 Discussion on Percentage improvement in material removal

ANOVA table for Percentage improvement in metal removal

Table 8: ANOVA Table for material removal

	Sum of		Mean	F	p-value	
Source	**Squares**	**df**	**Square**	**Value**	**Prob > F**	
Model	0.60	6	0.100	11.32	0.0002	Significant
A-mag flux	0.18	1	0.18	19.97	0.0006	
B-abr conc	0.17	1	0.17	19.02	0.0008	
C-no of cycle	0.14	1	0.14	16.17	0.0015	
AB	0.012	1	0.012	1.33	0.2701	

AC	0.057	1	0.057	6.52	0.0241	
BC	0.044	1	0.044	4.93	0.0447	
Residual	0.11	13	8.819E-003			
Lack of Fit	0.089	8	0.011	2.15	0.2076	not significant
Pure Error	0.026	5	5.167E-003			
Cor Total	0.71	19				

The Model F-value of 11.32 implies the model is significant. There is only a 0.02% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AC, BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 2.15 implies the Lack of Fit is not significant relative to the pure error. There is a 20.76% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Table 9: Variation in statics terminology for material removal

Std. Dev.	0.094	R-Squared	0.8394
Mean	0.81	Adj R-Squared	0.7652
C.V. %	11.56	Pred R-Squared	0.4832
PRESS	0.37	Adeq Precision	15.144

The "Pred R-Squared" of 0.4832 is not as close to the "Adj R-Squared" of 0.7652 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. My ratio of 15.144 indicates an adequate signal. This model can be used to navigate the design space.

6.4.1 Final Equation in Terms of Coded Factors:

Material Removal =

+0.81

+0.13 * A

+0.13 * B

+0.12 * C

+0.038 * AB

+0.085 * AC

+0.074 * BC

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

6.4.2 Final Equation in Terms of Actual Factors:

Material Removal =

+1.39785

-1.14460 * mag flux

-0.011250 * abr conc

-0.24946 * no of cycle

+0.015300 * mag flux * abr conc

+0.042375 * mag flux * no of cycle

+3.68750E-003 * abr conc * no of cycle

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

6.4.3Residual curve for Material Removal

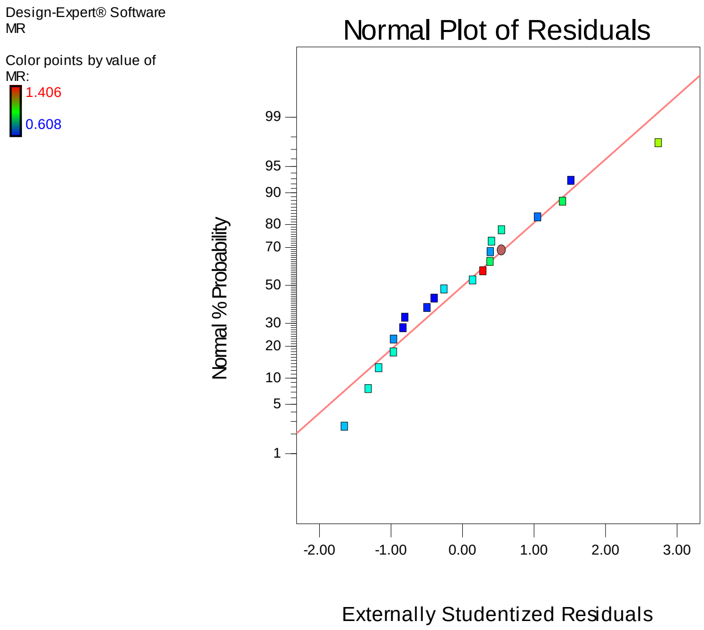


Figure 22: Graphs show the variation of normal probability and residual

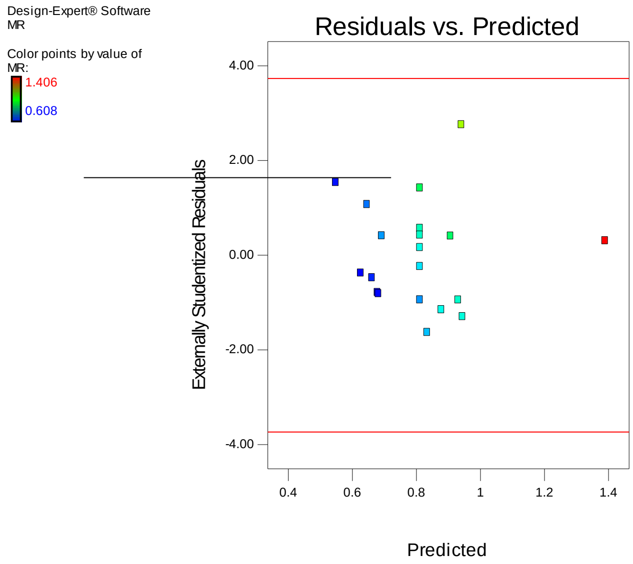


Figure 23: Graph shows the variation of residual to the predicted value

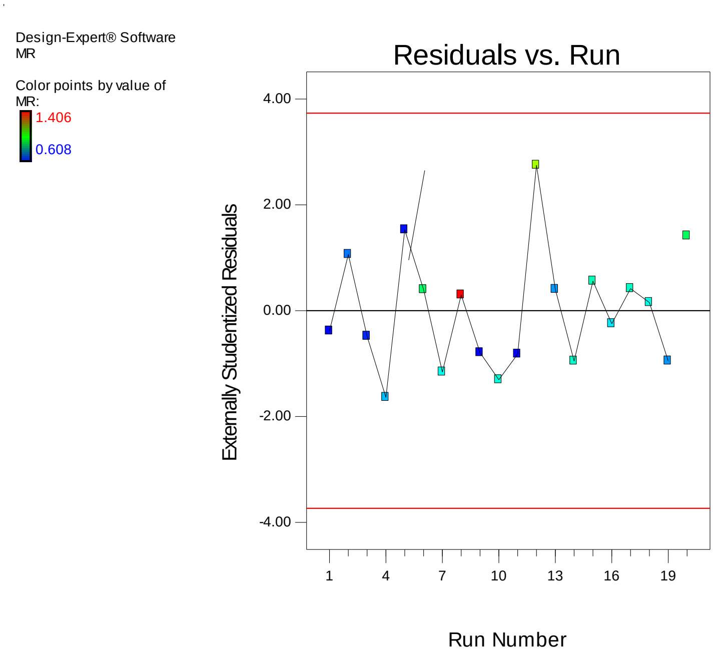
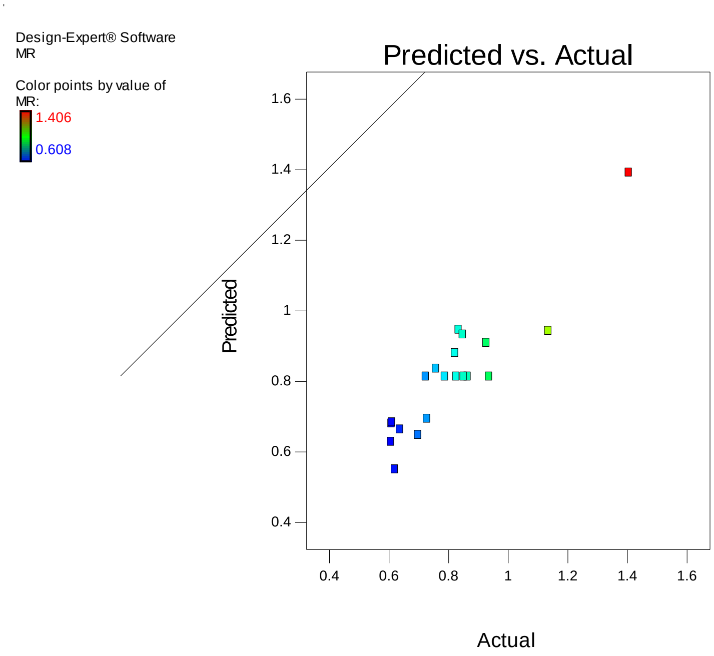


Figure24: graph shows residuall vs. run order



Model graphs for material removal

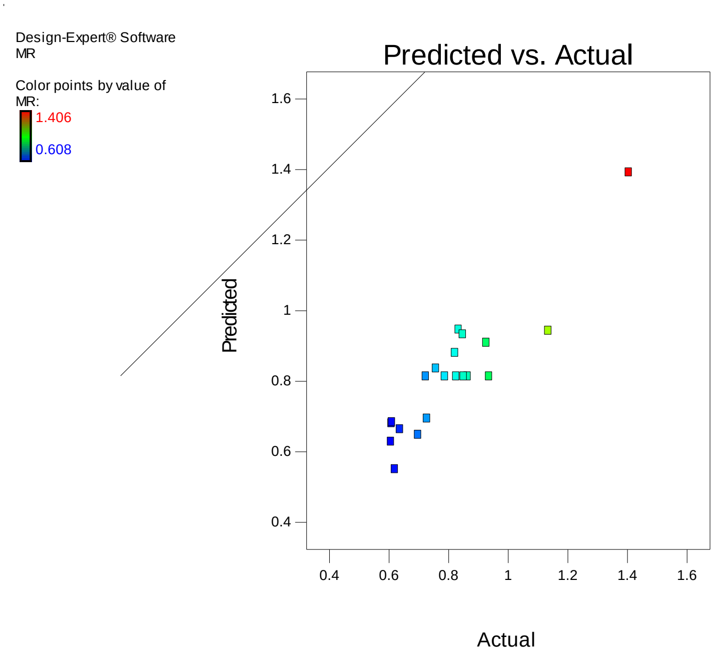


Figure25: Graph of predictable vs. actual

6.4.4. Model Graphs

3D surface of MR for magnetic flux

This graph clearly indicate that there is slight increase in MR as the magnetic flux increases

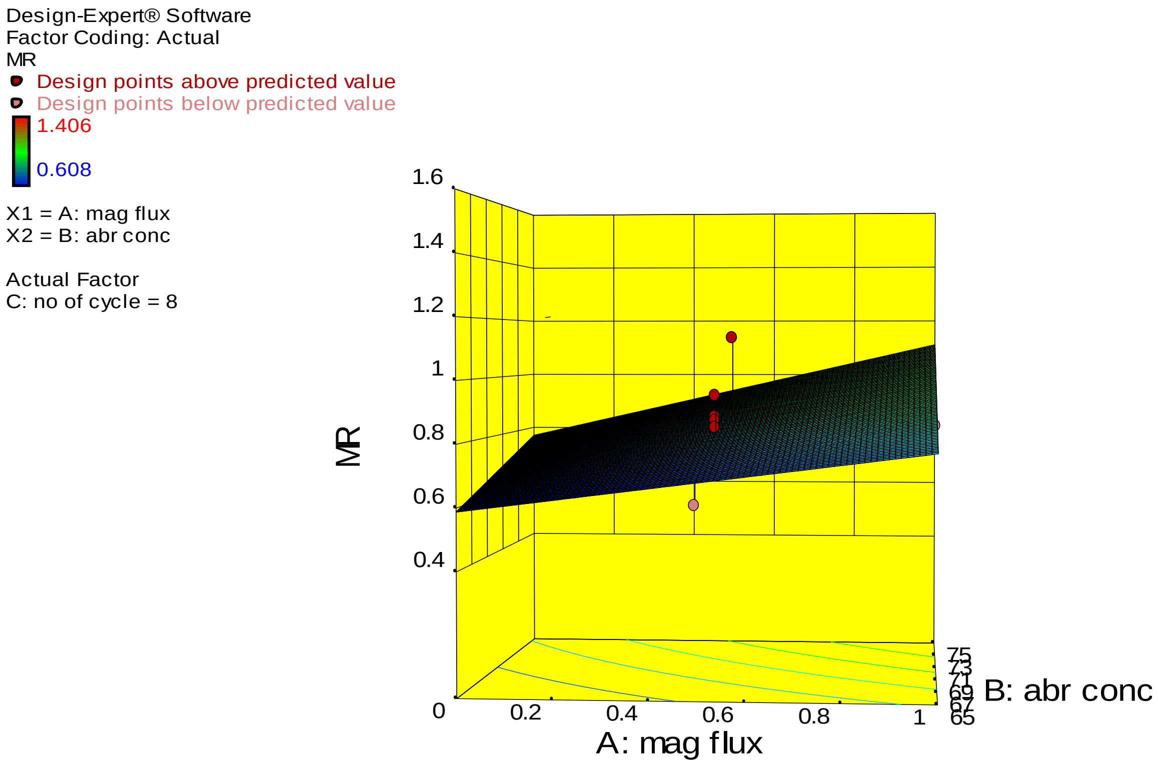


Figure 26: 3D surface model for magnetic flux

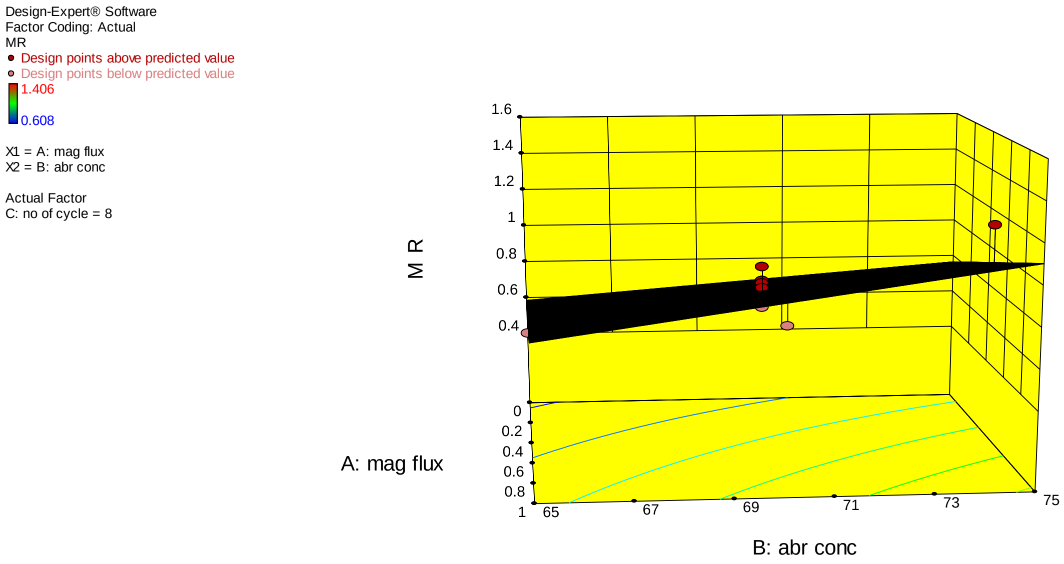


Figure27: 3D surface variation of material removal to abrasive concentration

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

There is a tremendous possibility of improvement in the process of Abrasive Flow Machining by using the magnetic force. It provides extra energy to the abrasive particle which increases the momentum to the abrasive particle so that it increases the material removal rate. Conclusion of various points can be drawn

CONCLUSION

1. The study of Magnetic force assisted AFM on brass was done successfully.
2. The effects of using variable magnetic force were properly analyzed.
3. It was seen that as the Magnetic flux increases initially the surface finish improves but later its slope decrease
4. As the amount of Abrasive concentration increases initially the surface finish improves but later it decreases.
5. As the No. of Cycles increases the surface finish increases.
6. It was obtained from the experiment that as pressure increases, material removal increases up to certain level after that it decreases.
7. Graph of % improvement in Ra follow the quadratic curve
8. If the Abrasive concentration increases, material removal increased up to some decreases and after that it increases.

SCOPE FOR FUTURE WORK

1. This process can be improved or automated by using servo control hydraulic units.
2. The life of the component increases due to better surface finish.
3. The set up can be optimized for many other process parameters like different shapes of work materials, different abrasives, flow rate of media etc.

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